Engineering Failure Analysis 31 (2013) 360–374

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Prediction of displacement induced by tilting trains running on ballasted tracks through measurement of track impact factors

Jungyoul Choi *

Dept. of Track and Railway Operations, Technische Universität Berlin, SG18 Salzfer 17-19, D-10587 Berlin, Germany

ARTICLE INFO

Article history:
Received 6 February 2012
Received in revised form 13 March 2012
Accepted 1 February 2013
Available online 17 February 2013

Keywords:
Track impact factor
Empirical dynamic wheel load
Tilting train
Speedup effect
Track component

ABSTRACT

In the track design and behavior prediction, the variable contribution of wheel load was evaluated by considering the design load for the tracks. Further, the track impact factor was used to calculate the dynamic wheel load as a single value, which was chosen according to the rail type (i.e., continuous welded rail or joint rail) and the design speed but did not take into consideration the track conditions (i.e., the ballast condition good or bad), train type (i.e., tilting train and EMU), and track components (i.e., sleeper type and fastening type). In this study, the measured track impact factor was applied to the time history function of the FE analysis in order to predict the displacement of ballasted tracks under real conditions, which included curved and the deteriorated tracks, thus increasing the train speed by approximately 20–30% of the existing train speed. Therefore, the dynamic wheel load and the rail and sleeper displacement were measured for two different trains running on four conventional curved track sections with two different sleeper types. The track impact factor was estimated from the measured dynamic wheel load, and the empirical dynamic wheel load was calculated using the measured track impact factor at each site. The measured track impact factors were used for simulating the dynamic wheel loads applied on the derived time history function for fast trains. A finite element analysis model using the derived time history function based on the empirical dynamic wheel load was used to predict the train-induced track displacement. The numerical simulations and field test results were compared with German and Japanese regulations for train-induced track displacement, and the speedup effect of a tilting train was compared with that of a general train (EMU).

The empirical track impact factors were 17–18% higher in the R400 sections than in the R600 sections. As the track curvature decreased, the impact on the track increased. Therefore, the empirical track impact factors were 21–23% higher in the WT sections than in the PCT sections. At 70 km/h, the impact on the track from a tilting train was 7–11% less than that from EMU. Although the tilting train sped up by 30% (90 km/h), its response level was similar to or less than that of the EMU. The analytical results reproduced the experimental results well within about 2–5% difference in the values. Therefore, the derived time history function based on the measured track impact factors is considered to provide sufficiently reliable FEA results in the investigation of the behavior of ballasted tracks. The difference between the maximum displacements for both train types on all the sections was about 15–20%.

The analytical results show that the speed limits of the tilting train were higher than those of the EMU by approximately 8–23 km/h at each test site. Therefore, the speed limit of each test site was estimated by considering the limit of sleeper displacement. It was shown that the time history function derived using the measured track impact factor on a small track curvature with wooden sleepers was higher than that in other test sections.

* Tel.: +49 177 368 6994; fax: +49 30 314 25530.
E-mail address: cjypassion@hotmail.com

1350-6307/$ - see front matter
http://dx.doi.org/10.1016/j.engfailanal.2013.02.004

Therefore, it would be advantageous to increase the weight of sleepers on existing lines to increase the train speed through the speedup effect without increasing the track curvature. The increase in the speed of a tilting train with a small track curvature was much better than that by a track curvature increased by approximately 10%.

1. Introduction

Since a tilting train (Tilting Train eXpress, TTX) can travel a curve much faster without decreasing passenger comfort, it is suitable for increasing train schedule speeds in the mountainous areas of Korea. The effective center of gravity of a tilting train is lower than that of an upright vehicle and the wheel load correspondingly decreases; the track forces for a tilting train traveling on existing tracks are expected to be lower than those of a normal vehicle and thus, stability when traversing the curve can be secured [1]. However, to convert main arterial railways to high-speed rail (HSR) lines by increasing the train speed through the use of a tilting car, it is necessary to consider the track components and the condition of existing tracks to estimate and predict track safety levels when running trains at speeds about 20–30% higher than normal vehicles. The important parameters in a numerical simulation to evaluate and predict the speedup effect and behavior characteristics of a ballasted track is the practical wheel load, which reflects the characteristics of the train and the track components, and the establishment of an analytical model that represents the condition of the actual ballasted track being used is also necessary. The procedure of prediction of train-induced track displacement using the measured track impact factor is shown in Fig. 1.

This study focuses on four existing ballasted track sections with track curvatures of 400 and 600 m and with wooden ties (WTs) or prestressed concrete ties (PCTs). The vertical rail and sleeper (tie) displacement and the dynamic wheel load, which depend on the track condition and train characteristics, are measured and the measured track impact factor, which will be used on the numerical simulation by the derived time history function using the empirical dynamic wheel load, is investigated. A prediction of the track displacement using the empirical dynamic wheel load can account for static train properties and track curvature but actual track conditions are difficult to include. Therefore, a representative dynamic wheel load is calculated by using track impact factors measured at the test sites in the theoretical expression of the wheel load. This is then used to calculate a time history function that is applied to a finite element analysis (FEA) model of the track behavior. The results of the FEA simulations are compared with the measured rail and sleeper displacements and simulation are performed for train speeds that would be impossible on a service line. The speed increase associated with a tilting train is evaluated and compared with the speed for a normal vehicle (an electricity motor unit, EMU) through a comparative

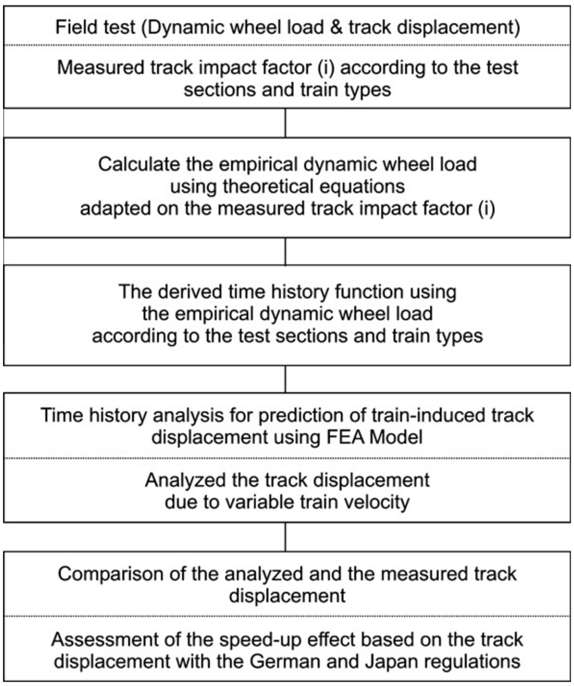

Fig. 1. Procedure of prediction of train-induced track displacement.