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SURFACE WAVE TESTING FOR CHARACTERIZATION OF BALLAST AND FOUNDATION LAYERS

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EXTENDED ABSTRACT

The subsurface structure of a track system consists of ballast bed and soil foundation. Ballast fouling due to degradation and infiltration of other materials from the ballast surface and the foundation has been a common problem with rail track performance. The efficiency of a track system decreases with time due to ballast fouling and/or loss of the shear strength of foundation soil. Monitoring and identifying the changes in mechanical properties of ballast and foundation soil in a track system are essential to schedule and predict maintenance costs and to improve safety. Unlike qualitative measurements with the electromagnetic waves, for example, Ground Penetrating Radar, wave velocity measurements provide an opportunity to estimate the distribution of rail system stiffness with depth that can be directly in design.

The objective of this study is to develop a track substructure (ballast and subgrade) condition assessment system based on the seismic surface wave method with the Spectral Analysis of Surface Waves (SASW) approach. This approach is non-intrusive, low cost, and can quickly appraise areas of a track. In particular, the quality of data collected with this approach can be judged in real time during the field data collection, which is necessary for efficient testing on rail track.

The main output of the field surface wave testing is measurement of time records from different receivers. In the SASW approach, each pair of time records is processed in the frequency domain to develop a dispersion curve, and the dispersion curves from different receiver spacings are combined to form a representative dispersion curve. This representative dispersion curve is used to derive a representative shear-wave velocity profile using a backcalculation or inversion process.

The equipment required for surface wave testing consists of impact energy sources, two or more receivers (geophones or accelerometers) placed along a line or lines on the ground surface, and a computer-based data acquisition system. Because the SASW approach is scalable, different energy sources with different intensities and impact durations can be utilized to generate surface wave energy over the range of frequencies compatible with the depth of interest. The receivers also should be selected carefully so they respond properly to the range of frequencies of interest.

Surface wave testing on a rail track is more complicated than that on soil sites or pavements because of the presence of ballast, crossties, and rails as well as the variation of shear wave velocity with depth in the ballast-soil foundation structure. Concerns for seismic testing of track substructure include coupling between receiver and ballast, effect of receiver mounting resonant frequency, high frequency scattering of ballast aggregate, attenuation of high frequency waves by ballast, influence of crossties, and analysis of dispersion data. To address these concerns, several series of studies were performed using small-scale laboratory testing, large scale field testing, and actual rail track testing.

For the small scale testing, a 3-ft (0.9 m) diameter laboratory specimen filled with compacted soil and 1-ft (0.3 m) thick AREMA 4 ballast (crushed limestone) was used. The goals of the small scale testing were:

1. develop practical receiver coupling and optimum impact-source coupling to the ballast; and
2. maximize the quality of signals at high frequencies (500 Hz to 3000 Hz) that relate to the ballast quality.

Based on the experience from the small scale testing it was recommended to use accelerometers instead of geophones to receive high-frequency signals. To generate a stable impact, a small metal strike plate was devised for placement on the ballast. Receivers should be fixed through a magnet to a light-weight spike to minimize the attenuation of high frequency signals.

For the large scale field testing, a 22 ft (6.7 m) long, 11 ft (3.3 m) wide and 1 ft (0.3 m) thick ballast bed was built on an existing well-compacted soil foundation. The ballast material is similar to that used in the small scale laboratory testing. This test bed was necessary to minimize the lateral reflections observed for the longer spacing and to delineate the tie-ballast interaction from sensor-ballast interaction. The goals of this large scale testing were:

1. investigate the consistency of data collected at different locations on the ballast bed;
2. confirm that accelerometers used in small scale testing also be effective in data collection at low frequencies (as low as 15 Hz) for deeper investigation; and
3. determine the impact sources that can effectively generate surface wave signals at different frequency ranges.

Tests with receiver spacings of 0.5, 1, 2, 4, 8, 12 and 16 ft (0.15, 0.3, 0.6, 1.2, 2.4, 3.9 m) were conducted to investigate the consistency of the data collected from different receiver spacings and to generate a full-range dispersion curve that can be used to derive a shear-wave velocity profile down to a depth of 10 ft (3 m) or more.

The actual rail track testing was performed at two locations. A section of a low-traffic freight railroad in El Paso, Texas was visited repeatedly to optimize the test set up and the data analysis procedure considering the effects of crossties and rails on the measurements. A second series of tests was performed on the FAST High Tonnage Loop at the Transportation Technology Center (TTC) near Pueblo, Colorado. The goal of testing at TTC was to characterize the ballast and foundation layers in different sections and different conditions in terms of shear-wave velocity.

The main findings of this study so far are:

- Due to the construction practices and the nature of the materials used for ballast, the mechanical properties of ballast are variable. It is more desirable to perform several rapid, short distance surface wave tests, as opposed to a more comprehensive long distance tests if the goal is only to evaluate the condition of the ballast.
- Average shear wave velocity of clean ballast varies from 650 to 720 fps (200 to 220 m/s).
- The mechanical properties of fouled ballast can be greater or less than comparable clean ballast depending on the nature of the fouling agent and the absence or presence of moisture.
- With the prototype set up, the surface wave method can quantify the mechanical properties of the foundation layer down to 10 to 15 ft (3.0 to 4.6 m).