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Analytical Study of the Vibration Attenuation with respect to Trackbed Systems

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Abstract

The vibration-attenuation was quantitatively compared by 3-Dimensional finite element analysis using ABAQUS, with respect to the change of the type of trackbed systems. Most common trackbed materials, including ballast and concrete were applied to the track structure, and the train-speed was set as 300km/h as Korea Train eXpress (KTX). The result of current study revealed that the ballast showed the most effective material for the vibration attenuation.

Keywords: *KTX, Trackbed, Ballast, Concrete, Finite element*

1. Introduction

Recently, a sophistication of the industrial society in Korea, lead to the heavy inter-city commute as well as supply transportation traffic has increased drastically. The day-to-day road traffic already reached a critical state. Consequently, several collateral problems such as environmental pollution have emerged. Therefore, the role of rail transportation as part of alternative transportation method has been being emphasized.

In railroad industry, running speed, in addition to the extension of high-speed rail is playing an important role in development of society. However, more diverse vibration patterns were observed with increase of train-speed [1]. Therefore, a variety of methods were applied to the design of track structure, in order to control and/or minimize the vibration of trackbed during the operation of train in the railway. In the case of studies, Wang *et al*. [2] and Zeng *et al*. [3] analyzed the ground vibration of high speed train according to the subgrade types and the speed of the train using a 3-dimensional finite element analysis. They compared the relative size of the vibration based on the analytical results. In addition, Itoh *et al*. [4] applied the train load method, based on the investigation that a continuous axial load generated by high-speed trains, reduces the load on the ground. Furthermore, in order to evaluate the train-speed effects on the trackbed system, they divided rail into several segments, and applied the load chronologically.

In Korea, Yang *et al*. [5] investigated the reduction effects of concrete track as well as the interactions among trackbed, tunnel, and ground. Finally, they compared the performance of vibration reduction effects of each method. Also Shin *et al*. [6] proposed a prediction method to estimate the vibration source based on the specific location above ground, as a result of the city tunnel ground vibration study. As such, many researches have been widely conducted in terms of the vibration caused by the load from the train operation, using a 3D finite element analysis

Therefore, the primary objective of current study was to analyze the relative attenuation of vibration in accordance with trackbed systems in Korea, using a three-dimensional finite element analysis.

2. Finite Element Analysis of Trackbed Systems

2.1 Description of finite element model

For finite element analysis, ABAQUS 6.11 [8], common program used in this field, was used. Fig. 1 showed a complete analysis model using national geotechnical data in Korea. In order to reduce the computational effort, the

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analysis was carried out based on the symmetric condition of the track structure, as shown in Fig. 2. Underneath the trackbed, subgrade layer structure was consisted of 3 layers: layer 1, layer 2 and layer 3. The slope of subgrade was 1:1.8.

Eighty-four sleepers were located with 600 mm intervals, with 8 m construction width, and lateral length of 50 m. This was designed to minimize the impact at the boundary of perpendicular direction of the road. Under the trackbed system was modeled 20.2 m, so that the influence of the lower boundary can be minimized. The thickness of the roadbed was 300 mm, and the reinforced layer was set as 400 mm, as stated under the provisions of national high speed railway (HSR) [1,9]. The boundary conditions were constrained in the X and Y-direction, with Y direction of cross-section boundary, all directions of the bottom surface. In order to obtain the accuracy of the finite element analysis, a 20-node quadratic reduced-integration was applied [2]. Independent variables were the type of trackbed systems. As shown in Fig. 3, commonly used trackbed systems including ballast and concrete material were applied in this study. The train-speed was set as 300 km/h, as the velocity of high-speed train, currently. Table 1 showed the details of variables used for finite element analyses.

Table 2 showed the material properties of each types of trackbed. Table 3 and 4 showed the material properties of

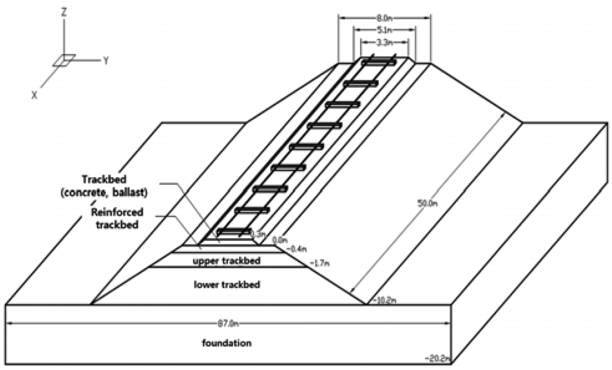


Fig. 1 Schematic design of track structure [7]

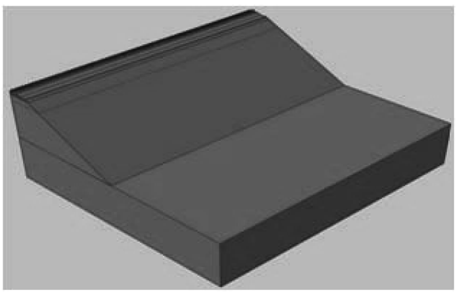


Fig. 2 3D finite element model of track structure [9]

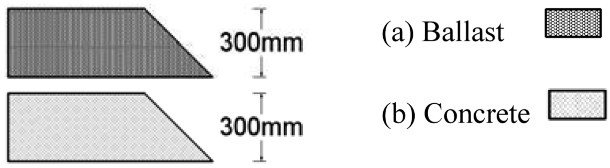


Fig. 3 Types of trackbed systems

Table 1 Parameters in accordance with trackbed systems

Trackbed	Model	Reinforced trackbed Thickness (mm)	Trackbed Thickness (mm)	Train-speed (km/h)
Ballast	R400B300	400	300	300
Concrete	R400C300	400	300	300

Table 2 Material properties of the track structure [9,10-15]

Level		Modulus of elasticity (MPa)	Poisson's ratio (ν)	Unit weight (t/m^3)	Damping ratio (%)	Thickness (mm)
Trackbed	Ballast	133.9	0.21	2.14	5	300
	Concrete	3000	0.21	2.55	2	300
Sub-trackbed		180	0.3	2.04	5	400
Layer 1		80	0.3	1.8	2	1300
Layer 2		60	0.3	1.8	2	8500
Layer 3		30	0.3	1.8	2	10000

Table 3 Rail material properties and Configuration [9,16-18]

Space (mm)	Cross sectional areas (mm^2)	Modulus of elasticity (MPa)	Poisson's ratio (ν)	Unit weight (t/m^3)	Damping ratio (%)	Geometrical moment of inertia (mm^4)
1,435	7,750	200,000	0.3	7.85	0	30,900,000

Table 4 Sleeper material properties and Configuration [17-20]

Length (mm)	Space (mm)	On bottom width (mm)	Width (mm)	Height (mm)	Modulus of elasticity (MPa)	Poisson's ratio (ν)	Unit weight (t/m^3)	Damping ratio (%)
2,600	600	300	260	200	40,000	0.167	2.3	5

the rail and the sleeper, respectively. Asphalt was the most vulnerable to the temperature change in summer. Therefore, the elastic modulus was set as 1196.8 MPa, which is the representative elastic modulus value in summer. The material properties of sub-trackbed, were analyzed applying the 180 MPa for reinforced trackbed, 80 MPa for top of subgrade, 60 MPa for layer 2, and 30 MPa for layer 3, respectively.

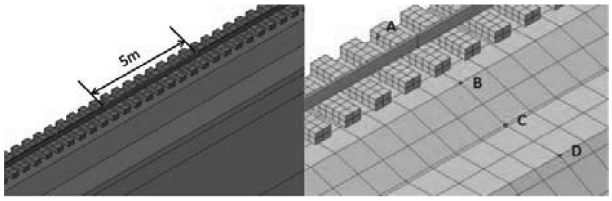
2.2 Train-load and evaluation of vibration

The train load was applied as following procedure. The static axle load of high speed train was computed by train weight divided by the number of axles. In the case of Korea Train eXpress (KTX), the static axle load was 170 kN [19]. The wheel load was a half of the static axle load. The driving wheel load (Pd), which considers the dynamic effects of the train load, was calculated by the static wheel load multiplied by the speed rate of impact, the function of train speed.

The impact coefficient (1 + 0.3 V/100) commonly applied to the Continues Welded Rail (CWR), was defined as the variation coefficient (mean value ratio of standard deviations. Therefore, the current study assumed the speed of train as 200 km/h, 300 km/h, and 400 km/hr, which was the generally used in Korea for high-speed train design, for the calculation of train wheel road [21]. The upper limit of driving wheel load for 300 km/h and 400km/h was set as impact ratio of 1.8. The vertical wheel load can be calculated by equation (1) [22].

$$P_d = P_s \times [1 + 0.3V/100 \ or \ 1.8] \quad (1)$$

P_d represented the vertical wheel load, P_s represented a static wheel load, V represented the train running speed (km/h).

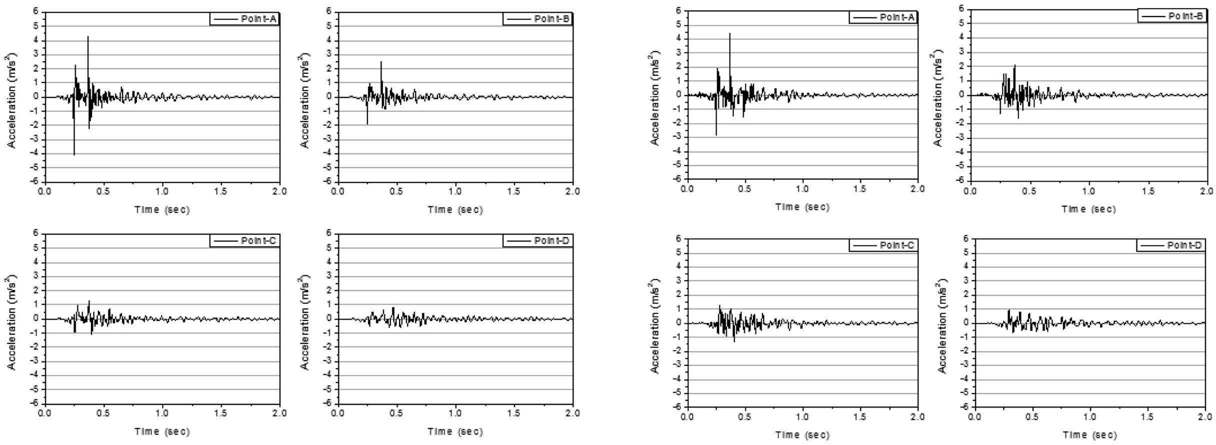


(a) load application (b) monitored locations

Fig. 4 Load application and monitored locations

In order to measure the accumulated vibration from the high speed train, 50 m rail was segmented into 10 elements- 5 m rails, and the uniform distribution load moved along with each segments. The wheel load was applied to each segment according to the running speed of high-speed train. For example, the wheel load was applied for 0.09 sec with train speed of 200 km/h, 0.06 sec with 300 km/h, and 0.045 sec for 400 km/h, respectively [2,4]. In order to calculate the vibration acceleration, four measuring points were set at the center of axial direction, as shown in Fig. 4(b). The potential boundary effect around the layer was considered especially for the case that the load delivering to the lower part of train during train traveling. The point A was located at the symmetry plane of the complete model, Points B and C was located at the upper and bottom of the trackbed, and point D was located above the sub-trackbed [23]

In order to analyze the relative vibration attenuation due to trackbed systems, the maximum value of the signal reached during a given time interval, A_{peak}, and the estimated energy content of vibration signal, were used for calculation of the amplitude of vibration, A_{RMS}. While the



(a) Ballast (b) Concrete

Fig. 5 Acceleration Time-History (V=300 km/h) time history was not taken into consideration for the calculation of the absolute value of maximum acceleration, the A_{RMS} was calculated with full consideration of a time history. It can be expressed as equation (2) and (3) [2].

$$A_{peak} = Max|a(t)| \tag{2}$$

$$A_{RMS} = \sqrt{\frac{1}{T}\int_0^T a^2(t)dt} \tag{3}$$

Here, T was defined as the total duration time (s), a(t) was defined as an acceleration at time (t).

Therefore, A_{RMS} considered the change rate per time, as well as presented vibration length, directly related to the destructive capacity of vibration. Therefore, A_{RMS} was proper for expressing the amplitude of vibration [6]. Also, A_{peak} was useful for presenting the amplitude like the impact at the very short time period. However, this value only expressed the maximum value of the moment, rather than presenting the change per time history. Therefore, the comparison of overall amplitude of vibration was difficult.

3. Results and Discussion

3.1 Vibration analysis

3.1.1 Vibration time-history due to time period

Fig. 5 showed the 3D finite element analysis results of vibration characteristics with respect to the trackbed systems. Fig. 5(a) showed the ballast and Fig. 5(b) showed the acceleration time history of concrete trackbed at the train-speed of 300 km/h [2,24]. All vibration analyses were conducted based on the z-direction results, as most of the vibration in the ground occurred at the perpendicular direction (Z direction) of the running direction. When train-speed was 300 km/h, the passing time of 50m point was 0.6 sec, and the vibration up to two seconds was shown in Fig. 5.

Therefore the first maximum value was related to the load applied to the fifth segment before the measurement point A. In addition, the second highest value was the result of the train load applied to the sixth segment, immediately following the measurement point A. At the points B, C and D, the acceleration of vibration at the locations away from the rail decreased

In the case of ballast trackbed system, as shown in Fig. 5(a), the vibration caused by load speed was overall low after 0.6sec, where the free vibration started. Hence, the ballast trackbed seemed effective in reduction of vibration, in comparison to the concrete trackbed. The energy of ballast trackbed during free vibration was significantly dissipated, even in a short period. [25].

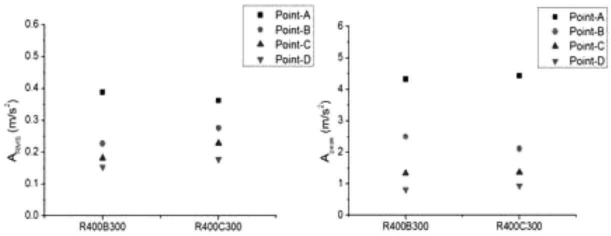


Fig. 6 Monitored vibration at each poiont(V=300 km/h)

Table 5 Vibration-attenuation according to trackbed types at V=300 km/h

Material	Point	A_{RMS} (m/s^2)	Reduction in A_{RMS}(%) as opposed to Concrete	A_{peak} (m/s^2)	Reduction in A_{peak}(%) as opposed to Concrete
Ballast (R400 B300)	A	0.3879	-7.15	4.3249	2.48
	B	0.2266	17.72	2.4926	-17.91
	C	0.1815	20.50	1.3403	1.59
	D	0.1532	13.84	0.8254	11.93
Concrete (R400 C300)	A	0.3620	-	4.4348	-
	B	0.2754	-	2.1139	-
	C	0.2283	-	1.3619	-
	D	0.1778	-	0.9372	-

3.1.2 Evaluation of vibration: A_{RMS} and A_{peak}

Fig. 6 showed the comparison of A_{peak} and A_{RMS} at each measurement point based on the train-speed and trackbed types. As shown in Fig. 6, with train-speed of 300 km/h, the value was at its lowest at measurement point A when trackbed was concrete. For the additional measurement points B, C, and D, the values were the lowest at the ballast system.

As for A_{peak} value, the value of ballast trackbed was higher than that of concrete trackbed at measurement point A and B. This indicated the maximum value of acceleration time history during the analysis, due to the prohibition of dissipated-energy of the system.

3.1.3 Numerical Analysis: A_{RMS} and A_{peak} of the vibration

The vibration acceleration according to the trackbed types was relatively compared and analyzed by the relative reduction rate of the vibration. For the evaluation of A_{RMS} and A_{peak} of ballast trackbed in terms of concrete trackbed, the differences in vibration reduction were observed at each measurement point, as the train-speed 300 km/h. Table 5 showed the relative vibration reduction rate for concrete trackbed at train-speed of 300 km/h. For

A_{RMS}, ballast trackbed was superior at vibration reduction to concrete trackbed, at all measurement points except for measurement point A. At monitored point C, the relative vibration reduction rate with respect to the ballast tracked to concrete trackbed was the highest as 20.50%. At monitored point A, the value of concrete trackbed was 7.15% higher than that of the ballast trackbed. Therefore, in order to reduce the vibration, the concrete trackbed was more effective than the ballast trackbed at monitored point A, using train-speed 300km/h. In the case of ballast trackbed, the vibration attenuation was overall effective, regardless of train-speed.

4. Conclusion

This study conducted the vibration attenuation with respect to the trackbed types and the train-speed, using 3-dimensional finite element models, ABAQUS. Additionally, based on the analysis results, A_{peak} and A_{RMS} were numerically analyzed and relative comparison of the trackbed systems was evaluated as followings:

1. Based on acceleration-time histories of the trackbed systems, the ballast trackbed system was significantly effective in terms of the vibration at short time period, in comparison to the concrete trackbed.
2. Finally, the ballast trackbed system effectively controlled the vibration at train-speed, v=300 km/h.

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