The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 25.6
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.25.6

Experimental test rig for simulating dynamic loads on subway systems

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Abstract

The availability of monitoring data is scatter and limited to specific operating conditions. In this paper, a new scaled down experimental facility is presented. This facility is able to produce railcar dynamic data and track's deformations. The scaled down experimental facility consisted of a track, a railcar with a tank or any other device that represents the cargo, and the instrumentation. The track is a closed circuit with curves in both directions. The scaled-down experimental facility is able to reproduce actual failures in a subway system.

Keywords: Experimental facility, Dynamic measurements, Dynamic loads, Scaled-down.

1 Introduction

The availability of monitoring data is scattered and limited to specific operating conditions. In this paper, a new scaled-down experimental facility is presented. This facility can produce dynamic railcar data and track deformations. This testing facility provides data obtained at different operating conditions and built with various simulated failures. The data helps validate railcar-track interaction models or the simulation of failures in a subway system.

The design of the experimental facility is the evolution of a previous facility built at BAM. The new facility incorporates recommendations from practical experience and the literature. Hoang et al. [1] presented the development of a wireless sensor for monitoring railroad bridges. Some of the problems for monitoring the substructure's dynamic loads are recording a large amount of data and the ability of the wireless system to transmit them. They use appropriate algorithms, especially for the duration of the railcar on the substructure, and data recovery and transmitting processed data to the operator. Thompson [2] presented a paper on noise and vibration on the railroad. He described the vibration sources and the effect of the wheel's circular frequency.

The health monitoring systems are the source for the maintenance of subway programs. Among the primary methods for maintaining the subway, infrastructure is monitoring the tracks and the railcar condition monitoring [3]. The subway operators require intelligent systems to predict and prognosis railway failures. These intelligent systems must include data acquisition systems, models for predicting the health condition based on the evolution of the data acquired, prognostic information, online reports of the health condition, and an alarm system to anticipate possible failures.

The maintenance records help model the deterioration process and develop mathematical models for defining relationships between measurements and predictions. Yang et al. [4] presented a method for modeling the deterioration process of railroad tracks. Their method includes an adaptive framework for measuring the data produced by a Comprehensive Inspection Train (CIT).

For creating the experimental facility, different recommendations were considered. The original model and the scaled model should have similar natural frequencies. The scaled and original model must have the same number of degrees of freedom. The scaled model represents the parameters that have been studied. Other researchers have analyzed the effect of scaling the dynamic behavior of vehicles; there are different factors and criteria to scale the model; some criteria are based on Buckingham's theorem.

2 Methods

The scaled-down experimental facility consisted of a track, a railcar with a tank or any other device representing the cargo, and the instrumentation (Figs. 1 and 2). The track is a closed circuit with curves in both directions. The track is instrumented with strain gauges along the circuit, and a railcar runs freely on the track. The railcar has a servomotor remotely controlled that can vary the speed at any moment.

The railcar is instrumented with a tri-axial accelerometer for measuring the accelerations in the orthogonal directions and three gyroscopes for measuring the rotations of the cargo or any device mounted on it. The vehicle's design has a scale factor of 1/10 [5,6]and it has a spring suspension between the bogies and the platform. The rotation between the bogies and the platform is friction-free through a roller bearing, and this design eliminates the yaw stiffness.

The track has a set of strain gauges at different positions along the curve. The strain gauges have a resistance of 120 Ohms connected to a one-quarter-of-a-bridge configuration. A data-acquisition system records the strain values and stores the data in ASCII files for further analysis. The velocity is controlled with the servomotor, and it is registered with the acquisition system. Some defects on the track create an impact on the vehicle that is only recorded with the accelerometers. The accelerometers box contains three orthogonal accelerometers and three gyroscopes, all of them are MEM's, while the data were stored in a portable memory during the entire test. A light battery powers the system for more than 24 hrs, and the data are recorded continuously at a sample rate of 1000 Hz. For synchronizing the two devices' measurements, a trigger set an impulse on the track, and both systems identified the beginning of the data acquisition period.


Figure 1: Close-loop track.

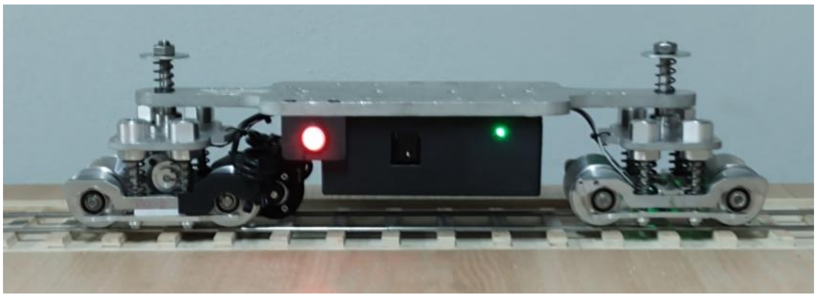
Figure 2: Scaled down railcar.

3 Results

The experimental facility was used for validating field data recorded on a subway system—the data corresponding to a section that presented a severe failure in the substructure. The substructure was part of an elevated track that showed severe damage and caused a dramatic accident. Before the accident, the monitoring system only recorded vibration signals from a set of accelerometers mounted on the train, and the acceleration data complemented the regular maintenance procedure. Unfortunately, the acceleration data was dispersing, and it was not easy to correlate it with the actual dynamic loading on the substructure. Thus, it was possible to emulate the dynamic conditions and reproduce the type of damage in the substructure with the experimental facility.

After a routine inspection, it was detected that the substructure of an elevated section of the track presented premature cracks. It was assumed that the crack was due to an earthquake. Therefore, it was decided to measure the dynamic effect of the train on the track. The health monitoring system consisted of accelerometers mounted on the train and the analysis algorithm. Measuring the track deformations was too expensive, and it required very complicated data acquisition equipment. Thus, the monitoring system relay on the acceleration measurements. The accelerometers were mounted underneath a bogie of one railcar. The train ran continuously, and the acceleration data were recorded. The cracks on the substructure were located at the bridge near one of the subway stations. The visual inspection identified that the sleepers were hanging (soft support), and the ballast had a different damping coefficient. It was estimated that 1 million railcars passed over the structure at the inspection time. This information confirmed that the failure was due to low cycle fatigue. The analysis was limited to the track section between the adjacent stations of the damaged area. It is essential to point out that the section has only four clear external excitations, the switch tracks.

After analyzing the field data, the experimental facility was adjusted to simulate similar conditions in the subway. It was possible to obtain comparable data, and the predictions on the actual track deformations confirmed the location of the failure.

4 Conclusions and Contributions

Monitoring is focused on finding faults and predicting degradation on the tracks. As the train runs over the track, the dynamic interaction changes in time and position, and the dynamic load is affected by tracks' elements, the sleeper's flexibility, and the ballast damping properties. The accelerometer data were registered while the railcar traveled on the track, but the dynamic force affected the substructure at fixed points. The speed of the rail, plus the train's dynamic parameters, modifies the force amplitude. The conversion of the acceleration data into an equivalent dynamic load provides more accurate data that can be the input for a health monitoring system. The result of this estimation considers only the contribution of the acceleration data that are related to the low cycle fatigue.

This paper demonstrates that a scaled-down experimental facility can reproduce actual failures in a subway system. The acceleration data can be converted into an equivalent force that improves the analysis of the dynamic loads. The equivalent force data facilitates the application to a health monitoring system and simplifies the development of predictive maintenance programs for the subway or railroad operators. This facility can produce simulated data sets that will be available for identifying cracks in the substructure or other defects. These data is helpful in validating analytical or simulation models.

Acknowledgements

The authors would like thank the Federal Institute for Materials Research and Testing, the Autonomous University of Queretaro for supporting this project and to CONACYT (National Science and Technology Council in Mexico) for support the scholarship of Mr. Gerardo Hurtado.

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