Rail Anchor Slip Force Testing – Year 1

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16. Abstract
Continuous welded rail (CWR) is increasingly adopted to replace jointed track due to its superior ride quality, extended fatigue life, and reduced maintenance costs. However, the absence of joints introduces challenges, such as thermal expansion-related track buckling. Maintaining the Rail Neutral Temperature (RNT) is essential for managing rail stresses and preventing these failures. Rail anchors are employed to distribute loads from rails to ties. The rail anchors enhance longitudinal track resistance by minimizing the rail's longitudinal movement. These anchors are crucial for managing the RNT, ultimately contributing to the prevention of rail buckling and the reinforcement of the track structure. Improving resistance to buckling is vital for minimizing derailments and enhancing railway safety. Despite their significance, there have been very few studies on the interaction between anchors and rail. For this study, a full-scale modified Track Panel Push Test (TPPT) setup was designed and fabricated to model a single rail. The modified TPPT setup was then used to examine the impact of rail anchors on track longitudinal resistance. The results indicate that rail anchors significantly improve longitudinal resistance and reduce rail movement, thereby enhancing track stability. However, the effectiveness of the anchors decreases with each load application and increasing load, highlighting the importance of considering these factors in the design and maintenance of rail anchor systems.

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List of Abbreviations

AAR	Association of American Railroads
CWR	Continuous Welded Rail
TPPT	Track Panel Push Test
USDOT	U.S. Department of Transportation
UTCRS	University Transportation Center for Railway Safety

Disclaimer

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1. Introduction

Ensuring the safety and reliability of Continuous Welded Rail (CWR) tracks is a critical challenge in modern rail infrastructure. This challenge arises primarily from two failure modes: track buckling and rail pull-apart failures (Kish and Samavedam, 2013). Both issues can lead to derailments, which disrupt operations, jeopardize safety, and result in substantial financial costs. While CWR provides numerous advantages over traditional jointed track—such as a smoother ride, reduced maintenance, increased strength, improved efficiency, and decreased noise—it also introduces distinct safety challenges, particularly related to track buckling and rail pull-apart failures. The rising costs associated with derailments underscore the need to address these issues.

To address these challenges, the rail industry relies on two critical parameters: lateral and longitudinal track resistance values. Markine and Esveld (1998) utilized the LONGIN program to analyze the longitudinal and lateral behavior of continuous welded rail (CWR) tracks. Xiao et al. (2018) conducted a full-scale experimental study on ballasted tracks to evaluate their service performance, longitudinal resistance, and the evolution of ballast beds under long-term cyclic longitudinal reciprocated loading. Their findings indicated that ballast beds tend to loosen due to the continuous longitudinal interaction and dynamic disturbance caused by the reciprocated motion of the track frame. Similarly, Jing et al. (2020) carried out field tests on end anchor-reinforced and unreinforced ties to assess changes in lateral resistance. They concluded that the use of full anchor ties is a more effective method for increasing lateral resistance than increasing the height of shoulder ballast. Trizotto et al. (2021) focused on quantifying the magnitude and distribution of longitudinal fastener loads, employing a validated method to assess the loads in both the rail and fastening system caused by passing trains.

Liu et al. (2021) performed a full-scale experimental study on ballasted tracks to examine the longitudinal and lateral resistances of ballast beds under varying temperature and humidity conditions. They observed that ballast bed resistance is lower in low-temperature, dry environments compared to normal temperatures, and that resistance is highly sensitive to changes in temperature. Nobakht et al. (2022) investigated the impact of vertical loads on the longitudinal resistance of ballasted railway tracks both experimentally and numerically. Their experimental study involved testing the longitudinal resistance of a track with five concrete ties under different vertical loads. Additionally, they developed a three-dimensional model using Abaqus software, revealing that the relationship between longitudinal track stiffness and vertical load is nonlinear.

Alizadeh et al. (2022 and 2023) conducted both experimental and numerical studies on the longitudinal resistance of ballasted railway tracks with wooden ties, as well as on tracks with steel ties. Potvin et al. (2023) reviewed key factors influencing longitudinal track resistance, noting that improved accuracy in measuring longitudinal resistance could lead to fewer broken components and more efficient CWR repairs following rail breaks or destressing events. Lastly, Dersch et al. (2023) performed a full-scale experimental study to evaluate the effects of tie type, fastening system, crib ballast height, shoulder width, and ballast condition on the longitudinal resistance of CWR tracks.

While lateral resistance has been extensively studied, longitudinal resistance, equally vital for longitudinal load analysis and RNT maintenance, lacks consistent definitions and comprehensive research. In this study, a full-scale modified Track Panel Push Test (TPPT) setup was designed and fabricated to model a single rail. The modified TPPT setup was then used to examine the impact of rail anchors on track longitudinal resistance.

2. Summary

This report presents the first-year findings from a study exploring the effect of rail anchors on longitudinal resistance. The study aimed to design and fabricate a full-scale modified TPPT setup to model a single rail section. The modified TPPT was used to evaluate the impact of various types of rail anchors on the track's longitudinal resistance, a key factor in preventing rail buckling and ensuring track stability.

The test apparatus, instrumentation, and measurements are discussed in detail, along with the methodology employed during the pre-test activities, which included workshops conducted in collaboration with MxV Rail and BNSF Railway. The results of the modified TPPT experiments provide insights into the behavior of three types of anchors under varying loads.

Key findings indicate that the load-displacement relationship is nonlinear. The results highlight the significant role rail anchors play in enhancing longitudinal resistance, which reduces rail movement and improves track stability. However, with successive load applications, the effectiveness of the anchors diminishes, stressing the importance of considering anchor wear in the design and maintenance of rail systems.

While the results offer valuable insights into anchor behavior, they are specific to the test setup used and should not be generalized across different systems. Future work will focus on refining the testing conditions and expanding the study to include other anchor types and track conditions.

3. Modified TPPT Setup, Instrumentation, and Anchors

3.1 Test Apparatus Setup

Figure 1 illustrates the setup of the modified TPPT conducted at the University of Texas Rio Grande Valley, showcasing the overall dimensions of the test apparatus, including the arrangement of the rail, hydraulic systems, and safety barriers used during the experiments. The construction of this testing setup and the application of modifications were integral components of the first year of this project, aimed at optimizing the evaluation of rail anchors' effects on longitudinal resistance.

3.1.1 Dimensions

The overall dimensions of the test setup are of 10 feet in length and 9 feet in width. The section containing the track and rail measures 10 feet in length and 3 feet in width, while the auxiliary section is 9 feet in length and 2 feet in width.

The earlier version of the setup featured smaller overall dimensions due to the upright configuration of the load controller, as shown in Figure 2. After modifying the load controller to accommodate larger loads, it was necessary to position it horizontally, as shown in Figure 1.

In this study, a short rail segment measuring 26 inches (approximately 2.2 feet) was employed. This length was selected to ensure adequate contact with the hydraulic cylinder head while maintaining symmetry across the rail tie. The utilization of a shorter rail segment effectively eliminates the influence of contact with multiple ties, which is crucial when using a single anchor. Additionally, this approach minimizes the potential impact of rail misalignment, allowing for a more concentrated analysis of the rail anchor performance.

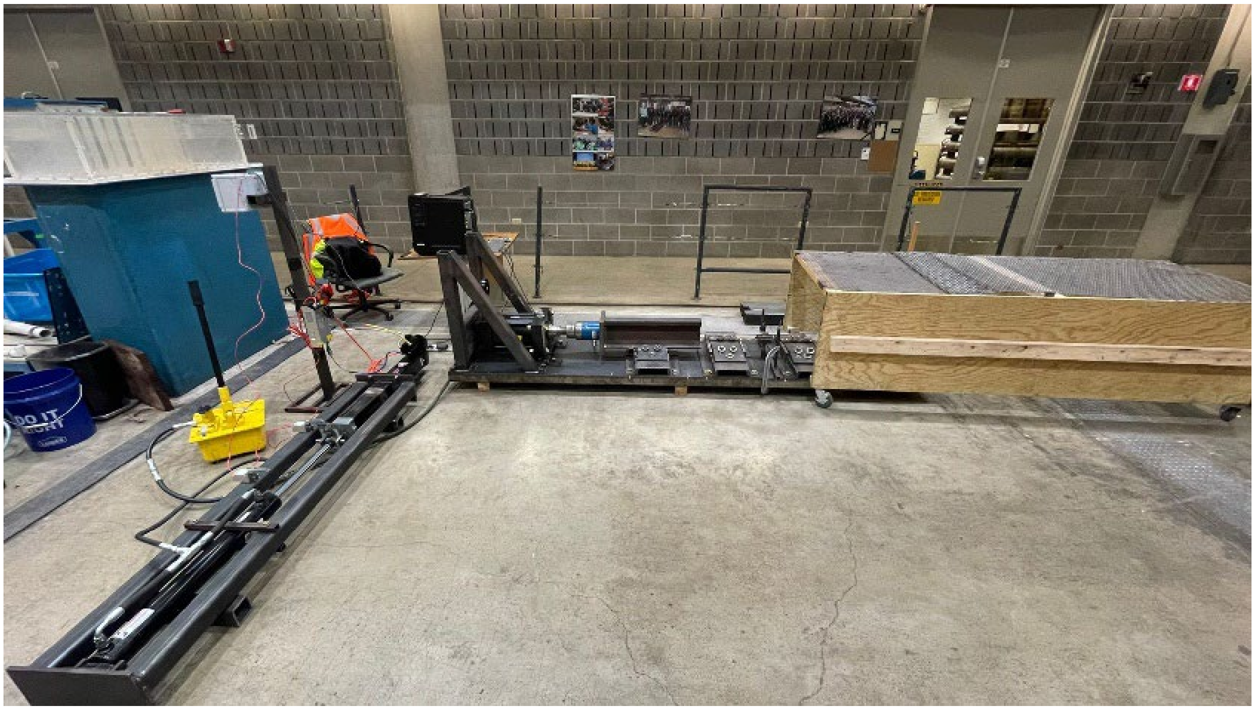


Figure 1: Modified TPPT setup

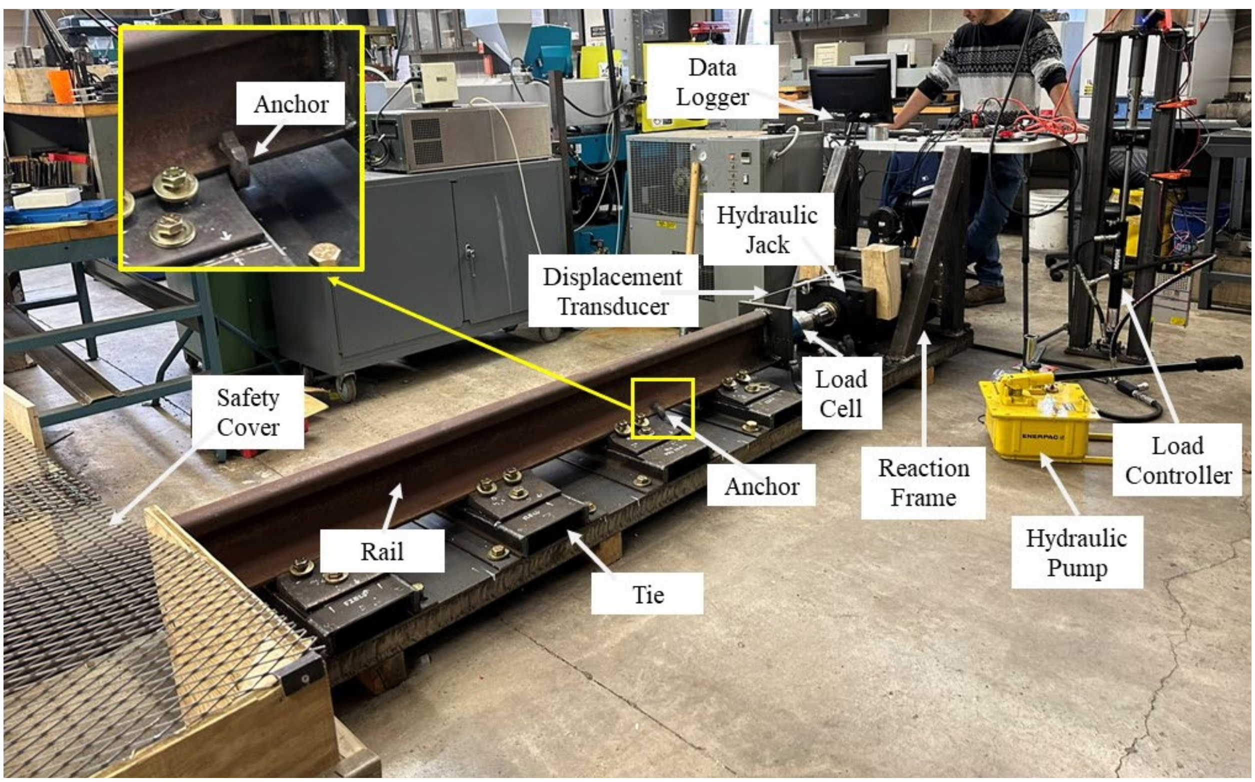


Figure 2: Early TPPT setup before modifications

3.1.2 Base Plate and C-Shape Steel Channel

To eliminate the influence of ballast and the type of ties (i.e., wood) on the study, both components were replaced with a thick steel base plate and a C-shaped steel channel, respectively. The use of hardened steel effectively simulates ballast and ties with significantly higher stiffness. Additionally, a steel plate is welded on the side that contacts the anchor, further enhancing the rigidity of the setup and eliminating anchor rotation. By opting for an all-steel setup instead of conventional ballast and wooden ties, the experimental work aims to isolate and assess the effect of rail anchors on slip force resistance decoupled from other factors that may influence anchor performance, such as anchor rotation or bending. As a result, longitudinal resistance is predominantly limited to the rail anchors, as much as possible.

Figure 3: Rail, tie, and anchor

3.1.3 Load Controller

The load controller regulates the voltage supplied to the jackscrew motor, thereby controlling the jackscrew's extension rate. By managing the extension through the load controller, a specified constant load rate can be applied to the rail. The jackscrew operates in conjunction with the auxiliary hydraulic cylinder, which is connected in series with the main hydraulic cylinder. The initial design utilized a smaller auxiliary cylinder and jackscrew for the load controller; however, testing revealed that a higher load capacity setup was needed.

3.1.4 Hydraulic Cylinders

The test setup features two hydraulic cylinders designed to facilitate precise load application. The main hydraulic cylinder directly contacts the rail at its horizontal polar moment of inertia, serving as the primary mechanism for exerting loads generated by the hydraulic circuit. This cylinder is crucial for simulating realistic loading conditions on the rail. In addition, an auxiliary hydraulic cylinder operates in conjunction with a screw jack to regulate the rate at which the load is applied to the rail. This dual-cylinder arrangement enhances the accuracy of load application, allowing for controlled testing conditions that can be adjusted as needed throughout the experiments.

3.1.5 Hydraulic Pump

The hydraulic pump is manually operated to apply load to the rail and is primarily used to preload the rail, consequently maximizing the auxiliary cylinder's stroke length. It has an oil capacity of 453 cubic inches and can operate at a maximum pressure of 10,000 psi.

3.1.6 Safety Barrier

The safety barrier is designed to ensure user protection and mitigate risk in the event of debris flying or anchors slipping and shooting out during testing. It is constructed of 1-inch-thick plywood on the sides and carbon steel expanded sheet on the top.

3.1.7 Anchor Installation

The rail anchors are installed by implementing the standard field method, which involves driving the anchor onto the rail with a sledgehammer. To minimize variability in the results due to different operators, a designated operator is assigned to each anchor installation to maintain consistency.

3.2 Instrumentation

3.2.1 Load Cell

A load cell is employed to monitor and record the load applied to the rail throughout the test, effectively capturing the load behavior (Figure 4). This device is also used to capture the maximum load exerted on the anchor through the rail-anchor interaction, which is critical for evaluating the anchor's impact on the longitudinal resistance of the rail. The load cell is positioned at the end of a hydraulic cylinder, aligned axially with the rail, to accurately measure longitudinal resistance. The load applied is continuously recorded for the duration of the test, until a large rail displacement occurs, typically ranging from 0.25 to 0.5 inches.

3.2.2 Linear Variable Differential Transducer Sensor

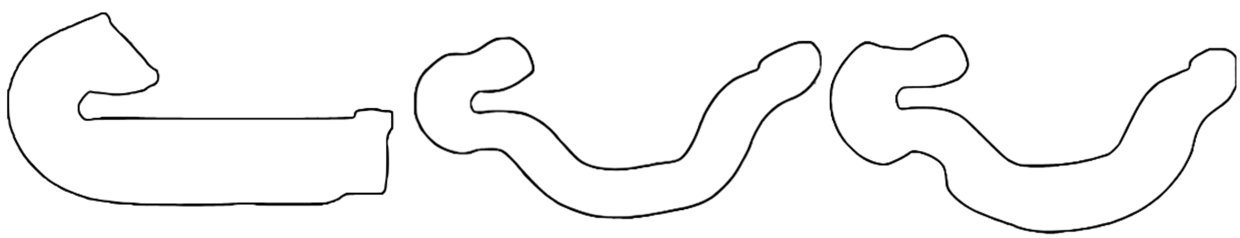
A linear variable differential transducer (LVDT) is utilized to measure the displacement of the rail relative to its initial position (Figure 4). The LVDT is installed at the end of the rail, opposite the load cell, to capture displacement data that are used to generate load versus displacement plots. The displacement is recorded continuously throughout the test at a frequency of 15 Hz. This data allows for the assessment of anchor displacement relative to its initial position on the rail. In earlier tests, the LVDT was mounted above the hydraulic cylinder, with its tip resting on the top side of the plate welded to the rail. However, in the final version, the LVDT was relocated closer to the rail's horizontal polar moment of inertia to minimize displacement deviations caused by potential LVDT rotation or bending.

Figure 4: Side view of the rail with LVDT (left) and Load Cell (right)

3.3 Anchor Types

For this study, three types of anchors were selected for evaluation: Type X, Type Y, and Type Z (Figure 5). These anchors were selected based on their structural characteristics and potential for resisting longitudinal loads. The installation of these anchors follows standard field methods, which involves driving the anchor onto the rail using a sledgehammer. To ensure consistency and minimize variability in results, a designated operator is assigned for the installation of each anchor.

Each anchor type is designed with specific dimensions and materials that influence its performance characteristics. Table 1 provides the internal width and clamping height (refer to Figure 6) measurements for each anchor type before testing.



(a) **(b)** **(c)**

Figure 5: Anchors (a) Type X, (b) Type Y, and (c) Type Z

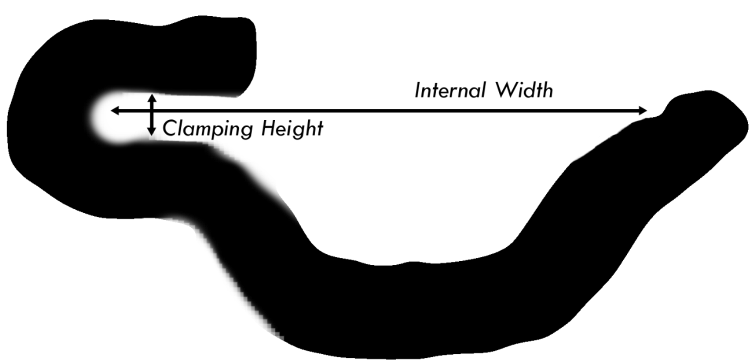


Figure 6: Schematic section of anchors

Table 1: Anchor dimensions before testing

Anchor Type	Internal Width (inch)	Clamping Height (inch)
X	6.10	0.60
Y	6.20	0.55
Z	6.10	0.50

4. Test Refinement and Workshop Guidance

As part of the pretesting phase, two training workshops were offered to the UTCRS-UTRGV students in coordination with engineers from MxV Rail and BNSF Railway (Figure 7 and Figure 8). These workshops were instrumental in improving the experimental setup and testing methodology. Preliminary testing highlighted several limitations in the design, which were addressed through the expert guidance provided by industry professionals during the workshops.

One of the significant changes involved relocating the original rail bases and ensuring proper installation with the correct tightness of the fastening bolts, as recommended by the engineers. This adjustment was crucial for ensuring the rail's stability and simulating field service track conditions, thereby improving the applicability of the test results. Additionally, the engineers demonstrated the proper methods for installing and removing the anchors, ensuring uniform application across all tests to reduce variability and potential human error. Safe operation of the experimental setup was emphasized during these workshops.

The workshops also resulted in other critical adjustments, such as modifying the load controller to handle larger load capacities. The placement of the LVDT sensor was revised to improve measurement precision, reducing potential deviations caused by rail rotation during testing. These refinements, informed by the expertise of MxV Rail and BNSF engineers, optimized the final laboratory test setup, allowing for more accurate assessment of rail anchors' longitudinal resistance, and enhancing the overall reliability and pertinence of the results.

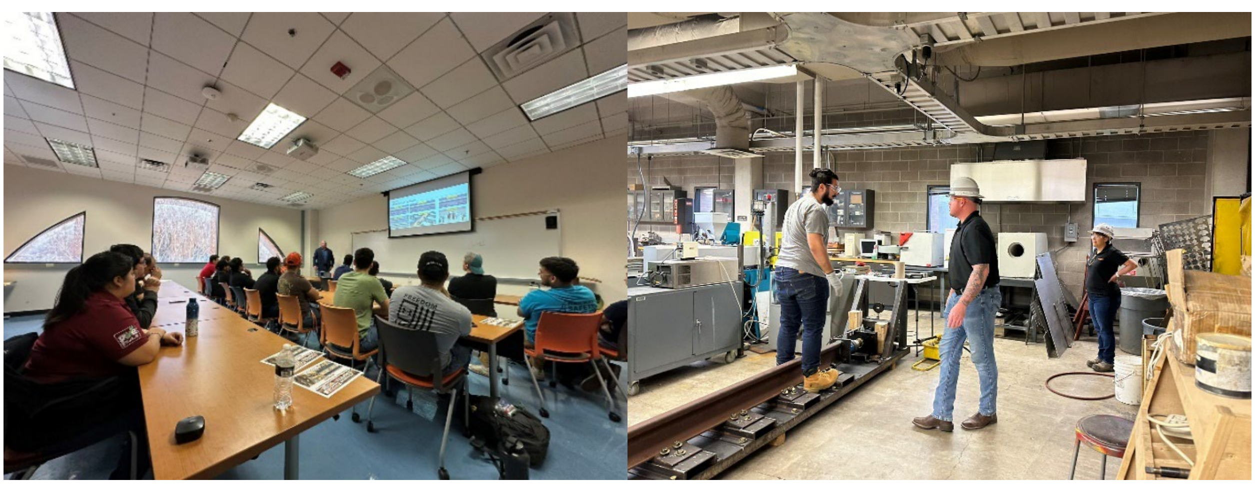


Figure 7: Training workshop on January 25, 2024

Figure 8: Training workshop on March 5, 2024

5. Results and Discussions

The load and displacement for three different anchor types, X, Y, and Z, are presented in Figure 9, Figure 10, and Figure 11, respectively. It is important to emphasize that these results pertain specifically to this experimental setup as described here and should not be considered as specification benchmarks. These results are not intended for direct comparison between different anchor types; instead, they serve to support the development of the laboratory test setup and the analysis of load-displacement behavior.

A total of 40 tests were conducted for each anchor type. The maximum and minimum peak forces for each anchor type were evaluated against the baseline rail resistance without an anchor, recorded at 250 lbf. For anchor type X, the longitudinal resistance forces recorded from the 40 tests conducted ranged from 7,800 lbf to 17,900 lbf. Anchor type Y exhibited longitudinal resistance forces ranging between 4,900 lbf and 13,700 lbf, while the longitudinal resistance forces measured for anchor type Z ranged from 5,600 lbf to 12,700 lbf. Figure 9, Figure 10, and Figure 11 summarize the results from the 40 tests performed for anchor type X, Y, and Z, respectively.

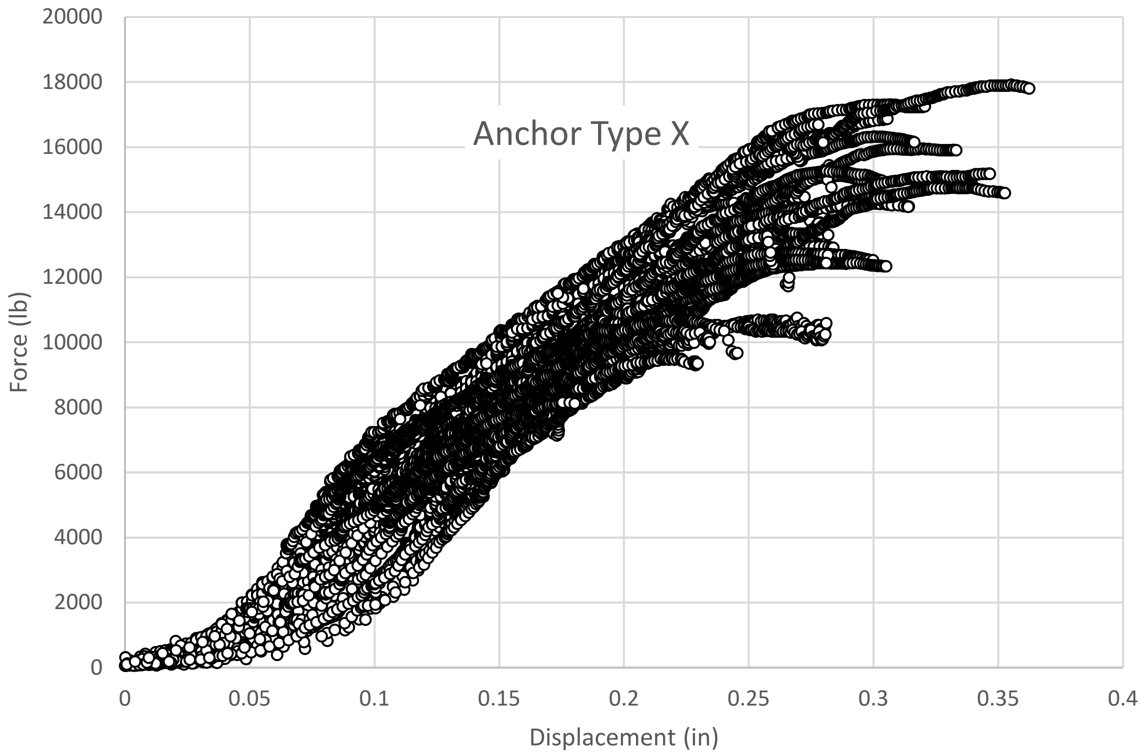


Figure 9: Anchor type X results

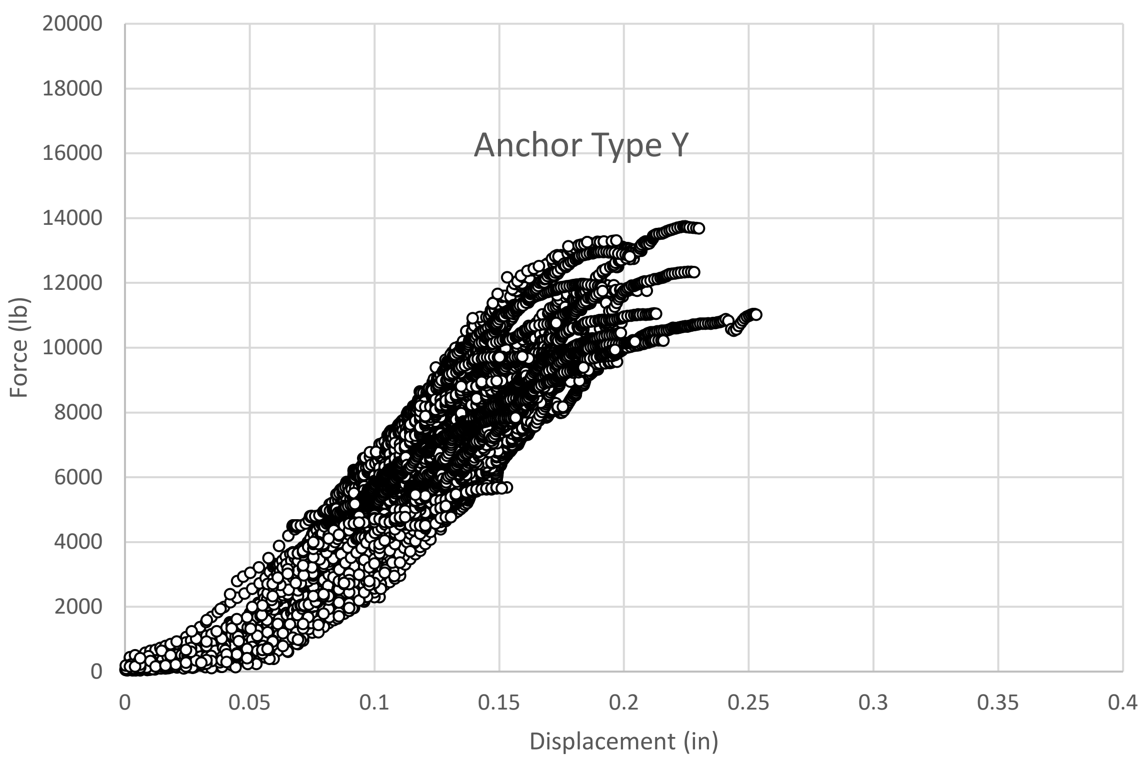


Figure 10: Anchor type Y results

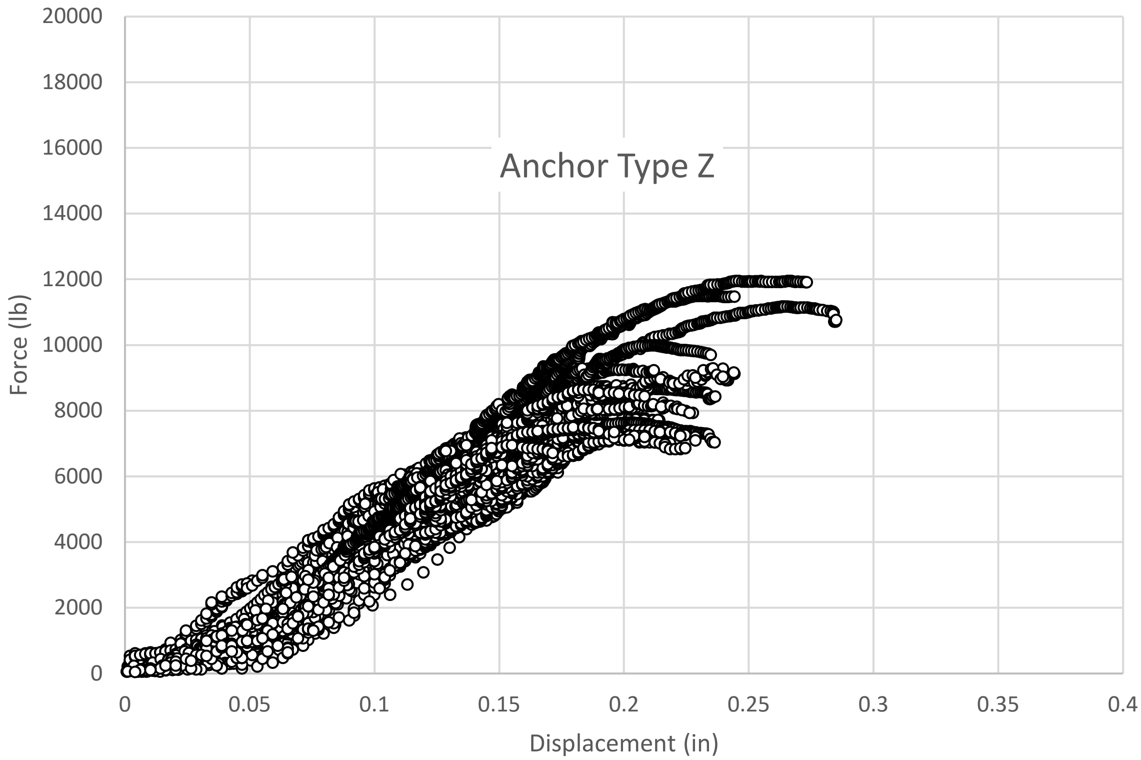


Figure 11: Anchor type Z results

6. Conclusions

The main objective of this study was to design and fabricate a laboratory test setup that can be used to assess and evaluate the longitudinal resistance forces of different rail anchor types. To that end, a full-scale modified Track Panel Push Test (TPPT) laboratory setup was designed and constructed to assess the performance of three anchor types: X, Y, and Z. A total of 40 tests were carried for each anchor type, and the load-displacement behavior was analyzed to determine the impact of the rail anchors on improving longitudinal resistance to track movement.

The results of this study are preliminary and should not be used to compare the performance of different anchor types directly, as they are specific to this test setup. All anchor types exhibited similar load-displacement trends, with displacement steadily increasing as load was applied. Results demonstrate that the implementation of rail anchors significantly increases the longitudinal resistance to track movement. Compared to the baseline longitudinal resistance of 250 lbf, the anchors improved the rail's ability to handle loads, with values ranging from 4,900 lbf to 17,900 lbf across the different anchor types. This demonstrates the important role that anchors play in enhancing the rail track's load-handling capacity, but also highlights the need to consider anchor wear and performance degradation over time, especially pertaining to repeated removal and re-application of these anchors.

7. References

Kish, A. and Samavedam, G., 2013. *Track buckling prevention: theory, safety concepts, and applications* (No. DOT/FRA/ORD-13/16). John A. Volpe National Transportation Systems Center (US).

Markine, V. and Esveld, C., 1998. Analysis of longitudinal and lateral behaviour of a CWR track using a computer system LONGIN. *Delft University of Technology, The Netherlands*, p.10.

Xiao, J., Liu, H., Wang, P., Liu, G., Xu, J. and Chen, R., 2018. Evolution of longitudinal resistance performance of granular ballast track with durable dynamic reciprocated changes. *Advances in Materials Science and Engineering*, *2018*, pp.1-11.

Jing, G., Ji, Y. and Aela, P., 2020. Experimental and numerical analysis of anchor-reinforced sleepers lateral resistance on ballasted track. *Construction and Building Materials*, *264*, p.120197.

Trizotto, M., Dersch, M.S., Edwards, J.R. and Lima, A., 2021. Analytical elastic modeling of rail and fastener longitudinal response. *Transportation Research Record*, *2675*(5), pp.164-177.

Liu, J., Wang, P., Liu, G., Dai, J., Xiao, J. and Liu, H., 2021. Study of the characteristics of ballast bed resistance for different temperature and humidity conditions. *Construction and Building Materials*, *266*, p.121115.

Nobakht, S., Zakeri, J.A. and Safizadeh, A., 2022. Investigation on longitudinal resistance of the ballasted railway track under vertical load. *Construction and Building Materials*, *317*, p.126074.

Alizadeh, M., Yousefian, K. and Zakeri, J.A., 2022. Numerical and experimental investigation into longitudinal resistance of ballasted railway track with wooden sleepers. *Construction and Building Materials*, *350*, p.128880.

Alizadeh, M., Imani, M. and Zakeri, J.A., 2023. Laboratory and numerical investigation on the longitudinal resistance of ballasted railway tracks with steel sleepers. *Construction and Building Materials*, *402*, p.132670.

Potvin, M., Dersch, M., Edwards, J.R. and Lima, A.D.O., 2023. Review of Critical Factors Influencing Longitudinal Track Resistance. *Transportation Research Record*, p.03611981231155170.

Dersch, M.S., Potvin, M., Lima, A.D.O. and Edwards, J.R., 2023. Effect of Critical Factors Influencing Longitudinal Track Resistance Leveraging Laboratory Track Panel Pull Test Experimentation. *Transportation Research Record*, p.03611981231155420.