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Monitoring structural degradation of rail pads in laboratory using impact excitation technique

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MONITORING STRUCTURAL DEGRADATION OF RAIL PADS IN LABORATORY USING IMPACT EXCITATION TECHNIQUE

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Abstract

In ballasted railway track, the deterioration of a sleeper and ballast support usually occurs due to both regular and irregular wheel/rail interactions. The repeated impact of train wheels over sleepers can reduce the lifetime of a sleeper and degrade ballast. To attenuate the effect of the impact loads on concrete sleepers, the resilient rail seat pads are used. After a certain time in service conditions, the worn rail pads have to be replaced. Assessment of the condition of rail pads is of great importance to track engineers and plays an important role in the overall track maintenance cost. A non-destructive methodology for evaluating and monitoring the dynamic properties of the rail pads has been developed based on an instrumented hammer impact technique and an equivalent single degree-of-freedom system approximation. In this study, the sample rail pads were collected during track maintenance work on a rail network in New South Wales, Australia. The measurements were performed using an instrumented hammer in a frequency range between 0 and 1,000 Hz. The effective mass, dynamic stiffness, and dynamic damping ratio were extracted in order to assess the current condition of the worn rail pads, thus assisting track engineers to optimise track maintenance operations.

Keywords: Rail pads, structural degradation, impact excitation testing, vibration characteristics, health assessment and monitoring.

1. Introduction

In the design, construction and maintenance of railway track, it is considered more and more important to establish reliable properties of the railway track components. This information is typically required for numerical simulations and finite element modelling of track structure to predict the response to a variety of dynamic loadings. In addition, the dynamic properties of track components can be used as the structural health indicators to facilitate the processes of maintenance and renewal of track structural components. These properties will enable to predict the behaviour of the railway track structures more accurately on such issues as noise and vibration emission, component service life, safety and structural damage. However, it requires dedicated testing methods to establish these properties and simulation methods to predict the behaviour.

In Australia, railway engineering problems such as track derailment, large settlement of track, rail corrugations, etc. are mostly attributed to heavy impact dynamic loading. This has prompted the need to

study the dynamic behaviour of railway tracks in order to identify their current condition and to predict the remaining capacity.

In general, railways have played an important role in transporting goods and resources over large areas of Australia, for instance, coal, cement, etc. The traditional ballasted track system is used throughout this country. In this system, rail pads, usually made from rubber or polymeric compound materials, are installed on rail seats in order to attenuate the dynamic forces from axle loads and wheel impact from the stock rolling. Since they behave as a softening media between rail track and sleepers, these pads are very important. There are many problems due to the improper or inadequate utilization of rail pads including cracking of sleepers at rail seats, large settlements of railway tracks, and ballast/subgrade breakage from heavy tamping. Thus, rail pads are one of critical track components for which track engineers require knowledge of its dynamic parameters at different ages. Variation of dynamic properties as a function of period in service could provide an important information about the existing capability of pads to reduce sufficiently the dynamic stresses and impact loads on sleepers [1]. To have a better insight into the dynamic characteristics of aged rail pads, it is important to develop experimental techniques to extract their dynamic properties. These are also used in the numerical simulation of track dynamics to identify the actual behaviors of railway track as a typical railway track model used for numerical simulations can be seen in Figure 1.

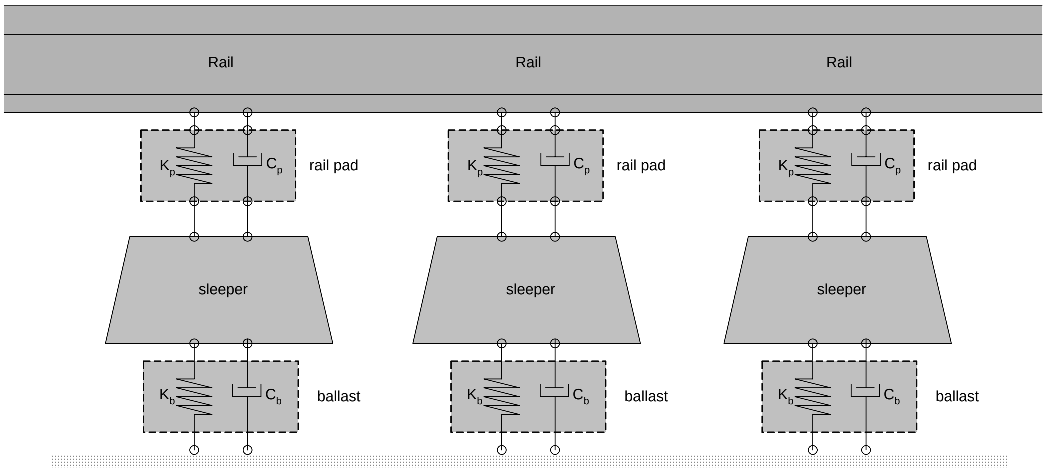
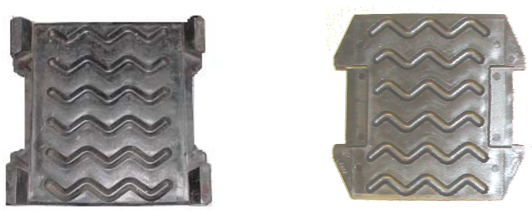


Figure 1: Example of numerical model of track system and dynamic properties of track components (after [1])

Currently, there are many types of rail pads, such as high density polyethylene (HDPE) pads, natural rubber pads, and resilient elastomer pads, all of which have different surface profiles [2]. Examples of plain HDPE profiles are illustrated in Figure 2. Until recently, the investigation of the dynamic characteristics of resilient pads have been limited, even though resilient rail pads are used extensively on all major Australian railway networks [1]. The dynamics of the resilient type have been studied mostly based on a two-degree-of-freedom (2DOF) models [3, 4]. In this paper, a SDOF-based method is proposed to help railway track engineers to evaluate the realistic values of the dynamic properties of aged rail pads required for the design and maintenance of railway tracks. An analytical formulation was utilised to curve fit the measured vibration responses. Vibration response measurements were obtained by exciting the rail using an instrumented hammer. The curve fitting method was applied to the frequency response functions (FRFs) obtained from modal testing measurements to extract the effective mass, dynamic stiffness and damping of resilient-type rail pads at each age.



a) HDPE 5.5 mm b) HDPE 6.5 mm

Figure 2: Examples of HDPE rail pad profiles

2. Impact excitation technique

Impact excitation technique is a technique based on experimental modal analysis (EMA) or generally called modal testing. This technique is a non-destructive testing methodology using the vibration responses of structures to the given excitation. The experimental modal technique enables many investigations related to structural dynamic problems. Over the past decade, the modal testing has become an effective means for identifying, understanding, and simulating dynamic behaviour and responses of structures. One of the techniques widely used in modal analysis is based on an instrumented hammer impact excitation. On the signal analysis basis, the vibration response of the structures to the impact excitation is measured and transformed into frequency response functions (FRFs) using Fast Fourier Transformation (FFT) technique. Subsequently, the series of FRFs are used to extract such modal parameters as natural frequency, damping, and corresponding mode shape. In a wide range of practical applications the modal parameters are required to avoid resonance in structures affected by external periodic dynamic loads. Practical applications of modal analysis span over various fields of science, engineering and technology. In particular, numerous investigations related to aeronautical engineering, automotive engineering, and mechanical engineering have been reported [5].

In this study, the new test rig has been developed based on the SDOF dynamic system as illustrated in Figure 3. Remennikov and Kaewunruen [1] have formulated an analytical dynamic transfer function of rail pads idealised as a simple mass-spring-damper SDOF system. The magnitude of the frequency response function $H(f)$ (Nm/s^2) is given in terms of frequency f (Hz) by

$$H(f) = \frac{1}{m} \frac{4\pi^2 \left(\frac{m}{k_p}\right) f^2}{\sqrt{\left[1 - 4\pi^2 \left(\frac{m}{k_p}\right) f^2\right]^2 + \left[4\pi^2 \left(\frac{m}{k_p}\right)\left(\frac{c_p^2}{k_p m}\right) f^2\right]}} \quad (1)$$

where m, c_p, and k_p generally represent the effective mass (kg), damping value (Ns/m), and stiffness (N/m) of rail pad, respectively. Based on Eq.(1), these dynamic parameters are extracted from modal data measured in the laboratory or in the field.

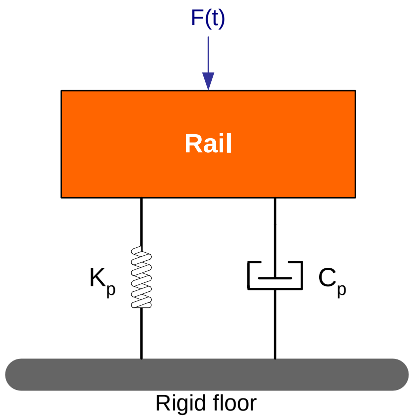


Figure 3: SDOF dynamic modelling

3. Aged rail bearing pads

The rail pads used in this study were collected from a railway network operated by Rail Infrastructure Corporations (RailCorp) in areas of New South Wales, Australia. Their service life was about eighteen years. Figure 4 shows the samples of aged pads employed in this study. All pads had HDPE 5.5mm profile. The new pads of the same type, provided by PANDROL Australia, were tested also using the same technique.

Figure 4: Example of worn HDPE rail pads.

4. Laboratory experiments

In order to investigate the dynamic characteristics of rail pads, a test rig for dynamic testing of rail pads has been developed at the University of Wollongong. The test rig consists of a concrete block that supports steel mass, preloading bolt system, and a rail pad as shown in Figure 5. The concrete block is isolated from surrounding noise by attaching on the very soft rubber over a strong floor representing the absolutely rigid foundation. An accelerometer is attached to the upper steel mass, as illustrated in Figure 5. An impact hammer is employed to excite the assembly of components. The frequency response function (FRF) is then obtained using the PULSE dynamic analyser in a frequency range from 0 to 1,000 Hz. The coherence function is also obtained to evaluate the quality of FRF measurements, which were averaged from 10 hits. In this case study, the properties of both new and worn PANDROL HDPE pad (plain type, 5.5 mm thick) were identified using the test rig. The case study results are presented in Figure 6. It should be noted that the results given are based on a 20 kN preload that represents the sustained load from fastening system (e-Clip).

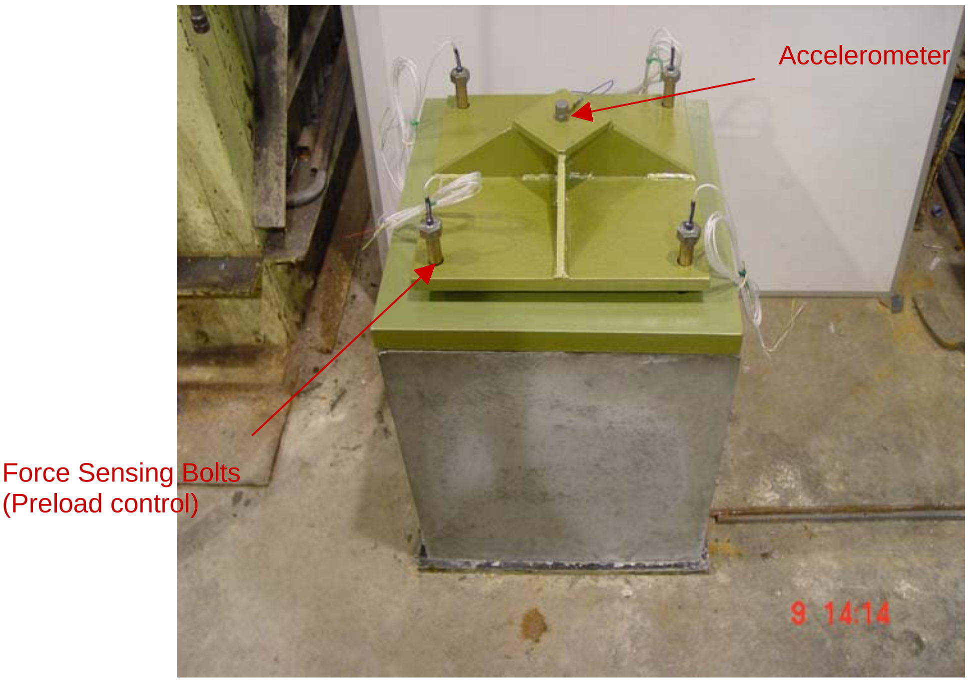


Figure 5: Innovative experimental rig for testing rail pads.

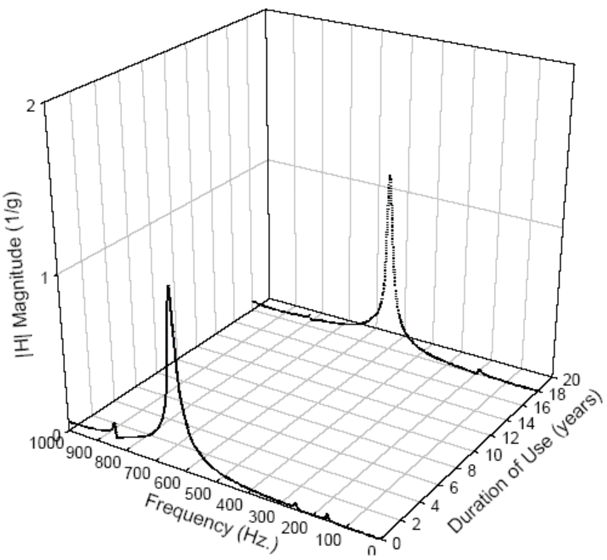
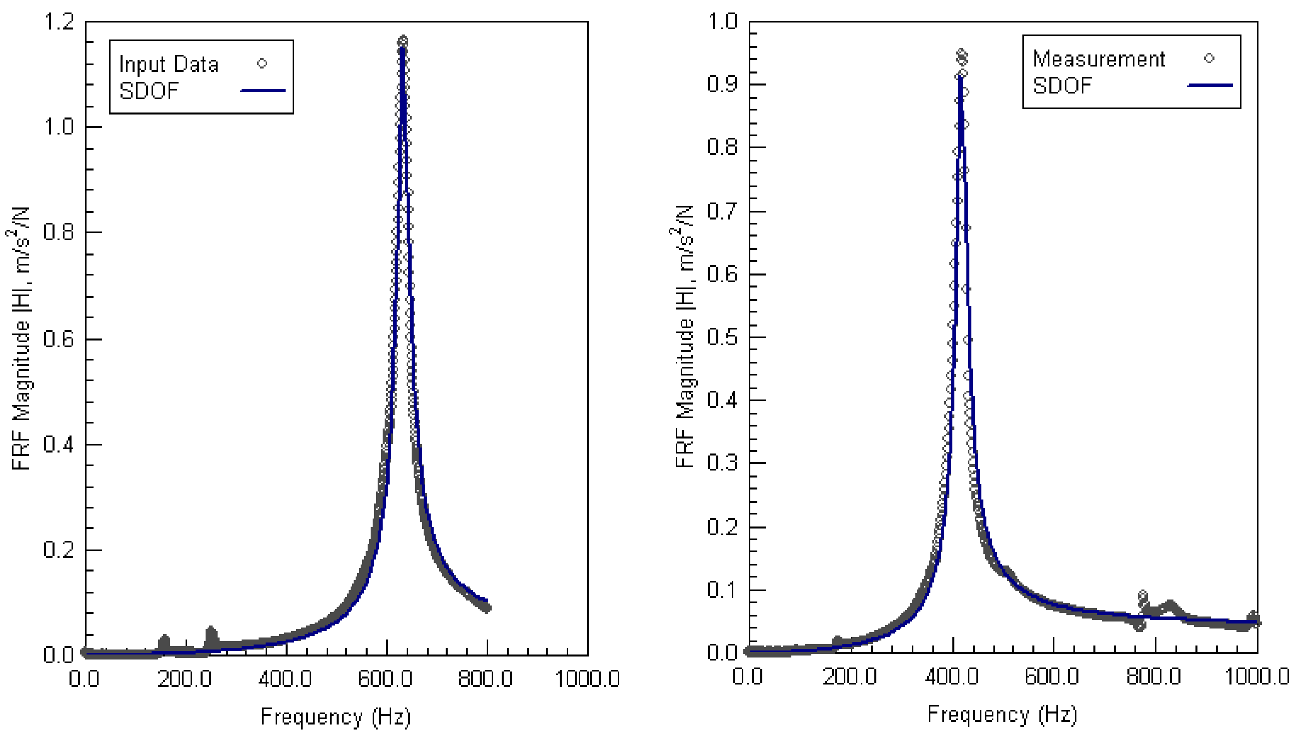


Figure 6: Frequency response function of HDPE 5.5 mm rail pad at ages

5. Results

To extract the dynamic properties of rail pads such as dynamic stiffness and damping coefficients, the curve-fitting optimisation approach is employed. An analytical expression for FRF of a SDOF system from Equation (1) is used to best fit the experimental measurements of FRF using the least squares method. In general, the curve-fitting procedures are be available from many general computational packages (e.g. MATLAB, Mathematica, Maple), or by using specialised curve-fitting computer codes (e.g. DataFit). Figure 7 demonstrates the curve fitting performed by a computer program DataFit [6]. Table 1 gives the determined modal parameters and the correlation coefficients r^2 of the curve fitting. Each value was averaged from three sampling pads tested. Excellent correlations were found for both new and aged rail pads (less than 2%). However, at this stage, the worn pads characteristics are available only for two age groups. Using linear regression analysis, the dynamic stiffness is predicted to deteriorate with the rate of 13 MN/m per year while the damping constant reduces approximately 41 Ns/m per year. The more comprehensive study of condition assessments of rail pads at more different ages will be continued in the near future.



a) new pad   b) worn pad

Figure 7: Curve fitting of frequency response functions.

Table 1 Structural degradation of rail pad (HDPE5.5mm)

Type	r^2	C (Ns/m)	K (N/m)
New	0.994593	3,458.0636	407,492,550.0
Worn (18 years)	0.986364	2,720.2489	171,146,658.0

6. Conclusions

Dynamic properties of structural elements can be used in various aspects of railway track dynamics such as analysis, modeling and, as presented in this paper, for monitoring the structural degradation rate. Modal testing is a non-destructive testing strategy based on vibration responses of the structures, which has proven to be a fast and effective test method for identification of the dynamic stiffness and damping constant of rail pads. In this paper, the applications of experimental modal testing to identify and monitoring the structural degradation of rail bearing pads are demonstrated.

Based on the linear regression of the results, it could be found that the annual rate of structural degradation of dynamic stiffness is about 13 MN/m and the rate for the damping is approximately 41 Ns/m. This information is very crucial in maintenance and renewal procedure in track engineering for which it has never been presented elsewhere. In addition, there has been the kindness of RailCorp to provide UoW more worn pads recently. The more comprehensive results of condition assessments of rail pads at more different ages, the degradation rates, and the optimum renewal period will be presented in the near future publication.

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