A Study on Field Behavioral Characteristics of the Roadbed according to the Speed Increase in High-Speed Train (HEMU-430x)

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Abstract

This paper is about the first experiment in Korea that was conducted on speeding increase up with rail speeds at 430km/h at high speed railway of designed 350km/h. and analysis data collected on vibration accelerations of roadbed. There are barely references on roadbed behavior measurement with rail speeds more than 350 km/h in Korea as it has never been conducted the experiment on it. So the experiments were confirmed the reliability through cross-checking the figures/values from respective sensors and measuring devices after measuring EMS and ICP types. Based on the study, values of vibration acceleration were less than 12% compared with the ones that conducted while speeding up of HEMU-430X. Also, figures of HSB for concrete bed tracks were 52% against the standard. According to the results, all the performance evaluation of vibration acceleration for roadbeds in transition zones is under the standard.

Keywords : *Field test, Speed up test, Vibration acceleration, HEMU-430X*

1. Introduction

The development of domestic and international rail technology has steadily been promoted based on the speed improvement and stability. In Korea, since the era of high-speed railway was started with the opening of the Gyeongbu high-speed railway (1-phase) on April 1, 2004, the technology in the field of high-speed railway has highly been recognized around the world for the stable operation. In particular, the opening of the Gyeongbu high-speed railway line between Daegu and Busan (2-phase) on November 1, 2010 has been evaluated to serve as an opportunity to improve the quality of high-speed railway due to the application of concrete tracks.

However, there is a relative lack of domestic research on the behavioral characteristics of track roadbed according to the speed improvement compared to this growth. In Germany and Japan, developed countries in

the field of railway, a variety of measurement data and DB has steadily been accumulated by conducting measurements and experiment to determine the behavioral characteristics of tracks and roadbeds during the operation of high-speed railways. However, since Korea has no survey data to identify the behavioral characteristics of the roadbed during the operation of high-speed railway at more than 350 km/h, and acquisition of international data is also not easy, the reality is that data accumulation informatization needs to be made based on domestic proprietary technology.

In this study, data accumulation and analysis was carried out by measuring behaviors of the roadbed during train operation according to the test on the speed increase up to 430 km/h from high-speed railway line with optimal design speed of 350 km/h. In addition, basic data that can be utilized to establish design criteria on the roadbed structures technologically available for the operation of 430km/h-grade vehicles was accumulated. Since the roadbed of the Honam high-speed railway on which trains can operate at the speed of more than 350 km/h is under construction in 2013, this study attempted to measure and analyze the behaviors of the roadbed due to the speed increase up to 300~421 km/h

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Table 1. Measurement location

Segment	S T A	Note	Measurement line
Transition zone of Gaya Overpass	305k087	Gyeongbu high-speed railway section (2-phase)	Up line (towards Seoul)

at the earthwork transition zone among phase-2 sections of the Gyeongbu high-speed railway.

2. Field Measurement Test

2.1 Overview

For field measurement location, bridge-earth transition zone of the Gaya Overpass, a plate girder bridge within the Gyeongbu high-speed railway (2-phase) sections with gross weight of 408T was selected. A target vehicle was the next-generation high-speed train (HEMU-430X), and a commissioning test section was the upper main line T2 between Busan and Gomo (120 km) of the Gyeongbu high-speed railway line (phase-2).

Field measurement locations In the first speed increase test, an increase in speed up to 350 km/h was completed based on the speed increase by 10 km/h per week from July 12, 2012 to September 12, 2013, and the speed increase to the maximum speed of 421 km/h was completed in the second speed increase test conducted from December 2, 2012 to March 31, 2013.

Table 1 shows the status of measurement location. The location of measurement target is the roadbed of transition zone in the Gaya Overpass, and target structures include abutment, HSB, approach slabs and HSB adjacent reinforced roadbed and roadbed slope area, etc. The vibration acceleration of the roadbed and concrete track according to the train loads was measured.

2.2 Measurement items and standards

As fill-in sensors using geotechnical drilling equipment such as earth pressure gauge, magnetic extensometer, pie-

Fig. 1. Installation status of the ground vibration accelerometer

(a) Roadbed drilling

(b) Sensor installation

(c) Logger wiring and accelerometer measurement

Fig. 2. Installation sensors and measurement

zometer and groundwater level meter can damage to the roadbed during installation, their use was rejected by the quest of the governing body. However, since the roadbed vibration accelerometer can be installed by digging up to 10cm from the surface, it was used for field measurement in this study. Fig. 1 shows the installation status of the ground vibration accelerometer.

Fig. 2 shows photos of the scene in which the vibration accelerometer ACC-01 is being installed. As shown in the figure, rubble stones on the upper surface in the side of HSB were removed, and sensors were installed in the reinforced roadbed.

Table 2 shows main specifications for measuring devices and roadbed sensors by installation location. Sensors are waterproof, and automated measurement is possible. As for measuring devices, three kinds of data loggers, including DEWETRON, CR9000X and NI cRIO-9025 were used in parallel, and duplicate measurement was made using two types of sensors such as MEMS and ICP. That's because there is no existing data carried on the roadbed behavior measurement at the train speed of more than 350km/h in Korea, which leads to the need to verify reliability by cross-examination on the results obtained from different sensors and measuring devices.

In selection of vibration accelerometer, the measurement Hz was taken into account. The ground vibration

Table 2. Measuring devices and roadbed sensors

Sensor name	Measurement method	Model name (Manufacturer)	Installation location	Measurement range	Measuring devices
ACC-01	MEMS	4810B (Measurement)	Reinforce roadbed in transition zone	$\pm 5 \text{ g}(0.0\sim 250 \text{ Hz})$	Waterproof-type automated and compatible measurement logger : DEWETRON, CR9000X, NI cRIO-9025, etc.
	ICP	393B31(PCB)		$\pm 0.5 \text{ g}(0.1\sim 200 \text{ Hz})$	
	ICP	393B12(PCB)		$\pm 0.5 \text{ g}(0.15\sim 1000 \text{ Hz})$	
ACC-02	ICP	393B31(PCB)	Reinforced roadbed in transition zone	$\pm 0.5 \text{ g}(0.1\sim 200 \text{ Hz})$	
ACC-03	ICP	393B31(PCB)	Upper roadbed in transition zone	$\pm 0.5 \text{ g}(0.1\sim 200 \text{ Hz})$	
ACC-04	ICP	393B31(PCB)	Lower roadbed in transition zone	$\pm 0.5 \text{ g}(0.1\sim 200 \text{ Hz})$	
ACC-05	ICP	353B52(PCB)	Upper HSB in transition zone	$\pm 10 \text{ g}(0.1\sim 200 \text{ Hz})$	
ACC-06	ICP	353B52(PCB)	Abutment structure	$\pm 10 \text{ g}(0.1\sim 200 \text{ Hz})$	
ACC-07	ICP	393C(PCB)	Approach slab in transition zone	$\pm 2.5 \text{ g}(0.1\sim 200 \text{ Hz})$	
ACC-08	MEMS	393B31(PCB)	Reinforced roadbed in standard banking setion	$\pm 0.5 \text{ g}(0.1\sim 200 \text{ Hz})$	
ACC-09	MEMS	4810B (Measurement)	Upper HSB in standard banking section	$\pm 5 \text{ g}(0\sim 200 \text{ Hz})$	

Table 3. Sensor specifications

Manufacturer	Sensor type	Model name	Details
Measurement	MEMS	4810B	<ul style="list-style-type: none"> • Range (g): ± 2 or 5 g • Sensitivity(mV/g): 1,000 • Frequency Response(Hz): 0~200 or 0~250 • Natural Frequency(Hz): 800 • Non-Linearity(%FSO): ± 1.0
PCB	ICP	393B31	<ul style="list-style-type: none"> • Range (g): ± 0.5 • Sensitivity(mV/g): 10,000 • Frequency Response(Hz): 0.1~200 • Non-Linearity(%FSO): ± 1 • Transverse Sensitivity(%): < 1 • Overload Limit (Shock): $\pm 40 \text{ g pk}$
PCB	ICP	393C	<ul style="list-style-type: none"> • Range (g): ± 2.5 • Sensitivity(mV/g): 1,000 • Frequency Response(Hz): 0.025~800 • Non-Linearity(%FSO): ± 1 • Transverse Sensitivity(%): < 5 • Overload Limit (Shock): $\pm 100 \text{ g pk}$
PCB	ICP	353B52	<ul style="list-style-type: none"> • Range (g): ± 10 • Sensitivity(mV/g): 500 • Frequency Response(Hz): 1~2,000 • Non-Linearity(%FSO): ± 1 • Transverse Sensitivity(%): < 5 • Overload Limit (Shock): $\pm 4,000 \text{ g pk}$

regards low-frequency band of less than 100Hz as the frequency of interest. Since the high-frequency band due to the vibration of trains decreases rapidly or disappears during the roadbed vibration propagation process, sensors

with high-frequency range as measurement target should be excluded from the selection of measurement frequency range for vibration accelerometer. In general, the ground vibration measurement range of high-speed trains

Table 4. Speed up test

Segment	Test date	Maximum speed	Segment	Test date	Maximum speed
1 st speed increase test	'12.7.15	300 km/h	2 nd speed increase test	'12.12.23	396 km/h
	'12.8.12	312 km/h		'12.12.27	394 km/h
	'12.8.16	321 km/h		'12.12.30	394 km/h
	'12.8.23	334 km/h		'13.01.17	370 km/h
	'12.9.01	342 km/h		'13.01.20	396 km/h
	'12.9.08	342 km/h		'13.01.27	400 km/h
2 nd Speed Increase test	'12.11.29	351 km/h		'13.02.03	400 km/h
	'12.12.02	354 km/h		'13.02.24	413 km/h
	'12.12.09	355 km/h		'13.02.28	412 km/h
	'12.12.13	378 km/h		'13.03.03	400 km/h
	'12.12.16	383 km/h		'13.03.28	421 km/h
	'12.12.20	386 km/h		'13.03.31	420 km/h

is up to 3 m/s^2 or less, and it is usually less than 1.0 m/s^2 . However, since the value of the ground vibration can become very large in the section where impact load occurs due to the difference of stiffness, point with poor track flatness and shock caused by defects in vehicles, and case where there is a gap between concrete track and roadbed as in transition zone, the durability of sensors can be damaged by the repeated action of acceleration that exceeds the measurement range. In this regard, it is required to select sensors with sufficient measurement range. Accordingly, the accelerometer with a measurement range of ± 5 to $\pm 10 \text{ g}$ was used in structure abutment and HSB where significant thermal vibration is expected to be delivered, and that of $\pm 2.5 \text{ g}$ was used for approach slabs of the abutment transition zone. In addition, the accelerometer with a range of $\pm 0.5 \text{ g}$ was used in the reinforced roadbed, upper roadbed and lower roadbed in which train vibrations are indirectly delivered to the ground.

2.3 Test conditions

As shown in Table 4, the speed increase of the next-generation high-speed train was proceeded by 10 km/h from 300 km/h at one to two week intervals, starting from July 15, 2012. Train operation was made three times with the same planned rate at about 1 hour and 20 minute intervals from the midnight. After train maintenance, the second speed increase test was conducted by increasing the speed by 10 km/h at one to two intervals from 350 km/h at the end of November 2012, and the speed increase was completed with maximum speed of 421 km/h on March 28. The ground vibration acceleration during

Fig. 3 ground acceleration at 300 km/h

Fig. 4 ground acceleration at 330 km/h

Fig. 5 ground acceleration at 355 km/h

train operation with speed of more than 350 km/h was measured by applying know-how technology in the second speed increase test after improving measurement methods and analyzing measurement data during the period of train operation.

3. Analysis of Test Results

The sampling rate was determined to be 2.5 kHz so that response distortion and data loss can be prevented in vibration acceleration measurement. In addition, an analysis was conducted with the frequency of interest as target by processing noise components except for the ground acceleration with low-pass filtering and hi-pass filtering methods using digital filters through frequency analysis. The frequency range of interest on the ground vibration is typically less than 100 Hz . In the case of the ground vibration accelerometer with small measurement range, as the error rate in the frequency measurement range is less than

Fig. 6 ground acceleration at 370 km/h

Fig. 7 ground acceleration at 394 km/h

Fig. 8 ground acceleration at 400 km/h

1.5% at less than 200 Hz, and the accuracy in value of frequency which is outside the range decreases, filters were set to have a low pass at about 300 Hz in the analysis phase.

The representative ground vibration acceleration measurement values by speed of next-generation high speed train (HEMU-430X) were schematized in Figs. 3~10. The ground vibration was measured by increasing the speed of the train by 10 km/h from 300 km/h to 421 km/h. In case of the speed increase, the maximum vibration acceleration of the roadbed increased from 0.8 m/s^2 to 1.4 m/s^2 , and the maximum RMS of the vibration acceleration was evaluated to be 0.74 m/s^2 . In FFT analysis results, the frequency band ranging from 18~20 Hz to 55~65 Hz was continuously detected during the train operation at the speed of 310~421 km/h. Since the battery (UPS) was used in measurement, the effect of 60Hz power-supply noise is expected to be insignificant.

As shown in Figs. 5~10, the power-supply noise was removed and ICP accelerometer was additionally installed

Fig. 9 ground acceleration at 412 km/h

Fig. 10 ground acceleration at 421 km/h

in case of the train speed of more than 350 km/h, so that the ground vibration caused by train axle loads and low vibration with less than 10 Hz could be detected well. However, since there are cases where the train axle-load ground vibration is not measured at the train speed of more than 320 km/h as in Fig. 4, the measurement was made by increasing the sample from the current 1 kHz to 2.5 kHz, and an accelerometer jig was installed to enhance the vibration sensitivity of the low-frequency band from 360 km/h.

Fig. 11 shows that as the train speed increased from 300 km/h to 421 km/h, the roadbed vibration acceleration also increased. As shown in Fig. 11(a), the maximum vibration acceleration of the roadbed was measured at 2.0 m/s^2 during the operation of HEMU train, and the maximum RMS value at 0.6 m/s^2 . In consideration that the standard of the roadbed vibration acceleration is 5.0 m/s^2 , the above figures were found to meet the standards, showing 40%, compared to the maximum value and 12% compared to RMS. In addition to ACC-01, ACC-02, ACC-03, and ACC-04 also satisfied the vibration standards.

Fig. 12 shows schematic diagram that displays measurement values of the roadbed vibration acceleration compared to standard values during speed increase test of HEMU-430X. As shown in Table 5, the vibration acceleration was measured at less than 12% in the roadbed, but it was 52% compared to the standard value in HSB of the concrete track. Accordingly, the results of performance evaluation on the vibration acceleration of the roadbed in

Fig. 11 Results of ground acceleration by speed

Fig. 12 Safety standard of ground acceleration

Table 5 Results of measurements

Measurement items	Segment	Standard values	Maximum measurement values (Speed)	Performance evaluation	Remarks
Vibration acceleration	Roadbed	5 m/s ²	0.6 m/s ² (394 km/h)	Within standards(12%)	LPF 300Hz RMS
	HSB	10 m/s ²	5.26 m/s ² (418 km/h)	Within standards(52%)	LPF 300Hz RMS

transition zone of Gaya Overpass with HEMU-430X as target were all evaluated to be behaviors within the range of standard values.

4. Conclusion

In this study, the vibration acceleration was measured in real time through the test of speed increase from 300 to 421 km/h on the high-speed train (HEMU-430x), which was conducted in the Gyeongbu high-speed railway sections (2-phase), and the behavioral characteristics of the roadbed due to the increase in train speed were analyzed experimentally. The analysis results showed that the maximum vibration acceleration was measured at less than 12%, which was within the standard of the vibration acceleration (5 m/s^2), showing the amount of increase from

0.6 m/s^2 to 1.4 m/s^2 as speed increased, and it was measured at 52% compared to standard values in HSB of concrete track. The maximum RMS value was evaluated to be 0.74 m/s^2 , and through FTF analysis, frequency bands ranging from 18~20 Hz to 55~65 Hz were consistently detected during the train operation at the speed of 310 to 421 km/h.

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