Stability analysis of the dynamic behavior of railway vehicle system

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ABSTRACT: Recently*, a high-speed railway vehicle is being developed to quickly and safely transport of the quantities in many countries. Especially, a railway vehicle dynamic model is modeled for performing a stability analysis and running safety analysis in the early stage of the railway vehicle development. Also, the safety analysis of railway vehicle performance is presented by the international standard UIC CODE 518 OR.*

In this study, in order to evaluate the running safety of the railway vehicle, a multi-body dynamic railway vehicle was modeled using commercial dynamic program ADAMS/Rail. Safety analysis was implemented through the international standard of the UIC CODE 518 OR. Also, appropriateness of the railway vehicle design variables was checked by running safety analysis results.

1 INTRODUCTION

Recently, a high-speed railway vehicle was developed for maximum speed more than 350km/h in the developed country. The next-generation railway vehicle is being developed for maximum speed 430km/h in Republic of Korea, too. The safety of the railway vehicle should be conformed before manufacturing the railway vehicle [1-2].

It is important to predict the running performance of the railway vehicle. The stability analysis and the safety analysis of the railway vehicle could be confirmed through the prediction of the dynamic performance. The railway vehicle was analyzed by running safety method before the introduction of development. Therefore, previously developed high-speed railway vehicle was already analyzed by the stability and the safety analysis under a driving simulation of an operating condition [3].

In this study, the high-speed railway vehicle of next-generation was modeled as a single-car system using commercial dynamic program ADAMS/Rail. Also, stability analysis and safety analysis was implemented by this model. Appropriateness of the railway vehicle design was checked by safety analysis results.

2 MODELING OF A RAILWAY VEHICLE

The high-speed railway vehicle was modeled by using ADAMS/Rail as a commercial program.

Suspension system affects running safety and ride stability of the railway vehicle. Suspension system of the railway vehicle is divided into a primary suspension system and a secondary suspension system. A bogie modeling was applied to a primary suspension and a secondary suspension. The primary suspension consists of a coil spring and a vertical damper which were applied to design value. The secondary suspension consists of an air spring, a vertical damper, a yaw damper and a lateral damper which were applied to design value. Various design parameters such as spring characteristic and damping coefficient were applied to railway vehicle model. A Z-link connects a vehicle's body and a bogie. The Z-link is a center-pivot which was implemented as a kinematic structure. Also, basically mass and inertia data were applied to railway vehicle and is shown in Table 1-2. The model for the railway vehicle is shown in Figure 1-2.

The next-generation railway vehicle is scheduled to be evaluated for dynamic characteristic by a prototype of the developing vehicle. In this study, a single car of the prototype was modeled and analyzed by ADAMS/Rail.

Table 1 Data of the weight condition

	Mass (kg)	Quantity (ea)	Total (kg)
Car (Sec. sprung)	39,275	1	39,275
Bogie (Pri. sprung)	3,911	2	7,822
Unsprung (Wheelset)	1,876	4	7,504

Table 2 Data of the inertia moment

	Ixx (kgm^2)	Iyy (kgm^2)	Izz (kgm^2)
Car (Sec. sprung)	94,360	1,824,100	1,824,100
Bogie (Pri. sprung)	3,508	3,834	4,720
Unsprung (Wheelset)	1,110	148	1,133

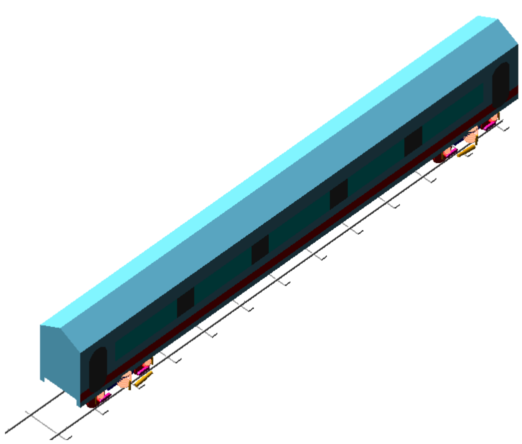

Figure 1. A single model of the railway vehicle

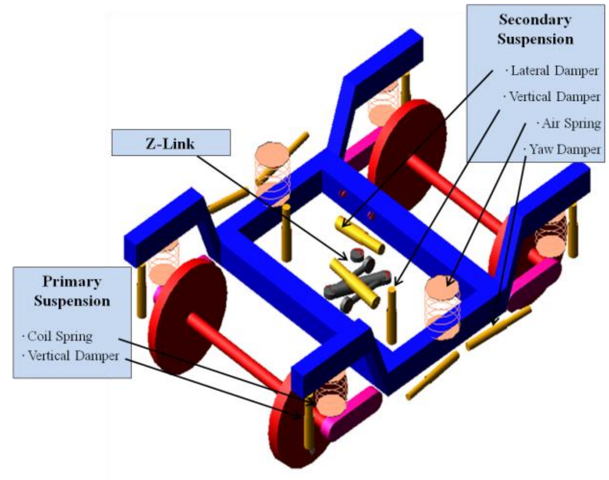

Figure 2. A bogie model

3 STABILITY ANALYSIS

One of the running characteristic of the railway vehicle is the hunting motion. Hunting is defined as the lateral motion of the wheelset [4]. When hunting motion increases rapidly at any speed above, the vehicle motion will be unstable and the vehicle speed is the critical speed at that time. The maximum speed of the vehicle should not exceed the critical speed because of the running stability of the railway vehicle. However, when the mileage of the vehicle is more increased, the equivalent conicity of the wheel profile will be increased and the conicity should be abraded at initial state. This factor determines the abrasion cycle of the wheel profile and stability analysis is necessary considering the conicity.

The equation of the motion can be formulated by the vehicle's damper, spring and other suspension elements. The generally linear equation of the vehicle and rail system is expressed in Equation 1.

$$[M]\ddot{q}+\left\{[C]+\frac{[D]}{V}\right\}\dot{q}+[K]q=[F] \qquad (1)$$

where [M] is the mass matrix, [C] is the damping matrix, [K] is the stiffness matrix of the system, respectively, [V] is the vehicle speed and [D] is the damping matrix depending on vehicle speed.

The expression for the first order differential equation of the Equation 1 is defined by Equation 2.

$$\begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}\left\{[C]+\frac{[D]}{V}\right\} \end{bmatrix}\begin{bmatrix} q \\ u \end{bmatrix}=\begin{bmatrix} \dot{q} \\ \dot{u} \end{bmatrix} \quad \text{where} \quad \dot{q}=u \qquad (2)$$

Stability analysis of the railway vehicle can be implemented by eigenvalue problem from Equation 2. And K matrix is depending on the conicity [4] .

The equivalent conicity of the developing railway vehicle is about 0.25. The conicity of the wheel profile is shown in Figure 3. Stability analysis was implemented by using ADAMS/Rail.

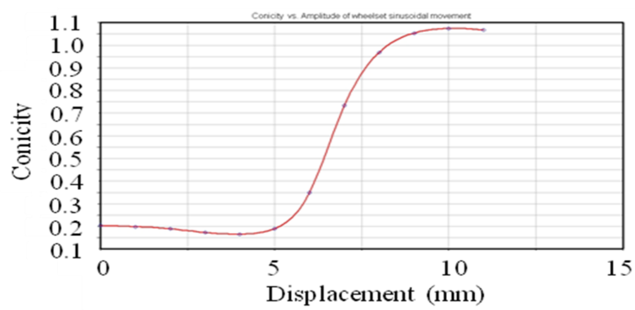

Figure 3. Conicity vs. wheelset sinusoidal movement

4 SAFETY ANALYSIS

The maximum speed of the next-generation railway vehicle is 430km/h and operating speed is 370km/h as its target speed. This vehicle differs from the operating railway vehicle (KTX train, Korea) about the driving system as well as upward adjustment of high speed and operating speed.

The developing railway vehicle is a decentralize power train. The safety analysis was performed by numerical model at UIC CODE 518 OR. Analyzed driving speed is 10% higher than target speed 430km/h. Therefore, analysis speed is 473km/h [5].

Acceleration measure points were appointed in the vehicle's body and bogie, and after that the railway vehicle was driven on the irregular track lines. Driving dynamic characteristics were analyzed in each point of the acceleration measurement.

Using the measured acceleration data, safety analysis results were derived from the presented UIC CODE 518 OR. Also, the simulation results were compared with limiting value. The safety was predicted by the simulation results including the curved track of railway. Track curve is 7,000m so test track is a large curve condition. Test track is the UIC 60 and the lateral and the vertical irregularity of the ERRI low which is given by commercial program (SIMPACK) are shown in Figure 4-5. This track irregularity is applied to ADAMS/Rail. Safety analysis is implemented considering the change of cant.

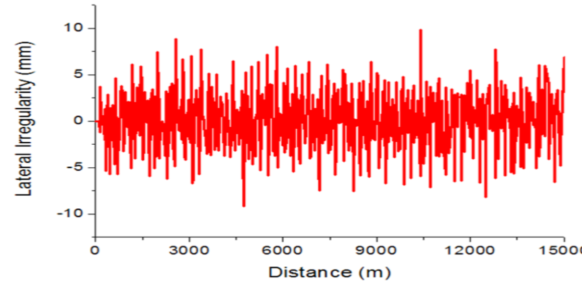

Figure 4. Lateral irregularity of the test track

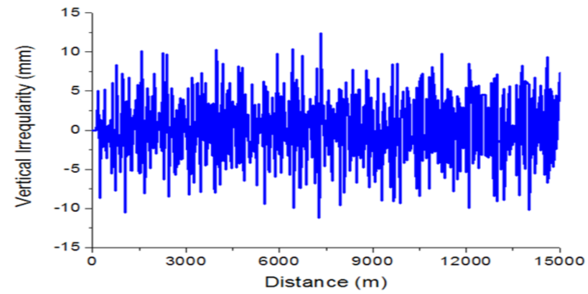

Figure 5. Vertical irregularity of the test track

Table 3 Filtering method for statistical processing

Evaluation list	Cut off freq.	Percent ile	K
Lateral acc. of a bogie	10Hz (Low pass)	F1=0.15% F2=99.85%	3
Lateral acc. of a body	6Hz (Low pass)		
Vertical acc. of a body	0.4~4Hz (Band pass)		

The driving analysis was implemented at the ERRI irregularity track. A test method is a simplified method which is presented by UIC CODE 518 OR. A frequency filtering method is presented by the simplified method as in Table 3. Also, Figure 6 shows the acceleration measurement points. Measured points are identified in the system of vehicle according to EN 14363 [6].

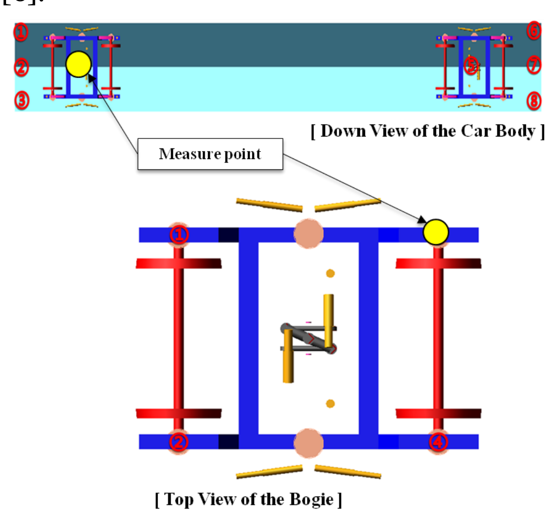

Figure 6. Acceleration measurement points

5 SIMULATION RESULTS

In the stability analysis, the conicity is the variable so conicity is inputted between 0.1 and 0.5 values. The analysis result is shown in Figure 7 and Table 3.

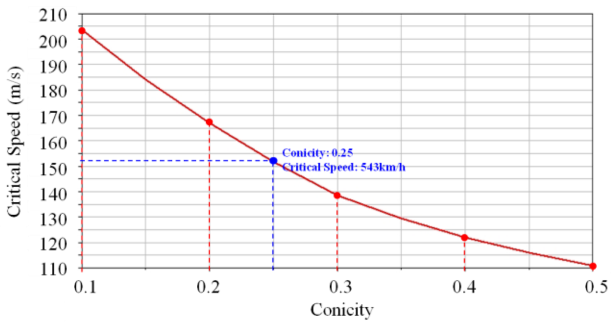

Figure 7. Stability analysis result (Conicity vs. critical speed)

Table 3 Critical speed depending on conicity

Conicity	Critical speed	
	(m/s)	(km/h)
0.1	203	730
0.2	166	597
0.25	151	543
0.3	138	496
0.4	122	439
0.5	110	396

In the safety analysis, using the measured acceleration of the simulation range, the estimated value of the acceleration was derived by filtering method as Table 3. The statistical analysis of the simulation is presented by mean value and standard deviation as Equation 3.

$$Y = \overline{y} + kS_y \tag{3}$$

where Y denotes the estimated value, $\overline{y}$ denotes the mean value of the assessment value, S_y denotes the standard deviation, and K denotes the factor of the assessment value as Table 3.

The evaluated acceleration according to statistically processing and the limiting value of the safety were compared by UIC CODE 518 OR. The acceleration values of the safety are expressed in Table 4. The evaluated value of the cant of 137mm doesn't satisfy safety criteria of lateral acceleration of a body because the running vehicle is unstable at curved track. When the vehicle drives the curved track, lateral motion of the vehicle is increased so the estimated value is over the liming value. In order to satisfy the safety criteria, the cant is increased from 137mm to 160mm. The estimated value at the cant of 160mm satisfies the limiting value of safety.

Table 4 Results of the safety analysis

Unit: m/s^2

Sections	Limiting value	Estimated value	
		cant 137mm	cant 160mm
Lateral acc. of a bogie	10.5	6.64	6.80
Lateral acc. of a body	3	3.03	2.94
Vertical acc. of a body	3	0.77	0.82

6 CONCLUSION

In this study, stability analysis and safety analysis were implemented by ADAMS/Rail for safety of the next-generation railway vehicle. The developing railway vehicle's conicity is 0.25 and the critical speed of the vehicle is 543km/h at the stability result. So, this vehicle's design parameters are stable. Also, when the value of conicity is 0.4, critical speed is 439km/h so we can know the abrasive cycle because of the target vehicle speed.

In safety analysis, the dynamic model of the railway vehicle was analyzed using simplified method of UIC CODE 518 OR. When the vehicle drives the curved track of which the radius is 7,000m, the analysis results satisfy the limiting value of the running safety at the cant of 160mm. In the future, this model will be implemented for the permissive maximum speed according to safety criteria at curve driving.

ACKNOWLEDGMENT

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