Application of WAK test to Identify Unstable Concrete Sleeper

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Abstract

In this study a new detection technique based on WAK is introduced that can be used for identifying unstable concrete sleeper installed in ballast by triggering activated wave on the sleeper surface. If a gap exists immediately below the concrete sleeper, static stiffness can be lower than stable case’s stiffness. The concrete sleeper is assumed as a single degree of freedom system (SDOF). The static stiffness $K$ can be obtained by iteratively calculated mass $m$, stiffness $k$ and damping coefficient $c$ of SDOF system. Those coefficients are used to specify the ballast condition such as a gap between the sleeper and ballast. Typical test results using a small sleeper model test are summarized and explained for proof of effectiveness of the WAK test for checking unstable condition of the sleeper.

Keywords: Track, Track stiffness, Gap, WAK, Nondestructive test

1. Introduction

The Wave Activated Stiffness (K) (WAK) test was developed originally by Briaud and Lepert in 1990[1] to check defects in concrete shallow foundation. The WAK test is a nondestructive test method to obtain the vertical static stiffness of the soil under a spread footing by using a hammer impact test. The original WAK test method was a dynamic load test performed by impacting the footing with a hammer instrumented with a force transducer. By analyzing the recorded force-time signal from the footing and the velocity-time signal from a geophone placed on the footing, an estimate of the stiffness of the footing-soil assembly can be performed.

In this study, concept of the WAK test is applied to the concrete sleeper embedded into the ballast. The concrete sleeper is considered as long flexible beam. This study is to investigate a way of that for maintenance purpose or after installing of the concrete sleeper, soil condition directly beneath the sleeper including a gap can be detected by the newly modified proposed WAK test method.

2. THEORY

2.1 Theoretical background

The concrete sleeper assumed to be installed into the ballast on track-bed foundation is modeled as a Beam-on-Elastic-Foundation (BOEF) that is called Winkler model. The ballast with track-bed foundation soil is modeled as a set of springs and dashpots as shown in Fig.1. The concrete sleeper is modeled as an elastic member with a mass $m$ per unit length (kg/m) of sleeper or a long beam and bending stiffness $EI$ where $E$ (N/m$^2$) is the elastic modulus and $I$ (m$^4$) the moment of inertia. For simple modeling, $m$ and $EI$ are assumed constant along longitudinal axis $z$. (Fig. 1)

Fig. 1. Damage and gap under railway system
The governing differential equation (GDE) for the dynamic behavior of the concrete sleeper can be represented as follows:

\[
EI\frac{\partial^4 y}{\partial z^4} + m\frac{\partial^2 y}{\partial t^2} + c\frac{\partial y}{\partial t} + ky = 0
\]

(1)

By adapting Vesic’s equation [2], it is easily verified that the sleeper be long flexible by the following criteria:

\[
\frac{\lambda L}{\sqrt{EI}} > \frac{k_s B}{E_b I_b}
\]

(2)

where \( k_s \) = soil reaction modulus, \( E_s \) = soil’s elastic modulus, \( \mu \) = Poisson’s ratio of soil, \( B \) = width of sleeper, \( E_b I_b \) = flexural rigidity of sleeper.

Since the impact force \( F(t) \) applied on the sleeper is assumed to be harmonic with time as follows, the coefficients of the GDE are constant

\[
F(t) = F_0 e^{i\omega t}
\]

(3)

The solution of Eq. (1) can be obtained by adapting the following solution form where \( \theta \) is displacement amplitude of sleeper with time, \( \omega \) is angular frequency and \( \kappa \) is complex wave number:

\[
y(z,t) = \theta e^{i(\omega t - \kappa z)}
\]

(4)

The velocity of the sleeper tip where the force is applied on is:

\[
v(z,t) = \frac{\partial y(z,t)}{\partial t}
\]

(5)

Thus, the mobility function of the sleeper that is embedded into the ballast is defined as a modulus of the ratio of the velocity \( v(t) \) over the applied force \( F(t) \):

\[
\text{mobility} = \left| \frac{v(z,t)}{F(t)} \right|
\]

The modulus function of the system is calculated as the Fourier transform of the output signal \( v(t) \) over the Fourier transform of the input signal \( F(t) \) that is a form of Frequency Response Function (FRF). However, the theoretical mobility function is independent of time but is a function of the frequency. One single impact test by sledge hammer on the sleeper provides the curve of \( v/F \) versus \( \omega \). The mobility function can be drawn point by point.

3. Wak Test

3.1 WAK test for scale-down model sleeper

In order to check the proposed WAK test for detecting a gap between a concrete sleeper and ballast, an experiment was done as follows.

Fig. 2. Sleeper Modeled as Beam-on-Elastic Foundation

![Sleeper Modeled as Beam-on-Elastic Foundation](image1)

Fig. 3. Schematic of WAK Test Setup

![Schematic of WAK Test Setup](image2)

Fig. 4. WAK test process for model scale-down concrete sleeper

![WAK test process for model scale-down concrete sleeper](image3)
was set up as shown in Fig. 3 and Fig. 4. Model track-bed was composed of ballast and was prepared after digging out some natural soil in the ground. The test procedure to determine the mobility function consists of performing a single impact test to a tip of the concrete sleeper by a sledgehammer. The velocity of the sleeper is recorded by a geophone.

The measured signals from hammer and geophone are in time domain. Thus, the signals must be converted into frequency contents through Discrete Fourier Transform DFT. The curve versus frequency can be obtained from a single impact test. The ratio of the maximum velocity of the track system over the maximum impact force is equal to the modulus of the transfer function.

A computer program to get Wave Activated Stiffness K was coded based on theoretical equations as shown in Eq. (6). The obtained mobility curves from the impact test on the model sleeper are compared with those obtained from theoretical computing program as shown in Fig. 7.

As a result of the test, the static stiffness K (No Gap: \( K=1.69 \times e^8 \) N / m, 17cm Gap: \( K=1.3 \times e^8 \) N / m) was shown. K value of the sleeper without a gap is larger than K of the sleeper that has 17cm gap as shown in Fig. 7. This study confirmed the proof of effectiveness of using a non-destructive evaluation system WAK by which unstable concrete sleeper can be detected. More model tests and theoretical improvements are planned and going to be performed for better performance of application of WAK test for railway track system.

4. Conclusion

The WAK test is a nondestructive testing method to obtain static stiffness K based on dynamic impact test on the sleeper that is installed in the ballast. It is found in this study that the mobility curves can be used to check gap existence below the model concrete sleeper. The maximum values of mobility function are found to be increased with increase of the gap width below the sleeper. This means that the WAK testing method can be used to detect
a sleeper above a gap or cavity in the trackbed foundation. However, in this study, the test is based on single model sleeper only. Therefore, more tests for a set of sleepers, rails and ballast are necessary in the future. Also, its usefulness of using WAK test method for concrete slab track should be verified further by model tests may for detecting gap existing directly below concrete slab track in the future.

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References

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