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Railway Track Substructure Evaluation Using Instrumented Wheelset (IWS) Continuous Measurements

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Abstract

This paper intends to propose a method for indirect evaluation of railway track substructure using the response measurements of the vehicle. Wheel/rail forces and accelerations are measured by instrumented wheelsets (IWS) and accelerometers, respectively. The IWS system is mounted on a freight railcar and collected data over a short line railroad over Canadian shield with large variation in track stiffness. The relative stiffness of the track could be calculated by the ratio of the magnitude of cyclic load and cyclic displacement. Cycle displacements can be interpreted through the integration of the accelerometer data at the most contributing frequency within both loads and accelerations. An algorithm is proposed to detect the most relevant frequency between load and acceleration and calculate the load/displacement ratio accordingly. To verify the proposed method a numerical simulation is developed in a finite element (FEM) software. Using the validated proposed method, the stiffness variation is estimated on a section consisting of an embankment with lateral supports and the grade crossing. The results confirmed the developed methodology could estimate the stiffness variations and detect track features such as the lateral support of the embankment and the grade crossing as well as soft section that may attribute to some poor subgrade conditions.

Keywords: Subgrade Evaluation, Railway Track Monitoring, Track Stiffness Variation, Singular Value Decomposition (SVD), Instrumented Wheelset (IWS), Beam on Elastic Foundation

1 Introduction

Instrumented cars are emerging as an important tool for measuring the wheel/load contact forces and acceleration signals to provide reliable data for monitoring railroad tracks. Compared to conventional methods, the instrumented cars could provide continuous information from the track without disrupting railway operations [1]. Railway organisations need to detect the problematic sections of rail tracks to schedule maintenance programs appropriately [2]. Regular condition monitoring is essential to detect track defects at an early stage before they cause major problems [2].

Substructure problems could be identified by measuring track stiffness, but direct measurements would be difficult due to limited equipment and regular railway traffic [7]. The stiffness variation along the track could be estimated based on the measured dynamic response of the train [3]. Abrupt stiffness variations along the track may cause the structure to deteriorate, resulting in changing vehicle dynamics at low frequencies [16].

In this research, continues measuring of dynamic wheel/rail forces performed using instrumented wheelsets (IWS) through deployed strain gauges installed on wheels. The hypothesis is that large dynamic loads are typically attributed to either large track deflections caused by soft subgrade or track sections with varying stiffness. In sections with low stiffness values, large displacements and large bending moments are expected that cause long-term fatigue conditions, whereas sections with high stiffness values experience small displacements and bending moments [5].

In this study, an instrumented wheelset (IWS) by National Research Council Canada (NRC) Automotive and Surface Transportation (AST), mounted on a freight railcar to measure wheel/rail forces and two side frame accelerometers collected the vertical acceleration data over a short line railroad over Canadian Shield with large variation in track stiffness. Signals provided by these sensors were used to estimate relative stiffness variation along the track. This study proposes a method for calculating the load/deflection ratio by detecting the most relevant frequency between the load and acceleration signals. The application of this methodology was examined on a part of field data to estimate the stiffness variation and detect track features along the section.

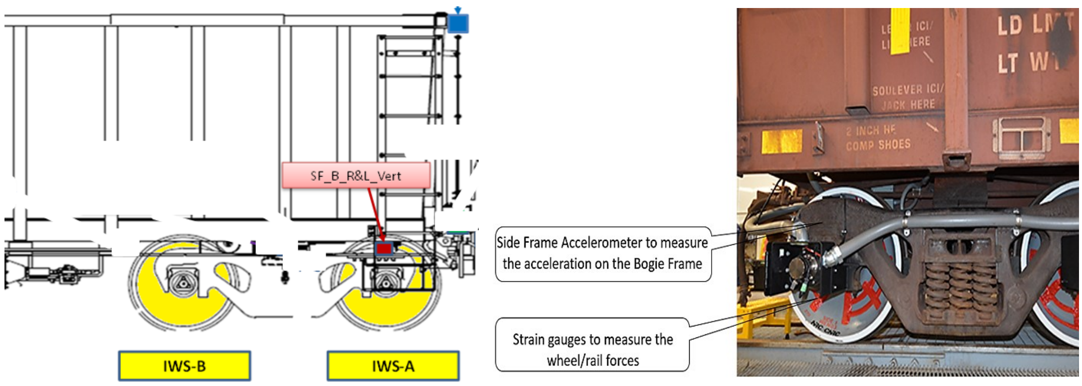

Figure 1- (a)Layout of Instrumented railcar (IWS, Side frame acceleration, GPS antenna) (b) Location of the Sensors (Strain gauge & Accelerometer) Side view of NRC's Instrumented Wheelset. (NRC, 2020)

2 Methods

A method is developed for evaluating stiffness variation using provided data, such as wheel-rail forces, side frame acceleration measurements from the trucks, speed, and GPS coordinates. The method is developed for calculating the load/deflection ratio. The moving window technique is applied on the load and acceleration data to divide them into smaller parts to consider different events more precisely along the measurements. For each section, the windowed load and acceleration signals are analysed in frequency domain to calculate the deflection and stiffness index respectively. The magnitude of cyclic deflection interpreted from the double integration of the accelerometer data at a common frequency which determined using the singular value decomposition (SVD) method [17-18]. The rail deflection then could be calculated by [19]:

$$d(t)_{cyclic} = D\cos(2\pi f t - \varphi) \tag{1}$$

$$a(t)_{cyclic} = -(2\pi f)^2 D\cos(2\pi f t - \varphi) \tag{2}$$

$$d(t)_{cyclic} = \frac{a(t)_{cyclic}}{-(2\pi f)^2} \tag{3}$$

In the equation, "D" represents the amplitude of the cyclic displacement in mm, "a" is the acceleration in mm/s^2, "f" is the frequency of motion in Hz, and "φ" is the phase shift in rad. Using the estimated deflection data and the load signal, track stiffness could be calculated by [8]:

$$K = \frac{P_{\max\_amp}}{d_{\max\_amp}} \tag{4}$$

$P_{\max\_amp}$: Magnitude of vertical wheel load

$d_{\max\_amp}$: Maximum rail deflection under the wheel

K : Stiffness

The following flowchart shows the steps to select common frequency and calculate the relative stiffness for each window accordingly.

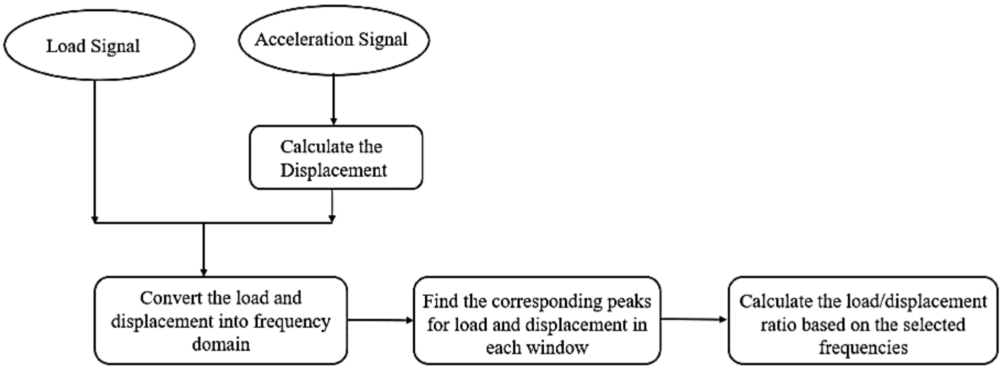

Figure 2. Flowchart for selecting the frequency of vertical load and displacement and calculate relative stiffness

Using the Winkler model, a finite element model of a continuous beam on a uniform elastic foundation is simulated to evaluate the implementation methodology. So, the simulation consists of a beam on an elastic foundation, and a sprung mass that moves along the beam. According to the experiments, the loads and acceleration are collected from the wheel and the sprung mass. A preliminary analysis is conducted over sections with known track structures, including an embankment, to determine whether the method can be used to estimate stiffness variation and detect structural features.

3 Results

The simulated beam on an elastic foundation is subjected to a moving sprung mass and collects the data accordingly. To model a section with varying stiffness, four springs with different stiffness are used under the beam. The proposed method is used to evaluate beam deflection and stiffness variation. The following plots show the vertical load at the contact point, acceleration of the sprung mass and the calculated stiffness variation along the beam. The results, shows the variation agrees relatively well with the simulation assumptions which represent that the stiffer part of the foundation is associated with the peaks while the softer part has lower values of the load/deflection plot.

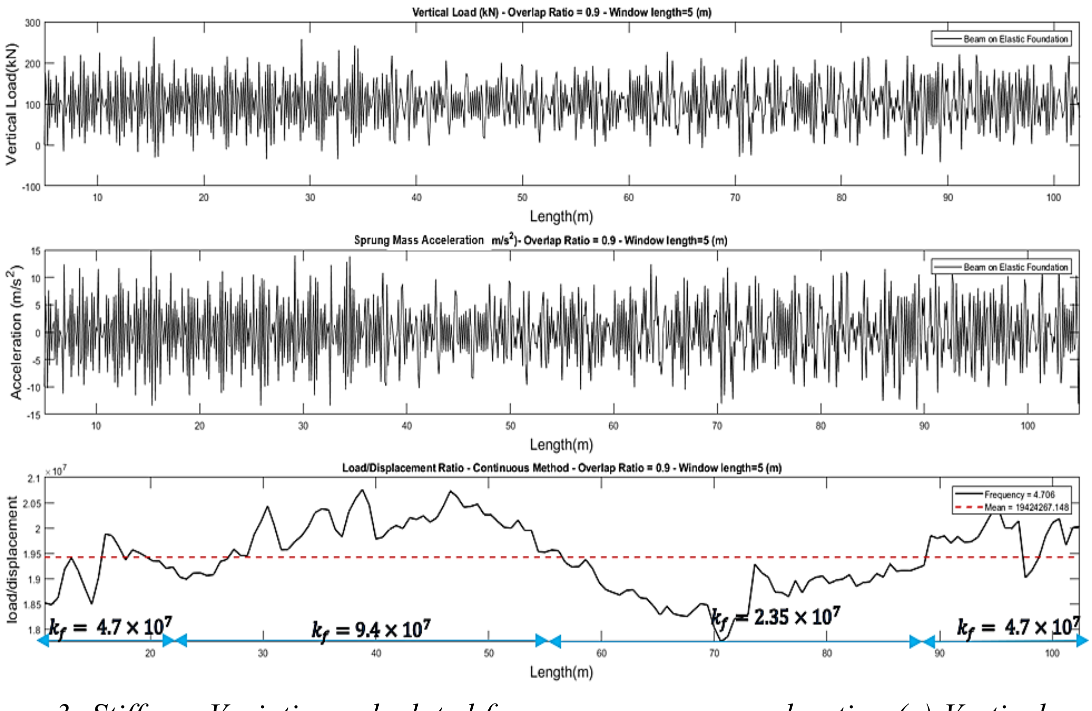

Figure 3- Stiffness Variation calculated from sprung mass acceleration (a) Vertical Load (b) Sprung Mass Acceleration (c) Stiffness Variation

The simulation results verified the proposed methodology and confirmed it potentially could be used to evaluate the stiffness variation of the beam's foundation using the load and acceleration measured on the wheel and sprung mass. To investigate the application of the developed method to evaluate stiffness variation using the IWS measurements, a preliminary analysis is conducted over sections that are known to have a large physical change, such as embankment with lateral supports. The load and acceleration signals for a 0.5 mile of track consisting of the embankment were selected to estimate stiffness variation. Figure 4(a) shows the exact coordinate and Milepost information of embankment and lateral supports, and Figure 4(b) represent the calculated stiffness variation along the selected section. GPS data consist of latitude and longitude coordinates are used to estimate the location of the track features and is used for aligning the results to evaluate the calculated stiffness and location of the variations.

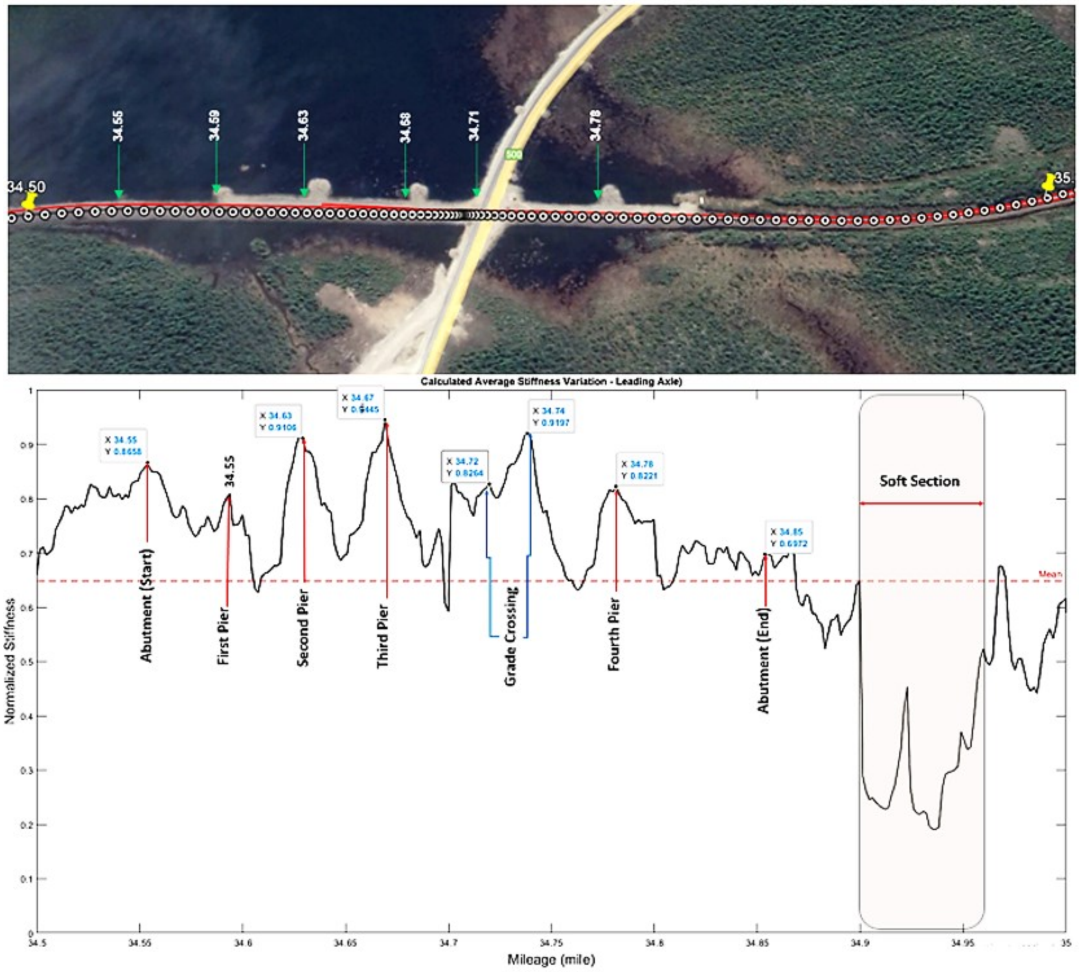

Figure 4- (a) Selected embankment and detailed locations (b) Calculated Stiffness Variation aligned with structural features

The results show the developed methodology could estimate the stiffness variations and detect track features like the lateral support in embankment and the cross grading along the section. The variations along the selected section are concurrently amplifies around the sub-structural changes like the location of the supports or grade crossing. Additionally, there is a part with the low value in the stiffness plot, which attribute to the soft subgrade.

4 Conclusions and Contributions

Wheel-rail dynamic forces are of major importance of rail track responses, which can be used to evaluate various factors of track performance such as the effect of different track features, stiffness transitions and track structural defects on the dynamic loads. Instrumented wheelsets mounted on an in-service freight rail car were used to measure wheel/rail forces along the track. Vertical load measurements at the contact point, in addition to acceleration and GPS data, are used to evaluate the condition of the railway substructure. A method was developed in this research to calculate stiffness variation using load and acceleration data as a key factor in railway track condition monitoring. The main assumption is that any change in track stiffness will affect the measured dynamic load. As the definition of stiffness, the developed methodology calculates the load/deflection ratio, while the load is directly measured by the IWS system, and the deflection by integrating the accelerometer's signals at the most contributing frequency between the signals. The singular value decomposition (SVD) was used to determine the dominant frequency in the calculation process. [18]. Using FEM software, a numerical model was created to verify the proposed methodology for calculating stiffness variations. To simulate the experiment, a beam on an elastic foundation model with a diverse stiffness was modelled and a sprung mass moved along the beam. The load and acceleration were collected at the contact point and sprung mass, respectively. The simulation results showed that the calculated stiffness variation was relatively consistent with the preliminary assumptions which has proved the concept of the methodology.

The load and acceleration signals for a section including an embankment were used to evaluate the subgrade condition based on the proposed methodology. Through the calculation process, the plot for normalized stiffness indicated that the remarkable variations coincide with the benchmark stiffness changes over the embankment. The case study from the IWS field measurements provided the promising results showing that the developed methodology can detect the major stiffness variations along the track such as the lateral supports in embankments or the grade crossings. The proposed methodology could be used to evaluate the stiffness variation over the long distances of railway network to detect the potential problematic sections for further maintenance decisions by railway operators. Nevertheless, there are some limitations, such as the need for judgement and knowledge of the site to interpret the sharp changes in the analysis.

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References

[1] Yang, Y. B., et al. "Track modulus detection by vehicle scanning method." Acta Mechanica 231(2020):2955-2978

[2] Malekjafarian, A.; OBrien, E.J.; Quirke, P.; Cantero, D.; Golpayegani, F. Railway Track Loss-of-Stiffness Detection Using Bogie Filtered Displacement Data Measured on a Passing Train. Infrastructures 2021, 6, 93.

[3] Quirke, Paraic, et al. "Drive-by detection of railway track stiffness variation using in-service vehicles." Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 231.4 (2017): 498-514.

[4] Berggren, E; Railway Track Stiffness Dynamic Measurements and Evaluation for Efficient Maintenance, Doctoral Thesis.

[5] Li M and Berggren E: A Study of the Effect of Global Track Stiffness and its Variations on Track Performance: Simulation and Measurement, submitted to the conference IHHA 2009. Candidate paper to Special Issue of Journal of Rail and Rapid Transit.

[6] T. Dahlberg, Railway Track Stiffness Variations – Consequences and Countermeasures,2009

[7] C. Esveld, Modern Railway Track, 2nd edition, MRT-Productions, Delft 2001.

[8] Selig, ET. and Li, D. 1994. Track modulus: Its meaning and factors influencing it. Transp. Res. Rec.,1470, 47–54.

[9] Fallah Nafari S. Gül M. Roghani A. Hendry M and Cheng JJR. 2018. Evaluating the potential of a rolling deflection measurement system to estimate track modulus. Proc. Inst. Mech. Eng. F J. Rail Rapid Transit, 232 (1), 14–24.

[10] Sussmann, TR., Ebersöhn,W., and Selig, ET. 2001. Fundamental nonlinear track load-deflection behavior for condition evaluation. Transp. Res. Rec.,1742,61–67.

[11] Hendry, M., et al. "Monitoring cyclic strain below a railway embankment overlying a peaty foundation using novel instrumentation." Proc. 61st Canadian Geotechnical Conference and 9th Joint CGS-IAH-CNC Groundwater Conference. Vol. 2. 2008.

[12] Li M. and Berggren E. 2010. A study of the effect of global track stiffness and its variations on track performance: Simulation and measurement. Proc. Inst. Mech. Eng. F J. Rail Rapid Transit 224(5), 375-382.

[13] Tzanakakis K. 2013. The effect of track stiffness on track performance in the railway track and its long-term behaviour. Springer Tracts on Transportation and Traffic, 2013(2), Springer, Berlin, Heidelberg.

[14] Fröhling, RD. 1997. Deterioration of railway track due to dynamic vehicle loading and spatially varying track stiffness, PhD-Thesis, University of Pretoria.

[15] Do, Ngoan T., Saeideh Fallah Nafari, and Mustafa Gül. "Estimation of track modulus over long distances using artificial neural networks." Procedia engineering 199 (2017): 2102-2107.

[16] Quirke, Paraic, et al. "Drive-by detection of railway track stiffness variation using in-service vehicles." Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 231.4 (2017): 498-514.

[17] Malekjafarian, Abdollah, and Eugene J. O'Brien. "Application of output-only modal method in monitoring of bridges using an instrumented vehicle." Civil Engineering Research in Ireland, Belfast, UK, 28-29 August 2014. 2014.

[18] Mousapour R., Haji Abdulrazagh P, Gul M and Hendry MT. 2021. Evaluating Railway Track Stiffness Variations Using Instrumented Wheelset (IWS) and Accelerometer Measurements. Canadian & Cold Regions Rail Research Conference, November 2021.

[19] Hendry MT., Barbour SL, and Martin CD. 2011. An evaluation of real-time deformation monitoring using motion capture instrumentation and its application in monitoring railway foundations. Geotechnical Testing Journal 34.6 (2011): 602-612.