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Evaluation of the High-Speed Train-Induced Environmental Vibration Data Based on Numerical Studies According to DIN 4150 of German Standard

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Abstract. The use of high-speed railway network is becoming widespread in Turkey. High-speed passenger trains with a maximum of 250–300 km/h speed and a maximum of 22.5 ton force axle loads, have the potential for generating high levels of ground-borne vibration, especially in the high frequencies. Railway traffic on soft soil deposits for which measured shear velocity value is as low as 200 km/h can cause structural damage to the surrounding buildings. There has been a substantial increase in the studies on ground-borne vibration problems in the vicinity of the railway lines due to passage of the high-speed trains in recent years. The aim of this study is to evaluate the effect of the high-speed train induced environmental vibration according to Human Exposure to Vibration in Buildings and Effects of Vibration on Structures (DIN 4150 - Part 2 and 3) norm by using the verified finite element model based on in-situ measurements. The 2-D finite element model dealt under plane-strain condition with simulation of the moving load fully considers the vibrational energy dissipation by using viscous boundaries along the truncated interfaces of the infinite soil domain. In order to make a comparison with the threshold values defined in this German standard, it is necessary to obtain the predominant frequency of the vibration records by using Fast Fourier Transform. For this purpose, velocity response curves and frequency content at the measurement points where the accelerometers are located in the free field are obtained numerically for different soil types according to Turkish Earthquake Standard (TBDY 2018). Generally, it is observed that the unfavourable effects on human perception and building safety are increased when the ground rigidity underlying of building foundation has decreased.

Keywords: High-speed trains, structural response, finite element analysis, free field motion, wave propagation.

1 Introduction

In recent years, development of railway networks for high-speed trains is rapidly growing in many countries including Turkey. The high-speed trains in Turkey are designed with maximum speed of 250–300 km/h. With the rise of railway networks for high-speed trains, the ground-borne vibration along railway lines have become a major environmental concern in densely built up urban areas. The propagation of the train induced ground vibrations through the surrounding soil layers cause damage to the nearby buildings and may affect the people living near the railway.

This paper intends to study the effect of high-speed train-induced ground vibration according to the German standards (DIN 4150) [1, 2] for the assessment of structural vibrations concerning building damage and human exposure. For this purpose, a verified two-dimensional finite element model based on in-situ measurements which was previously established by the authors [3] was used to obtain the velocity spectra and frequency content of the train-induced vibration records at the selected points.

2 Research Materials and Methods

A field test and ground-borne vibration experiment due to the passage of high-speed train with speed of 250 km/h were performed by the authors on Istanbul-Ankara high-speed railway in Turkey [3]. The place of the field measurement selected for this work was Kirkpinar which is located at the western end of the place in the Sapanca district. The field measurements have been performed in 4 measuring points in two directions during the passage of high-speed train. The directions are determined as perpendicular to the track (N-S) and vertical downward (U-D).The accelerometers were placed at distances 7 m, 14 m, 21 m and 28 m from the railway Line 1 (Fig. 1).

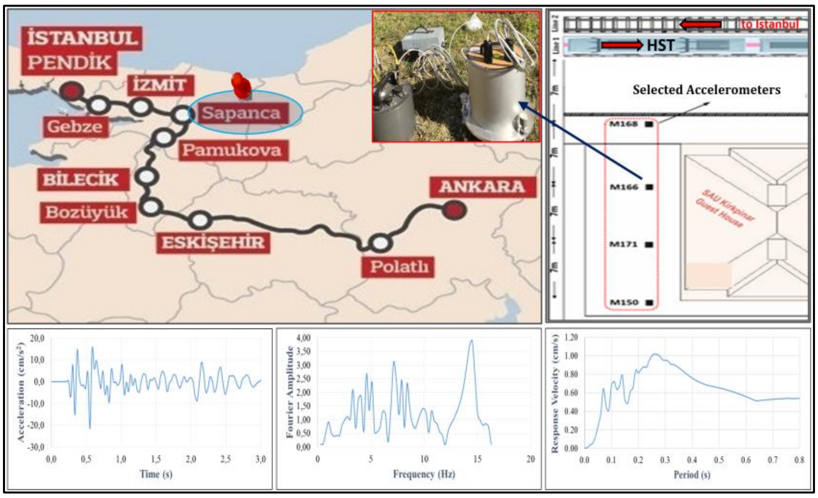

Fig. 1. The characteristics of the test site and investigated parameters for all selected points

The frequency content and velocity response curves were obtained at the selected measurement points in both directions (vertical direction and perpendicular to the track). The frequency content of Point A in vertical direction for ZE soil class is shown as an example in Figure 1.

The obtained results of the vibration measurements are used to validate the FE numerical model. By using the verified model (Fig. 2), the effect of train induced vibrations for different soil conditions according to Turkish Earthquake Standard [4] was investigated. As stated in the Earthquake Standard, the ZA and ZE soil classes are defined as hard rock and soft soil respectively [4].

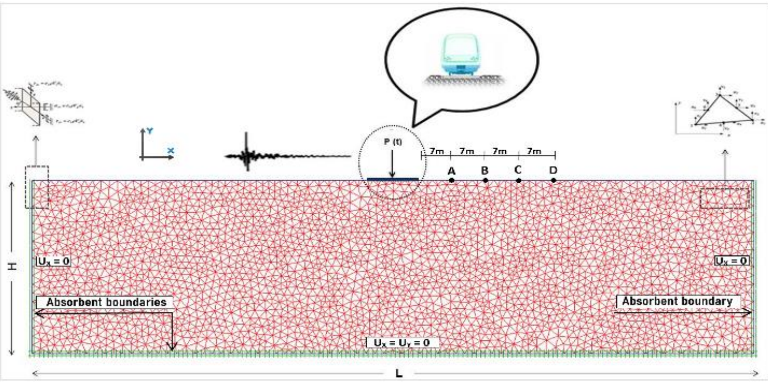

Fig. 2. 2D finite element model developed in Plaxis [3]

3 Results and Discussion

The frequency content and velocity response curves were obtained (Fig. 3–6.) in order to make a comparison with the limit values determined in German standard DIN 4150-2/3 [1, 2].

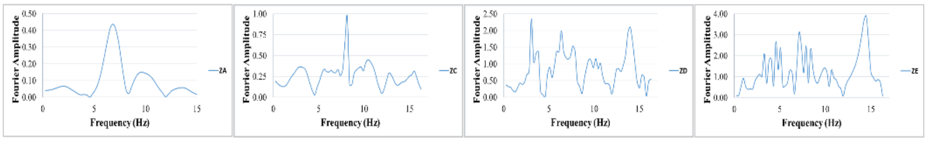

Fig. 3. Fourier amplitude spectra in vertical direction

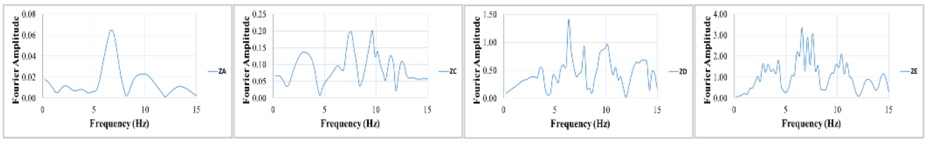

Fig. 4. Fourier amplitude spectra in perpendicular to the train line

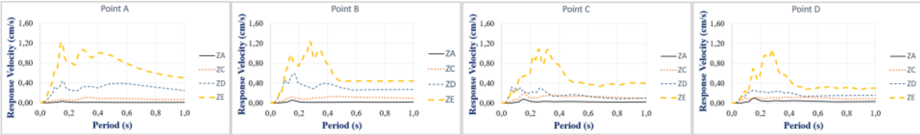

Fig. 5. Response velocity spectra in perpendicular to the train line

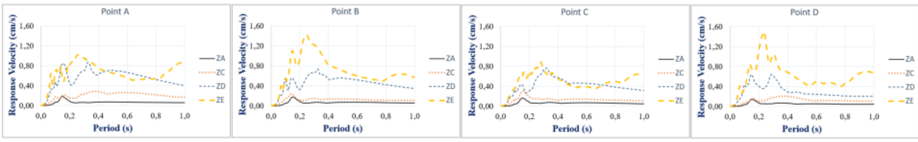

Fig. 6. Response velocity spectra in vertical direction

Frequency contents of the high-speed train induced vibrations generally concentrated at the range of 10-100 Hz. According to the obtained results, frequency contents of the train induced vibration values are between 3.05 to 16.27 Hz. Figures 5-6 illustrate that, the period interval of the maximum velocity values in both directions has widened as the soil stiffness decreased. By reviewing Figures 5-6 it is clearly seen that, the response spectral in the perpendicular and vertical directions for poor soil (ZE soil class) and nearby buildings (Point A) are different as expected. The results for both directions show that, the perpendicular direction of train vibrations has more impact than the downward direction. Structures close to the line with a dominant period in the range of 0.1-0.4 s were more affected due to passages of high-speed train. Results of the present study were evaluated in terms of building damage and human perception. The maximum response velocity and dominant frequency were compared with the limit values given by the norm DIN 4150-2/3 (Table 1-2).

Table 1. Evaluation of vibration levels in perpendicular to the train line

POINT	ZA		ZC		ZD		ZE	
	BD	HP	BD	HP	BD	HP	BD	HP
A	✓	TP	✓	NN	**✗: HB**	EN	**✗: RB, HB**	SN
B	✓	BN	✓	NN	✓	EN	**✗: RB, HB**	SN
C	✓	BN	✓	NN	**✗: HB**	EN	**✗: RB, HB**	SN
D	✓	BN	✓	NN	✓	EN	**✗: RB, HB**	SN

BD: Building damage; **HP:** Human perception**;** **RB:** Residential building; **HB:** Historical building;
TP: Threshold of perception; **BN:** Barely noticeable; **NN:** Noticeable; **EN:** Easily noticeable;
SN: Strongly noticeable; **VN:** Very strongly noticeable

Table 2. Evaluation of vibration levels in vertical direction

POINT	ZA		ZC		ZD		ZE	
	BD	HP	BD	HP	BD	HP	BD	HP
A	✓	NN	✓	EN	**✗: RB, HB**	SN	**✗: HB**	SN
B	✓	NN	✓	EN	✓	SN	**✗: RB, HB**	VN
C	✓	NN	✓	EN	**✗: RB, HB**	SN	**✗: RB, HB**	SN
D	✓	NN	✓	EN	**✗: RB, HB**	SN	**✗: RB, HB**	VN

As shown in Tables 1-2, vibration levels below the threshold values are defined with the symbol "✓" while the vibration levels above the acceptable limits are demonstrated with "✕". For instance, by examining the vertical direction results for the ZD soil class it is understood that the vibration levels at the points A, C and D are not suitable for residential and historical buildings according to DIN 4150-2/3. Furthermore, it can be seen that the vertical vibrations at the selected measurement points for ZD soil condition were strongly felt.

4 Conclusions

In this study, results of train induced vibrations are provided to compare with the acceptable ground-borne vibrations and thresholds stated in German standard DIN 4150. Assessment of vibrations impact on the building indicated the possibility of structural damages in residential and historical buildings by decreasing the soil rigidity. Furthermore, the human perceptibility level of vibrations increased in poor ground conditions as the stiffness of soil is decreased. In accordance with criteria and guidelines of the German standard, a cautious assessment in similar cases will be needed.

Acknowledgement

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