Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 33, No. B1, pp 129-132
Printed in The Islamic Republic of Iran, 2009

"Research Note"

DETERMINATION OF "V" SHAPED PERMISSIBLE RAIL DEFECT BASED ON WLR RATIO*

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Abstract– High-speed railway tracks require high quality track and accurate maintenance, but rail irregularities in main lines are inevitable. These irregularities are important sources for dynamic excitation. For the safety of trains at higher speed, the size of irregularities must be limited. In this paper, according to the Railways Standards, the wheel load reduction (WLR) ratio is introduced. Based on this ratio, the limitation for rail irregularity size is presented. Dynamic responses of track due to "V" shaped irregularity and rail corrugation is treated. A case study of rail corrugation is presented by real data measured from the Northeast district of Iranian railways.

Keywords– track dynamics, train–track interaction, track defect, wheel load reduction ratio

1. INTRODUCTION

Increasing axle loads and train speed, two main purposes of railway administration, need an accurate mathematical model and numerical solution for the dynamic problems of train-track interaction. Generally, higher train speed and heavier axle loads lead to greater dynamic responses of the track and vehicle. The interactive forces between train and track (via wheel/rail contacts) depend on the dynamic properties of the two, and also on the train speed, track components and wheel defects. Therefore, a rather comprehensive mathematical model of the compound system including both train and track should be used.

A dynamic analysis method has been developed by which the vertical responses of railway track subjected to a moving train can be investigated. In the model, the rail is treated as a continuous beam and discretely supported, via rail pads, to flexible sleepers. Andersson, Dahlberg and Suiker [1-3] have used a similar model. The rail structure is modelled by finite element method with two infinite elements treating the boundary conditions [4]. The contact between the wheel and rail is modelled by non-linear Hertzian spring elements. The model permits calculation of deflections, accelerations and forces in various track components, and can also study how parameters such as train speed, axle load, rail defects and such influence the track and vehicle components.

In this paper, the effect of "V" shaped single rail imperfection and rail corrugation on dynamic responses of track components is investigated. Railways standards for wheel load reduction (WLR) are introduced, and based on this ratio, permissible depths for rail imperfections are defined.

2. MODEL OF TRAIN-TRACK INTERACTION

The train-track interaction system and the generation of the equations have been presented in [4]. The vehicle is modelled with ten degrees of freedom including vehicle body mass and its inertia moment, two

*Received by the editors April 15, 2007; Accepted July 21, 2008.

bogie masses and their moments of inertia, and four unsprung wheelsets masses. Each bogie frame is connected to its unsprung wheels through the primary suspension springs and to the vehicle body through the secondary springs.

Finite track structures are commonly used for time-domain solutions. The main problem with a finite track model is the undesirable boundary effects in dynamic analysis. Therefore, in the discrete support model of this paper, the rail is modelled as a long beam by using finite elements and semi-infinite boundary elements. Computer software called *DATI* is designed to obtain the dynamic responses of train/track systems in the time domain model. This computer program may be used to solve all the problems listed in the next paragraph. Modifications to the program may easily be made to permit extension to the other problems, which have been treated by Zakeri [4]. The calculated results are well in accordance, both in response curves, in amplitudes and in distribution tendencies, with the existing experimental data [4] which verified the effectiveness of the analytical model and the computer simulation method.

3. APPLICATION OF MODEL TO SINGLE RAIL IMPERFECTION

Single irregularity of rail such as bad welded joints and settlement of ballast is another source of excitation to train/track interactions. In this section, responses of track structures under single irregularity of rail are treated. It is necessary to mention that the computer program, *DATI,* has the capability of dealing with many types of single irregularities. For instance, the "V" shaped irregularity in Fig. 1 is used and the dynamic responses of track during the passing of a bogie are shown in Figs. 2 & 3.

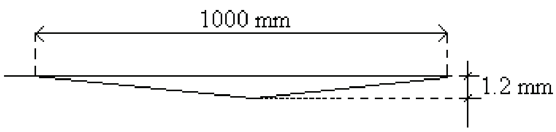

Fig. 1. The V-shaped irregularity

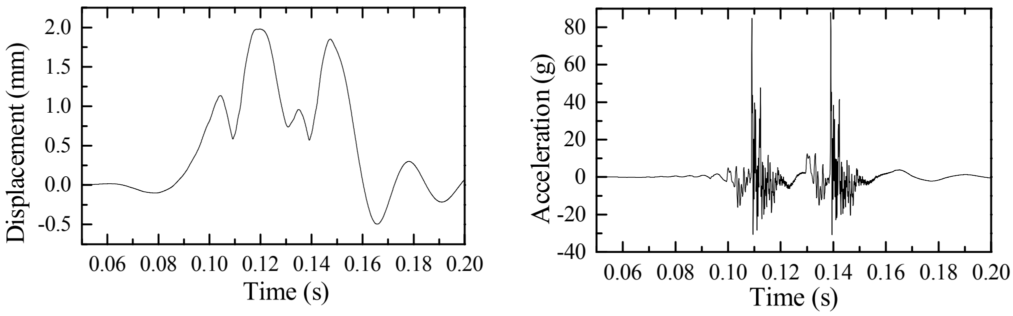

Fig. 2. Time history of rail acceleration and displacement

The calculated results in V shaped rail are compared with those in smooth rail as follows:

- Maximum displacement increases 117%
- Maximum acceleration increases 987%
- Maximum velocity increases 414 %
- Maximum wheel/rail contact force increases 198%
- Maximum rail/sleeper interactive force increases 243%
- Maximum sleeper/ballast interactive force increases 210%

These results indicate that the size of rail defects plays an important role in exciting dynamic responses in high-speed railway track. The existence of this defect increases overall track responses, and hence, reduces the safety of a moving train. This means that the depth of single defects related to length must be limited, and permissible depth related to length must be defined. Such limitations have been defined in Railways Standards indirectly by using wheel load reduction (WLR) ratio as follows:

$$\frac{\Delta P}{P} \leq 0.6 \tag{1}$$

This inequality shows that the variation of wheel load must be limited to 1.6. Here, wheel load reduction ratio (WLR) is obtained as 1.98. According to Iranian Standards, a single defect of 1.2 mm depth for a 1000 mm length is impermissible. By further research about this case, it is found that when the defect length is kept as 1000 mm, the depth must be less than 0.92 mm. This procedure is an indirect way to define the limitation for defect size.

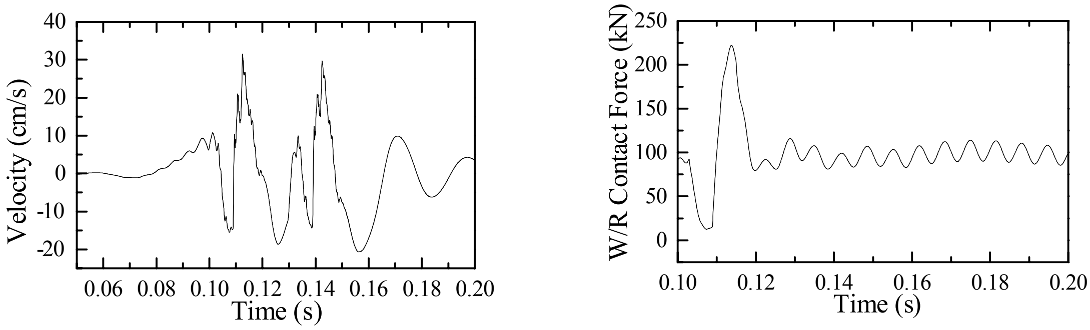

Fig. 3. Time history of rail velocity W/R contact forces

4. CASE STUDY: RAIL CORRUGATION

Parameters of rail corrugation were measured in the Northeast district of Iranian railways. The dominant wavelength was 230 mm and the corrugation amplitude varied from 0 to 0.35 mm. The maximum train speed (design speed) is 180 km/h in this line. The calculation results indicate that track responses fluctuate smoothly under corrugation excitation. When the amplitude of corrugation increase, these fluctuations increase sharply [5]. Figure 4 shows the variations in wheel-rail contact forces. It is evident that fluctuation of the wheel-rail contact force is strongly influenced by corrugation amplitude. The losses of contact occur periodically when the amplitude is 0.4 mm. The maximum value of this force is 113% of the static responses in smooth rail and 1.94 times of that in corrugated rail. The results show that the rail/sleeper interactive force and the sleeper acceleration increase rapidly with the increase of corrugation amplitude. This force and acceleration vary between 68~157 (kN) and 2.2g~18.8g, respectively. The limitation for rail corrugation can be determined by using the Wheel Load Reduction (WLR) Ratio. In this condition, the results indicate that a corrugation amplitude of less than 0.185 mm is allowable when train speed is up to180 km/h.

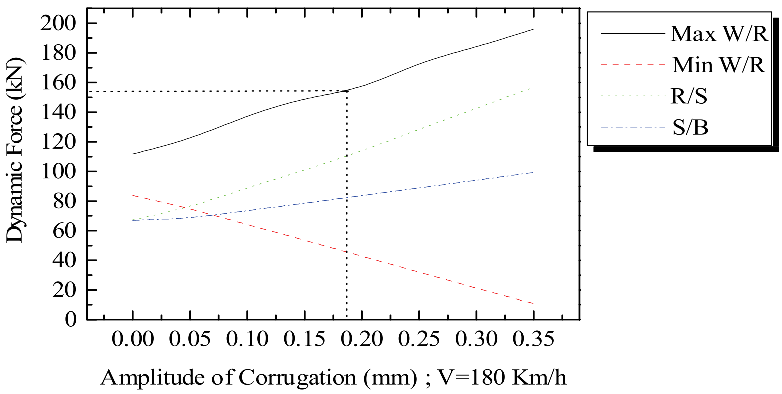

Fig. 4. Variations in interactive forces with corrugation amplitude

5. CONCLUSION

A dynamic analysis method has been developed by which the vertical responses of railway track subjected to a moving train can be investigated. The model permits calculation of deflections, accelerations and forces in various track components, and can also study how parameters such as train speed, axle load, rail defects and such influence the track and vehicle components. Railways Standards for wheel load reduction (WLR) are introduced and based on this ratio, a permissible depth for rail imperfections is defined. Dynamic responses of track structures under single irregularity and rail corrugation are treated. It is found that by using the assumption of this paper, the depth of a single defect must be less than 0.92 mm, and the corrugation amplitude must be less than 0.185 mm. This means that in high-speed lines, when train speed is up to 180 km/h, the corrugation amplitude must be limited to 0.185 mm. The procedure of defining the limitation for defect size is presented by the indirect method.

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