Proceedings of the Sixth International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 7, Paper 19.6
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.7.19.6

Advanced Measurement of Railway Track Layer Deformations using a Combined Multi-Depth Deflectometer and Global Navigation Satellite System Technique

Y. Lim[1], P. Bahati[2] and V. Le[3]

[1]Department of Civil and Railroad Engineering, Paichai University, Daejeon, S. Korea
[2]Department of Civil Engineering, RP/IPRC KIGALI (Rwanda Polytechnic/Integrated Polytechnic regional center-Kigali) Kigali, Rwanda
[3]Department of Civil Engineering, Kumoh National Institute of Technology, Gumi, S.Korea

Abstract

This study introduces a sophisticated measurement system combining a Multi-Depth Deflectometer (MDD) with a Global Navigation Satellite System (GNSS) to monitor deformation in railway slab track layers. The MDD/GNSS system integrates two laser-equipped MDD modules fixed at the top of the track slab. Installed at a test site, this system underwent a nine-month evaluation of concrete track layers. It demonstrated the capability to measure settlement accurately, overcoming traditional MDD limitations where firm endpoint fixation is challenging. The results underscore the system's potential to significantly improve railway track settlement monitoring.

Keywords: multi-depth deflectometer, global navigation satellite system, total station, trend model, railway, track settlement.

1 Introduction

As high-speed rail networks increasingly adopt slab track systems, monitoring settlement caused by train loads becomes crucial. Settlement can disrupt track alignment, affect wheel-rail dynamics, and compromise overall structural integrity, thus necessitating continuous monitoring for timely maintenance [1-3]. Multi-Depth

Deflectometers (MDDs) are instrumental in this regard, offering precise measurement of soil deformation and track stability (Figure 1)[3]. They play a pivotal role in identifying and mitigating settlement issues, ensuring safe and reliable rail operations.

This study presents a new method for monitoring slab track settlement by combining GNSS technology with Multi-Depth Deflectometers (MDDs). GNSS receivers are placed with one as a base station beside the track and another as a rover station on the slab track. The MDD is installed beneath the rover to measure deflections at various depths under train loads. This setup allows for accurate measurement of both relative deflections between track layers and total deflection at the slab top, addressing the limitations of traditional MDD systems impacted by soil shifts.

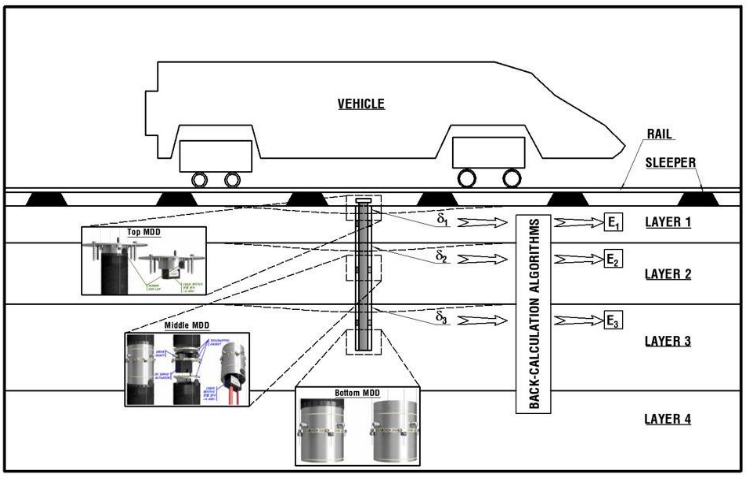
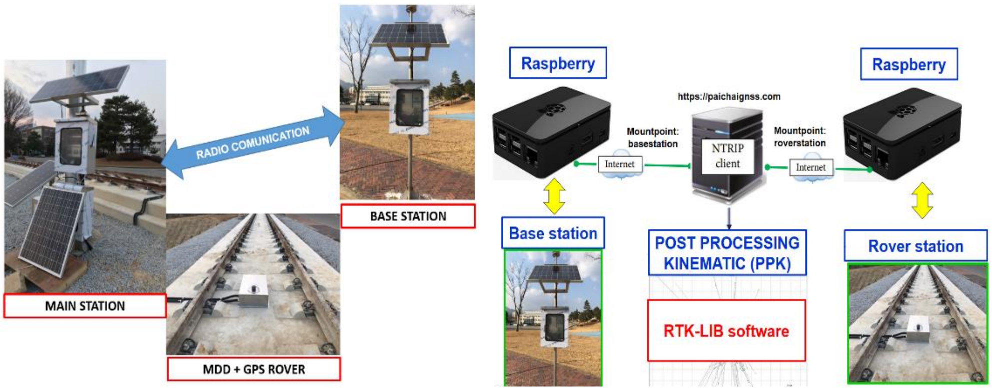


Figure 1: The concept of Obtaining Track deformation based on MDD Device (Bahati et.al,2023)

2 Methods

The study developed a multi-depth deflectometer (MDD) system for slab tracks with capabilities for wireless data transmission, enabling continuous monitoring. Measurement points were established at a test site in S. Korea, using a firm ground base station for reference. Ublox GNSS receivers were strategically positioned above the MDD for rover stations and on pillars for the base station, with GPS providing antenna phase center coordinates. Precise base station coordinates were determined using Virtual Reference Stations from the Korea National Geographic Information Institute.



(a) (b)

Figure 2: a. MDD system b. GPS system for monitoring slab-track settlement

The study introduced a Multi-Depth Deflectometer (MDD) system tailored for measuring displacements in concrete track layers due to train loads. This system comprises two modules that capture wheel load interactions at different depths, offering insights into how the track structure behaves. Installed securely for precise measurements, the MDD monitors both elastic and plastic deflections. The collected data aids in evaluating the track's structural performance and overall condition, with regular measurements taken to analyse deformations using Equation (1).

$$S_{MDD}(t) = D_t - D_0 \qquad (1)$$

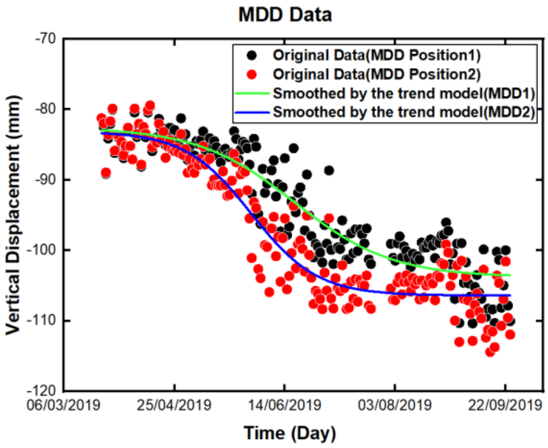
where S_{MDD} is the MDD deformation,D_0 is the MDD initial position and D_t is the displacement at time "t".
The statement emphasizes the use of continuous GNSS measurements to monitor track stability and identify emerging issues in rail systems, ensuring their safety and reliability. It also highlights how the absolute settlement of railroad tracks over time is calculated based on the initial GNSS-Rover position using the ENU coordinate system as follow:

$$S_{GPS}(t) = |U_t - U_0| \qquad (2)$$

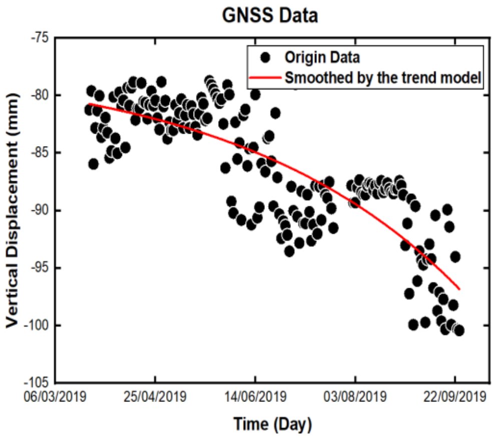
Where S_{GNSS} is the settlement observed by the GNSS -Rover, U_0 is the initial Z-position, and U_t is the current Z-position in the ENU coordinates of the GNSS-Rover.

3 Results

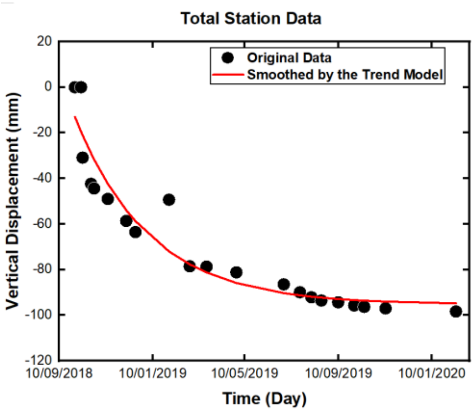
The study employed a LOESS trend model, a statistical technique, to analyze MDD and GNSS measurements of concrete tracks. This method fits a smooth curve to the data by calculating a locally weighted average, which is effective for detecting nonlinear trends and managing outliers, as seen in Figures 3. By minimizing errors and revealing underlying patterns, the LOESS model enhances the analysis and visualization of track deformation trends over time [3,5].



(a)



(b)



(c)

Figure 3: a.MDD data b. GNSS data and c.Total station data

Furthermore, the study applied the Bootstrapping method to assess the variability of GNSS and MDD data in concrete track deflection measurements. For a detailed methodology on Bootstrapping, refer to W. Zhu (1997) [6].

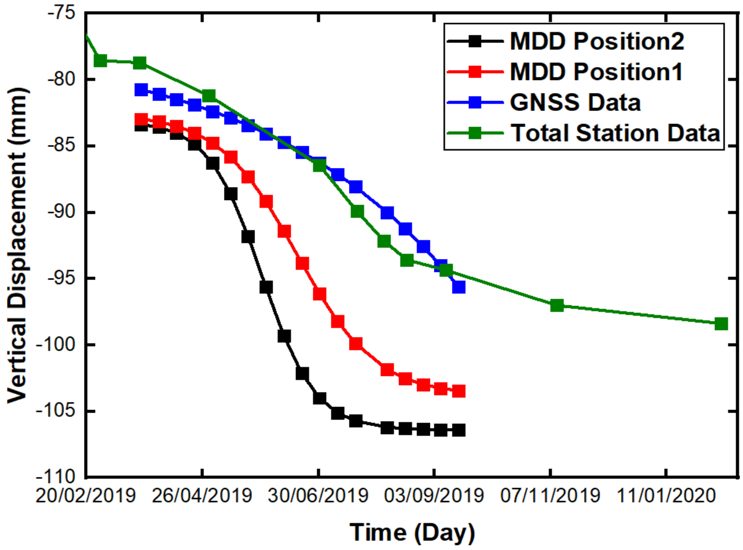


Figure 4: comparison of MDD, GNSS data and Total station data by using Bootstrapping method

For comparison and validation of GNSS results, we compared the GNSS monitoring data with the total station monitoring results obtained from a location near the side of the slab track. As shown in Figure 4, there is a similarity between the GNSS and total station monitoring results, confirming the authenticity and reliability of the data monitored by MDD/GNSS.

4 Conclusions and Contributions

The study introduced an innovative MDD/GNSS system for monitoring settlement in railway slab tracks, demonstrating its effectiveness over a nine-month evaluation period at Dongyang University. By integrating MDD modules fixed on the track slab with strategically positioned GNSS receivers, the system accurately measures settlement, addressing traditional MDD limitations. This approach ensures precise monitoring of track deformation, enhances structural performance evaluation, and contributes to maintaining safe and reliable rail operations. The study also utilized statistical techniques like LOESS trend modelling and Bootstrapping to analyze and validate MDD and GNSS data, confirming the system's reliability and robustness in track settlement monitoring.

References

[1] Juanjuan, R.E.N., Wengao, L.I.U., Jiale, L.A.I., Wenlong, Y.E., Shijie, D.E.N.G., Xueyi, L.I.U. and Bin, T.A.N., 2024. Performance deterioration and structural state diagnosis of slab tracks for high-speed railways: A review. *Engineering Failure Analysis*, p.107955.

[2] Liu, X., Xiao, J., Cai, D., Su, Q., Yang, G., Yuan, S. and Jiang, G., 2023. Recent advances in subgrade engineering for high-speed railway. *Intelligent Transportation Infrastructure*, *2*.

[3] Bahati, P.A., Le, V.D. and Lim, Y., 2023. A Multi-Depth Deflectometer/Global Navigation Satellite System Method for Measuring Concrete Slab Track Deformation. *Applied Sciences*, *14*(1), p.82.

[4] Xue, W., Flintsch, G.W. and Diefenderfer, B.K., 2020. Measuring pavement permanent deformation in accelerated pavement testing. *Transportation Research Record*, *2674*(5), pp.340-348.

[5] Xue, W., Flintsch, G.W. and Diefenderfer, B.K., 2020. Measuring pavement permanent deformation in accelerated pavement testing. Transportation Research Record, 2674(5), pp.340-348.

[6] Xue, W., Flintsch, G.W. and Diefenderfer, B.K., 2020. Measuring pavement permanent deformation in accelerated pavement testing. Transportation Research Record, 2674(5), pp.340-348.