IJR International Journal of Railway
Vol. 6, No. 2 / June 2013, pp. 64-68

ISSN 1976-9067(Print)
ISSN 2288-3010(Online)

Review of the Improvement Plans on Catenary Systems for Speed Increase in Gyeongbu High-Speed Line

Ki Young Eum, Jangho Yun, Kiwon Lee and Jung Hwan Kim†

Abstract

In recent years, the speed of a train has been recognized as one of the important factors to determine the competitiveness as a mean of transportation. In line with this, infrastructure improvements and enhancements are being made with increases in the speed of train. Accordingly, there is a need to establish plans for infrastructure improvements through a comprehensive analysis of signals, track/civil engineering, catenary and environment, etc. to improve the speed of a train of high-speed train service sections in Korea. This study proposes improvement plans for catenary systems by investigating the possibility of improvements through performance analysis of catenary equipment by speed increase based on the analysis on catenary systems in Gyeongbu high-speed line, and analysis the applicability of catenary improvements and economic feasibility.

Keywords **:** *Catenary, Economic feasibility, Infrastructure, Gyeongbu high-speed Line*

1. Introduction

1.1 Research background

The speed of a train has recently been recognized as the important factors to determine the competitiveness as a mean of transportation. In particular, the top speed not only has a symbolic meaning that forms the image of transport, but also boosts the self-esteem of people and contribute to the improvement of national competitiveness by showing the technical level of transportation at home and abroad.

Railway is composed of various systems and technologies, so it is required to develop the infrastructure when the speed of a train is up. In japan, a developed country of the train, infrastructure improvements have already been made, along with increase in the speed of the train. Therefore, it is required to establish plans for infrastructure improvements through a comprehensive analysis to improve the speed of trains of high-speed train service sections in Korea.

In particular, it is necessary to determine whether the system can be applied in each field through interface between infrastructures for review of speed increase, and must analysis the improvement of schedule speed based on TPS(Train Performance Simulation) through comprehensive application of the system between each field. Therefore, since analyzing the improvement of schedule speed on catenary field individually raises the question of equity, the analysis of schedule speed improvement on the plans for catenary system improvement was excluded.

In this regard, this study propose improvement plans of catenary systems through performance analysis of existing catenary equipment by speed increase in Gyeongbu high-speed line and analyzed the applicability of catenary improvements and economic feasibility .

1.2 Current status of catenary systems

Since the speed improvement of high-speed line is one of the policy directions promoted at home and abroad, this study investigated the improvement plans of the current catenary system by speed increase in Gyeongbu high-speed line. Especially, it is performed in high-speed track sections in Gyeongbu line as shown in Table 2.

† Corresponding author: HSR System Research Team, KRRI, Uiwang 437-757, Korea
E-mail : akdang84@krri.re.kr
* HSR System Research Team, KRRI, Uiwang 437-757, Korea
** HSR System Research Team, KRRI, Uiwang 437-757, Korea
*** HSR System Research Team, KRRI, Uiwang 437-757, Korea

http://dx.doi.org/10.7782/IJR.2013.6.2.064

Table 1 Current status of high-speed lines

Segment		Gyeongbu high-speed line	Honam high-speed line
Design speed		350 km/h	350 km/h
Catenary wire	Type	Grooved trolley wire Cu 150 mm^2	Grooved trolley wire CuSn 150 mm^2
	Tension	20,000 N	26,000 N
Messenger wire	Type	Bz 65 mm^2	Bz 116 mm^2
	Tension	14,000 N	20,000 N
Dropper	Spacing	4.5 m / 6.75 m	4.5 m / 6.5 m
	Material	Bz 12 mm^2	Bz 12 mm^2
Automatic tension adjusting device		Individual pulley-type	Individual pulley-type
Contact wire height		5,080 mm	5,100 mm
Encumbrance		1,400 mm	1,400 mm
Maximum span		63 m	65 m
Catenary system		Simple catenary	Simple catenary

Table 2 Current status of routes in Gyeongbu line

General track	Seoul ~ Siheung	Dajeon ~ Panam	Sangri ~ Daegu	Entry part of Busan Staion
Distance[km]	19.183	11.335	13.694	0.38
Design speed	150	150	150	150
Operation speed	135	135	135	135
High-speed track	Siheung ~ Dajeon	Panam ~ Sangri	Daegu ~ Busan Station	Disance Of high-speed track (376.9 km)
Distance[km]	134.435	115.123	127.369	
Design speed	350	350	350	
Operation speed	350	300	300	

2. Catenary System Improvement Plans and Economic Analysis

2.1 review directions

In this study, the maximum operation speed of Gyeonbu high-speed line section was examined first, and then the increase in tension due to the catenary wave propagation velocity and life of catenary was investigated. Lastly, improvement plans for catenary equipment was established in terms of economic efficiency and maintainability.

2.2 review on the maximum operation speed of high-speed line

According to the government's basic plans, the design speed of Gyeongbu high-speed line is 350 km/h, and the maximum operation speed is 300 km/h as shown in Table 2.

Table 3 International standards(EN & UIC)

EN 50119(2001)
Operation speed is less than 70% of C
UIC CODE 799-OR(2002)
C = V_{max}(maximum operation speed) + 40 m/s(144 km/h)

*C : wave propagation velocity[km/h]

Table 4 Reinterpretation of design speed on Gyeongbu line

International standards	Calculation
EN 50119 (2001)	→ Operation speed = 441 × 70% → Operation speed ≒ 309 km/h
UIC CODE 799-OR (2002)	→ C= 308 km/h + 144 km/h → C= 452 km/h → 308 ÷ 452 = 0.68 → Design speed ≒ 70% of C

*C of Gyeongbu high-speed line(Cu 150 mm^2) = 441 km/h

However, discrepancies of the basic plans were found, and problems of the interpretation of terms were raised by the technical review committee for selecting catenary system of Honam high-speed line in 2008. In a rated move, the following amendment(article 2 of railway construction rules) was completed in 2009. "Design speed refers to the speed limit that serves as a criterion when designing the track.

With the change in definition of design speed, the maximum operation speed of Gyeongbu and Honam high-speed line according to the wave propagation velocity(C) was reinterpreted based on the international standards of EN and UIC CODE as shown in Table 3.

2.2.1 reinterpretation of design speed in Gyeongbu high-speed line

The design speed of 350 km/h was applied to high-speed line at the beginning. However, according to the change in definition of design speed and international standards of C, operation speed for stable operation of the train was determined to be 70% of C. From the results of the calculation as shown in Table 4, 308 km/h was selected as the maximum operation speed(design speed) of Gyeongbu high-speed line.

2.2.2 reinterpretation of design speed in Honam high-speed line

The design speed of 350 km/h was also applied to Honam high-speed line at the beginning as shown in Table 1. As above, 70% of wave propagation velocity of Honam high-speed line was determined to be suitable. From the results of the calculation as shown in Table 5, 350 km/h was selected as the maximum operation speed of Honam high-speed line.

Table 5 Reinterpretation of design speed on Honam line

International standards	Calculation
EN 50119 (2001)	→ Operation s peed = 502 × 70% → Operation speed ≒ 351 km/h
UIC CODE 799-OR (2002)	→ C= 308km/h + 144km/h → C= 494km/h → 350 ÷ 494 = 0.708 → Design speed ≒ 70% of C

*C of Honam high-speed line(CuSn 150 mm^2) = 502 km/h

Table 6 Review on tension of catenary by speed increase

Speed increase	calculation	308 km/h	310 km/h	320 km/h
C	→ $V_{max} = C \times 70\%$ → $C = V_{max} \div 70\%$	441 km/h	443 km/h	457 km/h
T_0	→ $C = 3.6 \times \sqrt{\frac{T_0}{\rho}}\%$ → $T_0 = \frac{C^2 \times \rho}{3.6^2}$	20,000 N	20,200 N	21,500 N

*V_{max} : Maximum operation speed [km/h],
T_0 : Standard tension of catenary[N]
ρ : Unit mass of catenary[1.334 kg/m]

Table 7 Review on tension of catenary by speed increase

Speed increase	calculation	308 km/h	310 km/h	320 km/h
A	→ $T_a = \frac{\sigma \times A}{s}$ → $A = \frac{T_a \times s}{\sigma}$	138.5 mm^2 (D:11.8)	139.8 mm^2 (D:12)	148.9 mm^2 (D:12.7)
Allowable wear amount	Cu 150 mm^2 (D:13.6 mm)	1.8 mm	1.6 mm	0.9 mm

*T_a : Allowable tensile force[N], σ: Breaking load[336.6 N/mm^2]
A : Allowable cross section[mm^2], S: Safety rate(2.2)
D: Residual diameter[mm]
*In this case, T_a is calculated by adding suppression resistance of 5%

2.3 Plans for speed increase of Gyeongbu high-speed line

For improvement of speed increase of Gyeongbu high-speed line, the life of catenary, wear amount of catenary and compatibility, wave propagation velocity by speed increase (308 km/h, 310 km/h, 320 km/h) was calculated

2.3.1 Review of tension and life by speed increase

First, the maximum operation speed of the train was set to 308 km/h, 310 km/h and 320 km/h, and then tension which is appropriate to the speed was calculated by figuring out the required wave propagation velocity as shown in Table 6.

Second, since catenary(Cu 150 mm^2) takes the form of polygon, not circle, it is difficult to calculate cross-sectional area and residual diameter. Accordingly, the remaining cross-sectional area was calculated with standard tension set, and the residual diameter was calculated using a CAD Program as shown in Table 7.

Lastly, Table 9 shows the life of catenary which was predicted based on the wear rate measurement during 4 years of use after the opening of Gyeongbu high-speed line in 2004 as shown in Table 8. However, the actual life of catenary replacement may vary depending on the type of train operation in case of the life of catenary in this section.

Table 8 The wear rate measurement Data of catenary

Time of measurement	Type of wire	Measurement value	Wear value	Cumulative ware value
2006 year	Cu 150 mm^2	13.43 mm	0.17 mm	0.17 mm
2007 year		13.28 mm	0.15 mm	0.32 mm
2008 year		13.16 mm	0.12 mm	0.44 mm
2009 year		13.12 mm	0.04 mm	0.48 mm
Average wear amount per year				0.096 mm

*The Contact wire value record shows measurement results after the opening on April 1, 2004, and it was obtained from Osong Electricity Office of the Korea Railroad Corporation.

Table 9 The predicted life of catenary by speed increase

Speed increase	308 km/h	310 km/h	320 km/h
Allowable wear amount	1.8 mm	1.6 mm	0.9 mm
Predicted life	19 years	17 years	9 years

*Calculation, ex) Wear amount(1.6 mm) ÷ average wear amount per year(0.096 mm) ≒ 17 years

Table 10 Review results by speed increase

Speed increase	308 km/h	310 km/h	320 km/h
Wave propagation velocity	441 km/h	443 km/h	457 km/h
Allowable wear amount	1.8 mm	1.6 mm	0.9 mm
Predicted life	19 years	17 years	9 years
Catenary tension	20 KN	20.2 KN	21.5 KN

2.3.2 Review results and improvement plans by speed increase

From the review results as shown in Table 10, 308 km/h was selected as the maximum operation speed(design speed) for Gyeongbu high-speed line, and 350 km/h for Honam high-speed line respectively.

Since 308 km/h is the current maximum operation speed of Gyeongbu high-speed line, it doesn’t require improve-

Table 11 The improvement plans by speed increase

<table>
<tr><th colspan="2" rowspan="2">Segment</th><th colspan="3">Train operation speed</th></tr>
<tr><th>308 km/h</th><th>310 km/h</th><th>320 km/h</th></tr>
<tr><td colspan="2">Catenary wire</td><td>No change</td><td>No change</td><td>Replacement</td></tr>
<tr><td colspan="2">Messenger wire</td><td>No change</td><td>No change</td><td>Replacement</td></tr>
<tr><td rowspan="2">Tension</td><td>Catenary</td><td rowspan="2">No change</td><td>Adjustment</td><td>Adjustment</td></tr>
<tr><td>Messenger</td><td>No change</td><td>Adjustment</td></tr>
<tr><td colspan="2">Tension adjusting device</td><td>No change</td><td>Improvement</td><td>Improvement</td></tr>
<tr><td rowspan="2">Dropper</td><td>Spacing</td><td rowspan="2">No change</td><td>Adjustment</td><td>Replacement</td></tr>
<tr><td>Material</td><td>No change</td><td>Replacement</td></tr>
<tr><td colspan="2">Railway electric pole</td><td>No change</td><td>No change</td><td>No change</td></tr>
<tr><td colspan="2">Catenary height</td><td>No change</td><td>No change</td><td>change</td></tr>
<tr><td colspan="2">Other ancillary velocity</td><td>No change</td><td>Adjustment</td><td>Replacement</td></tr>
<tr><td rowspan="3">Review comments</td><td>308 km/h</td><td colspan="3">The current maximum operation speed</td></tr>
<tr><td>310 km/h</td><td colspan="3">Need to review the life</td></tr>
<tr><td>320 km/h</td><td colspan="3">Applied to Honam high-speed line</td></tr>
</table>

ment of catenary equipment as shown in Table 11.

In case of speed increase to 310 km/h, a similarity exists between the life of existing catenary and wave propagation velocity, but there is a need for tension adjustment, improved tensioning device, dropper adjustment and adjustment of other ancillary equipment.

In case of speed increase to 320 km/h, the life of catenary is less than 10 years, which is disadvantage in terms of maintenance, and excessive expenditure of maintenance costs due to the reduced life is expected.

In this context, in case of speed increase up to more than 320 km/h, it would be appropriate to make improvements through Honam high-speed line system which is under construction after its development by "A study on the technology development for 350 km/h-grade catenary system".

2.4 Economic analysis of catenary field by speed increase

An analysis on economic efficiency of system improvements in catenary field according to the distance of high-speed line in case of speed increase by 308 km/h, 310 km/h and 320 km/h was conducted based on the construction unit cost standards of the Korea Rail Network Authority and construction costs of catenary in Gyeongbu high-speed line as shown in Table 12.

As its results, it was found that economic efficiency is low due to the construction costs of the improvements of existing systems. It is expected that in the case of 310 km/h, improvement can be achieved by partial adjustment of the power supply-off time for the existing operation lines, but overall improvement according to the speed increase up to more than 320 km/h will lead to disadvantageous results due to the increase in construction costs and hindrance of railway operation.

Table 12 The Approximate construction costs by speed increase

Speed increase	Facility improvements	Approximate construction costs [won]
308 [km/h]	• No change	-
310 [km/h]	• Tension adjustment • Improved tension adjusting device • Dropper spacing adjustment • Adjustment of other ancillary equipment	10.2 billion
320 [km/h]	• Tension adjustment • Replacement of catenary and messenger • Improved tension adjusting device • Dropper spacing and material replacement • Change of catenary height • Replacement of other ancillary equipment	277.5 billion

* Distance of high-speed track(376.9 km)

3. Conclusion

This study proposed improvement plans for catenary systems by investigating the possibility of improvements through performance analysis of catenary equipment by speed increase based on the analysis on catenary systems of Gyeongbu high-speed line, and analyzed the applicability of catenary improvements and economic efficiency.

First, the maximum operation speed of Gyeongbu high-speed line was determined to be 308 km/h according to the change in definition of design and international standards of wave propagation velocity.

Second, concerns about material supply of tension weight due to an increase in tension are raised in case of speed increase to 310 km/h, but facility improvement can be made. However, since an increase in tension of the catenary is inevitable in case of the speed increase, and separation ratio and contact force of the catenary due to the increase in tension cannot be verified, a verification through a current-collection performance simulation is required. In case of the catenary Cu 150 mm^2, a verification need to be conducted through empirical experiments since there exist no operation results in more than 20 KN. In addition, the prediction of life may lead to flexible outcomes due to the lack of accurate data.

Third, the life of catenary was estimated to be less than 10 years in case of speed increase to 320 km/h, which indicates that improvements by as increase in tension of the existing systems are not valid in terms of economy and maintenance, and the overall improvement of catenary was found to be disadvantageous due to the increase in construction costs and hindrance of railway operation.

Fourth, it would be appropriate to make improvements through Honam high-speed line systems of 350 km/h-grade in case of speed increase up to more than 350 km/h.

Thus, in the case of speed increase of Gyeongbu high-speed line, the effects of speed increase due to the improvement of catenary system can be anticipated, but an analysis shows that there are practical difficulties in the overall improvement of systems and the final determination of improvement plans through a validation study of ancillary systems. In addition, since the train load increases in case of the high-speed operation of trains, there is a need to review the adequacy of the transformer capacity and voltage drop through a power flow simulation on the basis of the train operation plans.

Acknowledgement

This study was carried out as part of the research titled, "Development of technology for a trial application of 400km/h-grade high-speed rail infrastructure" supported by the ministry of Land, Transport and Maritime Affair.

References

1. Korea Railroad Research Institute, "Report on the overall high-speed rail infrastructure and interface research", 2002.
2. Korea Railroad Research Institute, "Development of improved technology of the line system for improving speed", 2005.
3. Korea Rail Network Authority, "Final report on plans for establishment of signal system by stage according to the speed-up of railway construction lines", 2011.
4. Korea Rail Network Authority, "Report on the design of Gyeongbu high-speed line(Step 1, Step 2) ", 2006.
5. Korea Railroad Research Institute, "Final report on development of technologies for rail system improvement for speed increase of existing lines(4^{th}years)", 2005.
6. Seoyeong ENG, "Study analysis in the field of track by improving scheduled speed", 2011.
7. Korea Railroad Research Institute, "Report on reinforcement cost research of infrastructure by improving operating speed of high-speed train", 2010.
8. Overseas Railway Technology Cooperative, "Speed increase of shinkansen", P11-46, 2008.