Study on Calculating Maximum Tangent Length When Driving Super-Highway

Joonbeom LIM [a], Soobeom LEE [b], Jiyeon HONG [c], Sungkab JOO [d], Xiaokun LI[e]

[a] *Ph.D Candidate, Dept. of Transportation Engineering, University of Seoul, Seoul, Korea; E-mail: t_safety@hanmail.net*
[b] *Professor, same as the first author; E-mail:mendota@uos.ac.kr*
[c] *Research Professor, same as the first author;E-mail:cathy56@uos.ac.kr*
[d] *Master Course, same as the first author; E-mail:suckap@hanmail.net*
[e] *Master Course, same as the first author; E-mail:lxk123713@naver.com*

Abstract: The purpose of this study is to calculate the maximum tangent length where driver's drowsiness occurs while driving at running speed over 140km/h on super-highway.

For this study, we used a driving simulator, tried to find out a position where drowsiness EEG occurs while driving along the tangent section road with length over 15km, and calculated the maximum curve radius where the subjects started to have the same attitude as that of tangent section while driving curved section for each curve radius.

As a result of testing the driving simulator for the maximum curve radius that shows drowsiness EEG and tangent section driving attitude, drowsiness EEG occurred on 9.6km point of the tangent section road, and tangent section driving attitude occurred on the road with curve radius over R=3000. Therefore, when a tangent section road with curve radius over R=3000 is designed, it should be designed below 9.6km.

Keywords: M*aximum tangent length, Super highway, Brain wave, Driving Simulator*

1. INTRODUCTION

1.1. Study Background

At present on the domestic highways, the design speed of roads has been at a level of 120km/h since the opening of the Seoul-Busan Expressway whereas in developed countries in terms of traffic order such as the US, Germany, and Japan, super-highways with design speed at a level of 130km/h ~ 160km/h are being designed. Korea is staying at a level of 70% compared to advanced countries. However, because of recent improvements in the performance of vehicles and developments of information technology, demands of people for faster, safer, and more convenient driving are increasing. Therefore, together with international trend called 「low-carbon green growth」, interests in the construction of super-highway are getting deeper in the Road Traffic field, and Ministry of Land is promoting "SMART Highway Business" to enhance international competitiveness by overcoming the limitation of distances in domestic regions and developing leading technology of the world in the road traffic field.

1.2. Research Contents and Purpose

Because the design speed will get faster on the super-highway than that of the present domestic highways, road design elements should also be reestablished. Recently, efforts to reflect characteristics of drivers (human) in the stage of establishing road design standards have been growing, and especially the U.S. is making design guidelines that focus on Human Factor called NCHRP (National Cooperative Highway Research Program) Report based on the road design standard of AASHTO. If a super-highway with design speed over 140km/h is to be built, the minimum curve radius will get bigger, and the length of tangent will get longer, making drivers constantly drive on roads almost close to a tangent line. At this point, many psychological problems of drivers that are not being considered during the present designing of geometric structure such as boredom or anxiety due to high speed driving occur.

To solve those problems, it is necessary to establish geometric structure standard which corresponds to the design speed considering ergonomic factors that are not being used for the establishment of the domestic road design standard.

This study calculates maximum tangent length when driving at a speed over 140km/h through driver drowsiness EEG measure and driving data analysis. 4

2. LITERATURE REVIEW

Yun, Byung Jo (2010) examined the volume of traffic on freeway free-flow on the study about the microscopic characteristic of freeway free-flow speed, and it turned out that, on the road with the limited maximum running speed of 100km/h, V85 was over 115km/h during the middle of the night that showed low running speed, and was over 142km/h during daytime that showed the highest running speed.

Kim, Yong Seok (2004) et al. tested the assumption on drivers' driving attitude inherent in the running speed profile model through research data of long tangent-curve connection line, and as a result attitude of reduction of speed distinctly appeared in comparatively small curve radius section.

Bae, Jun Hyung (2008) et al., on bio-signal extraction, selection, and quantification for comparison of drivers' physiological reaction by ages according to unexpected situations, proved that if a variable that represents the size of bio-signals and a variable that shows the amount of change of bio-signal are used together, then the physiological reaction according to unexpected situations could be measured more precisely.

Kecklund and Akersted(1993) determined that, targeting 28 truck drivers, when they drove for a long time, as they felt tired and drowsy, Theta wave and Alpha wave increased in the center lobe of their brains.

Park, Seong Suk (2009) et al. measured drivers' bio-signals such as EEG, nictitation, ECG (electrocardiogram), electric resistance of skin, and temperature change of skin, and analyzed occurrence point of anxiety and tension, and occurrence point and degree of drowsiness and tiredness, in Korea Research Institute of Standards and Science.

Son, Young Tae (2009) et al. showed that the road type influenced the recognition response of drivers, by measuring EEGs for each roadway segment through site driving test of 6 subjects. Especially, it could be found that the roads that had intersections where unexpected situations could easily take place greatly influenced the recognition response of drivers.

Kim, Seon Woong (2003), on the development of measurement of driver's fatigue using a physiologic signal, measured fatigue and drowsiness quantitatively by using physiologic signals, and determined that fatigue dramatically increased 60-90 minutes after the beginning of driving.

Cabon (1992) suggested that Alpha wave increased when driving without tension, and Theta wave increased when driving under stress. Korea Research Institute of Standards and

Science suggested through Beta wave analysis that the anxiety of drivers reached a boiling point at the entry section leading from large curve to small one.

Kim, Jung Ryong (1999) examined how sensitively characteristics of EEGs of each Lobe showed work load of driving, by extracting EEG signals among physiologic signals of drivers that appeared while driving on highways. Relative Energy Parameter could discriminate the difference of situations of driving and non-driving, and the proportions of Alpha wave and Beta wave turned out to partially separate loads for each driving situation.

Coope (1980) gained relative power spectrums of each EEG through FFT (Fast Fourier Transform) for processing EEG data with an EEG signal interpretation method.

Hwang, Min Chul (1998) normalized the relative power spectrum values when analyzing data based on driving situations, and used them for parameters of EEG analysis.

Lim Joon Beom et al (2012) conducted a research, which reflects characteristics of drivers (humans), on the design speed of super highway that corresponds to the need of humans wanting a high mobility. They compared powers of anxiety EEG when the subjects drove at the running speed between 110km/h and 160km/h, and analyzed geometry, speed, anxiety EEG when the subjects (drivers) were freely driving without speed limitation. Anxiety EEG was carried out by analyzing a physiological signal wave and as a result, the study showed that drivers feel nervous when driving at over 150km/h.

3. EXPERIMENT SUMMARY

3.1 Test Subject and Examination Place

The total number of the subjects was 30, consisting of 25 males and 5 females, among whom 13 of them were in their 20s, other 13 were in their 30s (20 males and 6 females), 2 of them were in their 40s, and the rest 2 were in their 50s (4 males).

Table 1. Experiment summary

	Contents
Data/Time	- preparatory experiment. : 2012. 03. 23 - experiment : 2012. 03. 24.～2012. 03. 25. (2days)
Place	- Simulator Lab of ‘University of seoul’
Characteristics of Subjects	- Total numver of subjects : 30 - Male : Female = 5 : 1 (Male 25, Female 5) - Ages : 20’s = 13, 30’s = 13, 40’s = 2, 50’s = 2

3.2 Experiment Process

The experiment of this study is divided into two scenarios. The first scenario is to learn the point that drivers show driving concentration deterioration (drowsiness occurrence) on the road of tangent section 15km section, and the second scenario is to learn until what size of curve radius the test subjects show tangent section driving attitude. First of all, we randomly chose one map and let subjects drive to get accustomed to sensitivity and operation of the simulator. During the testing driving, curve radius was set randomly from R=1,400m to R=6,000m, and we obtained data by excluding driving data for those who did lane departure or crashed into a median strip, and re-experimenting.

3.3 Experimental Devices

3.3.1 Driving simulator

A Driving Simulator is used when it is needed to direct road driving situation, making up virtual roads, because conducting measure and tests on real roads could critically damage test subjects and is much too dangerous. it is also possible to test in safe circumstances, for it can rule out unexpected accidents that could happen in the real test.

The Driving Simulator is a variety of I-drive 3ch., and 2DOF MP, and it consists of 32 inch 3 channel, 1/4 vehicle shape cabin and CFLS, 2 axis electronic type one-seater motion platform, one running computer, and lightning and one air conditioner.

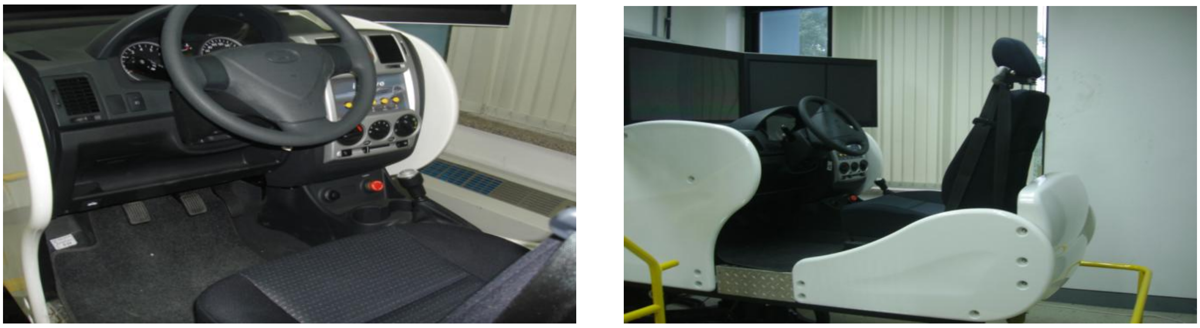

Figure 1. Driving Simulator

3.3.2 EEG measuring system (PolyG-I & Telescan)

EEG (electroencephalogram) is recording brain activity by inducing delicate and rhythmic electrical activities of brain cell groups to scalp, representing bio-signal of brain function status. Through EEG analysis, we can evaluate and analyze conditions such as emotional status of men, and EEG can be used for an indicator that shows drowsiness for safe driving of drivers.

PolyG-I system was used to measure EEG of drivers on this study, and though there are many kinds of EEGs, we used only theta wave that can reveal drowsiness of drivers. We started EEG measure by attaching electrodes above frontal lobe and temporal lobe of drivers. Software “Telescan” is used for recording and analyzing measured EEG, and this software can set time, channel, and frequency band, and it is possible to print out analysis results through power spectrum.

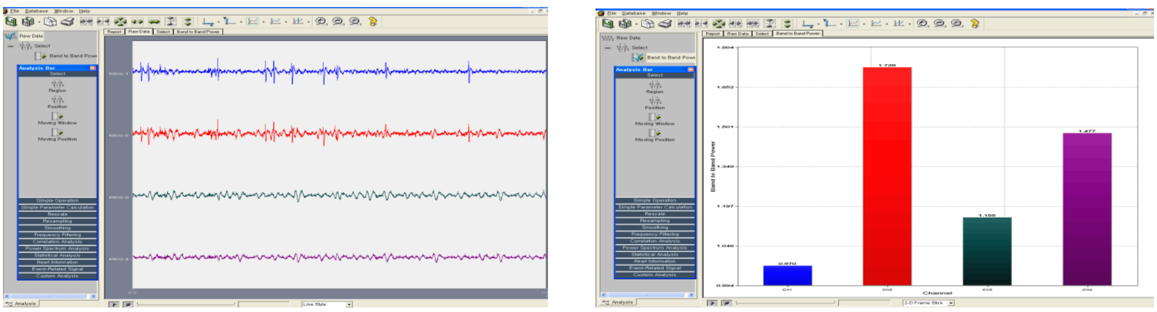

Figure 2. “S/W”, Telescan

3.4 EEG Recording

We used ten-twenty electrode system to measure physiologic signals, and for determining drowsiness occurrence of drivers, we conducted measure on the frontal lobe that is the primary production part of Theta wave, and on the temporal lobe that is the main production part of Alpha wave.

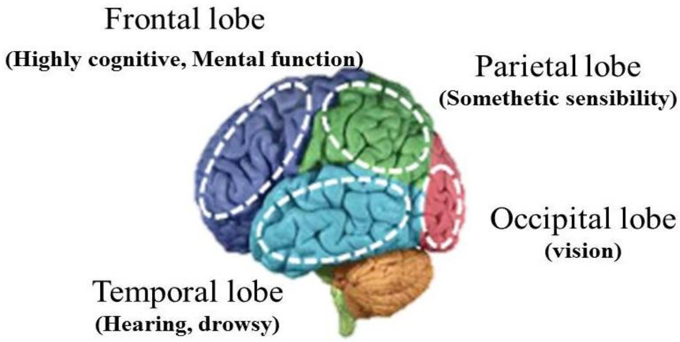

Figure 3. Brain wave creation

The types of EEG analysis can be largely divided into Band to Band Power Spectrum analysis and Absolute Power Spectrum analysis. Band to Band Power Spectrum analysis shows the proportion between Theta wave which is the analysis target and Alpha wave that is generally generated during normal time, and Absolute Power Spectrum analysis represents absolute values of the wave of the analysis target.

We used Band to Band Power Spectrum analysis for the purpose of calculating drowsiness EEG. This analysis gives us the proportion between Alpha wave that is generated when drivers are driving the initial 2km having no drowsiness and Theta wave when drowsiness occurs due to driving on a long tangent section.

Calculation formula : θwave(4hz~7.99hz) / αwave(8hz~12.99)

Table 2 shows the frequency band and characteristics of each brain wave that can be measured by PolyG-I.

Table 2. Frequency band and characteristics of each brain wave

brain wave	frequency band	state of consciousness	measurement spot
δ (delta wave)	1-3.99 Hz	deep sleep	-
θ (theta wave)	4-7.99 Hz	drowsy, deep meditation	frontal lobe, temporal lobe
α (alpha wave)	8-12.99 Hz	relaxation, creative thinking	occipital lobe, parietal lobe
β (beta wave)	13-29.99 HZ	awake, anxiety / tension, conscious of action	occipital lobe, parietal lobe
γ (gamma wave)	30-50 HZ	highly cognitive action	-

4. RESULT ANALYSIS

4.1 Analysis Categories and Methods

The data obtained from the driving experiment can be divided into 4 categories : EEG, running speed that shows the speed of subjects' vehicle; Lane Placement; RPM (Revolution Per Minute) that represents acceleration and reduction of speed ;and idle running time. When measuring the maximum tangent length, after driving 15km tangent road, we calculated the point where drowsiness occurred through EEG analysis, running speed and Lane Placement, and RPM analysis.

For calculation of curve radius size that tangent section driving attitude occurs, first, drivers drove on the randomly selected 6 types of maps of R=1,400m, R=2,000m, R=3,000m, R=4,000m, R=5,000m, and R=6,000m. Second, by conducting statistical analysis on the first 1km point of driving, curve radius running speed, and Lane Placement, we determined if there is any difference between tangent section and curved section driving attitude.

Because driving data of the Driving Simulator is generated by accumulated distances, we conducted analysis on running speed and Lane Placement for each section by setting 100m as 1 section, for the sake of convenience. The running speed was kept constant when drivers focused on driving, and we examined the speed change when their concentration deteriorated, and checked if LanePlacement occurred due to concentration loss.

4.2 Maximum Tangent Length Calculation

4.2.1 Drowsiness EEG occurrence point calculation

We drew a graph that shows drowsiness EEG occurrence degree for each section (driving distance) by using data measured by 30 drivers' driving long-tangent 15km section.

As a result of drowsiness EEG occurrence analysis based on driving distance, the drowsiness EEG power was maintained at about 200 until 9.6km point, and showed dramatic changes after that section.

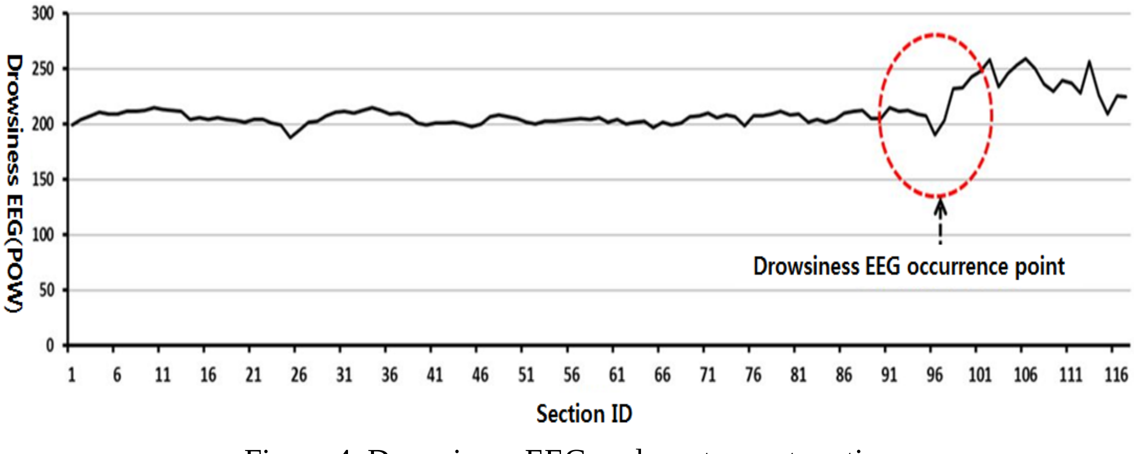

Figure 4. Drowsiness EEG on long-tangent section

For statistical verification of those results, we conducted paired t-test on the EEG measure data of the subjects for initial driving section ID 1-10 (Sta.0+000～Sta.1+000), and 96-106 (Sta.9+600～Sta10+600) where drowsiness EEG occurred.

We set up hypothesis for paired t-test as follows.

Null Hypothesis $H_0()$	The drowsiness EEG value averages of initial driving 1km section (Sta.0+000～Sta.1+000) and drowsiness EEG occurrence 1km section are the same as each other.
Alternative Hypothesis $H_1()$	The drowsiness EEG value averages of initial driving 1km section (Sta.0+000～Sta.1+000) and drowsiness EEG occurrence 1km section are different from each other.

Paired Samples Statistics

		Mean	N	Std.Deviation	Std. Error Mean
Pair 1	Initial driving section	206.9858	10	4.01262	1.26890
	Drowsiness EEG occurrence section	245.7428	10	10.23104	3.23534

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Initial driving section & Drowsiness EEG occurrence section	10	.126	.728

Paired Samples Test

		Paired differences					t	df	sig. (2-tailed)
		Mean	Std.Deviation	Std.Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial driving section - Drowsiness EEG occurrence section	-38.75703	10.50754	3.32278	-46.27367	-31.24038	-11.664	9	.000

Figure 5. t-test of Initial Driving 1km and Drowsiness EEG 1km Section

As a result of paired t-test, Sig. value was less than 0.05, rejecting the null hypothesis, and so the difference of average values of the initial driving section (Sta.0+000m～Sta.1+000) and drowsiness EEG occurrence onward section (Sta.9+600～Sta.10+600) turned out to be statistically significant at a 95% confidence level.

4.2.2 Driving data analysis on the drowsiness EEG occurrence point

As a result of analyzing the running speed, a delicate speed reduction change took place on the initial acceleration section and driving distance 7km section, but it is thought that this was a change not by drowsiness EEG but by speed control attempted by subjects, and there was a bit of running speed acceleration on 9.6km point. As a result of analyzing RPM(Revolution Per Minute), subjects drove without any distinct change until drowsiness EEG occurrence point, except for RPM change for reaching running speed over 140km on the acceleration section. There was no big change from the 9.6km section to the termination point.

As a result of analyzing Lane Placement, drivers reached 9.6km section without noticeable changes, but from this point the first Lane Placement change appeared due to drowsiness EEG occurrence, and it is judged that the change width got bigger while controlling the wheel to be located in the center of the road. The absolute value is 5cm, which is fairly small, but we can judge that this is a result of drowsiness occurrence, for it shows a different shape from that of the initial driving on the graph.

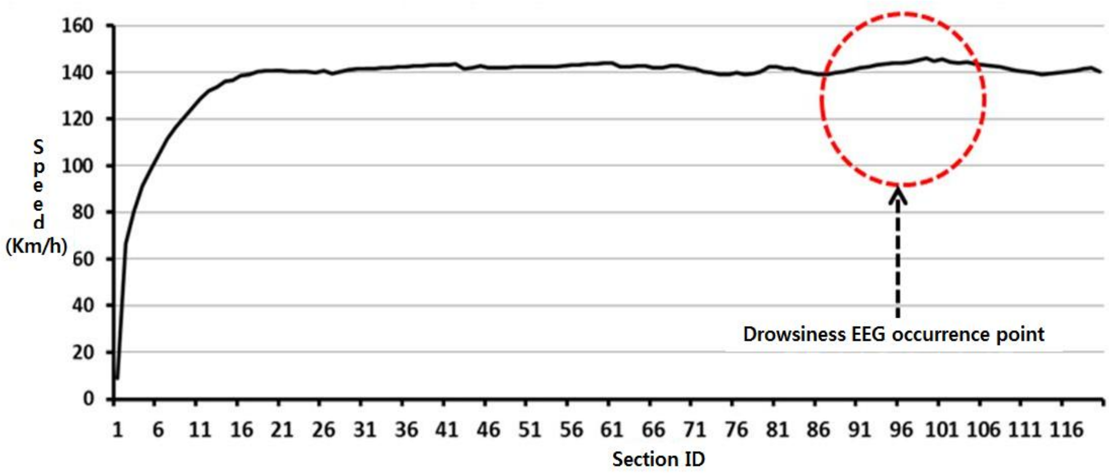

Figure 6 Speed on long-tangent section

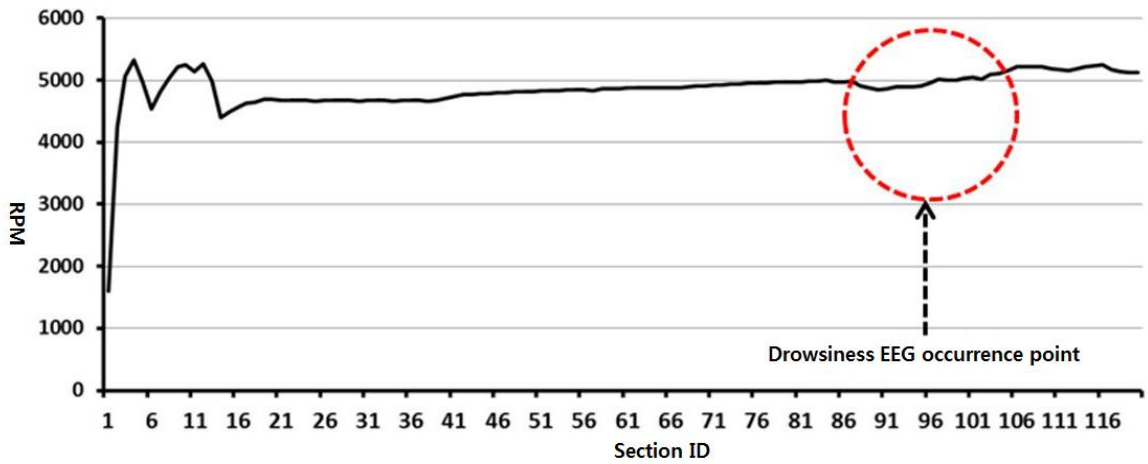

Figure 7. RPM(Revolution Per Minute) on long-tangent section

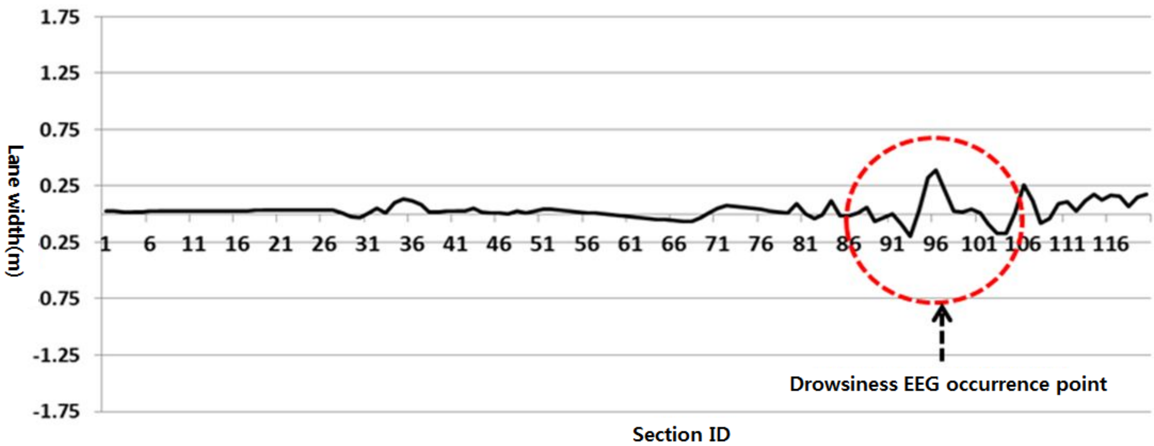

Figure 8. Lane Placement about Long tangent section

The figure below is a graph that represents driving data and drowsiness EEG together, and here the running speed and RPM doesn't show distinct change on the point where drowsiness EEG increases, but comparatively LanePlacement shows driving attitude change on the drowsiness occurrence point.

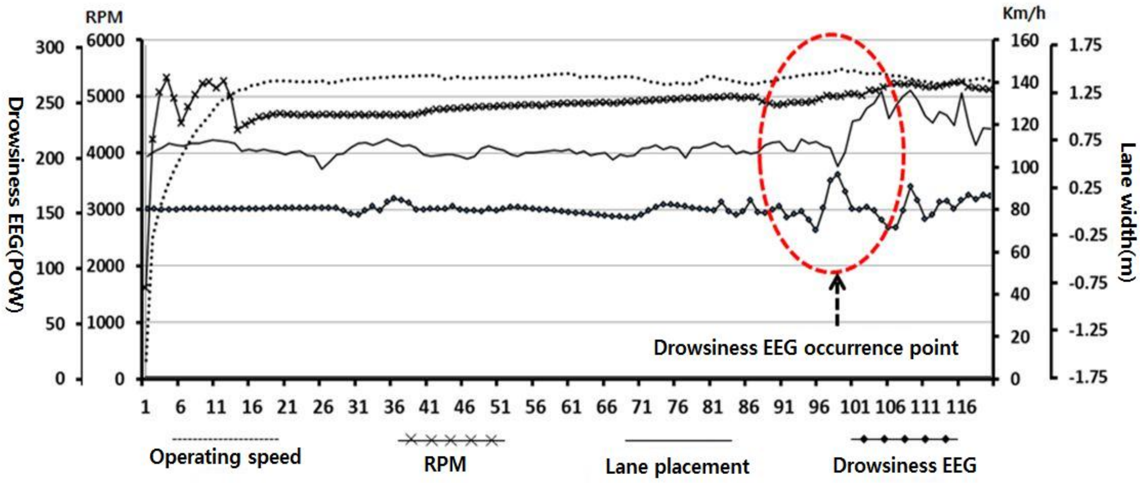

Figure 9. Driving Data and Drowsiness EEG on long-tangent section

4.3 Calculation of Curve Radius That Tangent Section Driving Attitude Occurs

Driving attitude in the aspect of curved section running speed means the attitude that drivers reduce speed until curved section peak after entering curved section and accelerate speed again passing through the curved section peak (Jung, Jun Hwa 2000, An analysis on attitudes of vehicles that drive on the curved section). If drivers take their feet off the accelerator when entering the curved section, no reduction change by acceleration or delicate change appears from the aspect of running speed, but change of RPM shows fundamental change compared to that of speed.

Curved section driving attitude in the aspect of lane center position for vehicles means that vehicles are pushed to the opposite side of the curve (left curve: right side from the lane center) by centrifugal force when vehicles are running on the curve radius. 0~2km section is a tangent section to separate tangent section driving attitude and curved section driving attitude, and from 2.1km are curved sections composed of each curve radius.

4.3.1 Driving attitude when curve radius R=1,400m

The running speed got markedly reduced from 140km/h to 120km/h where curve radius starts, 2km point, and then subjects drove at a speed of 120km/h on the curve radius, which indicates that the running speed reduced is influenced by the curved section. RPM showed dramatic reduction of speed from 2km/h point where curve radius starts, and it was kept constant until termination.

Lane Placement didn't show distinct change until the curved section starts, and then it leaned toward the right side from the curved section start point, which is seen as a move by the drivers who tried not to deviate from the center of the road within the curved section.

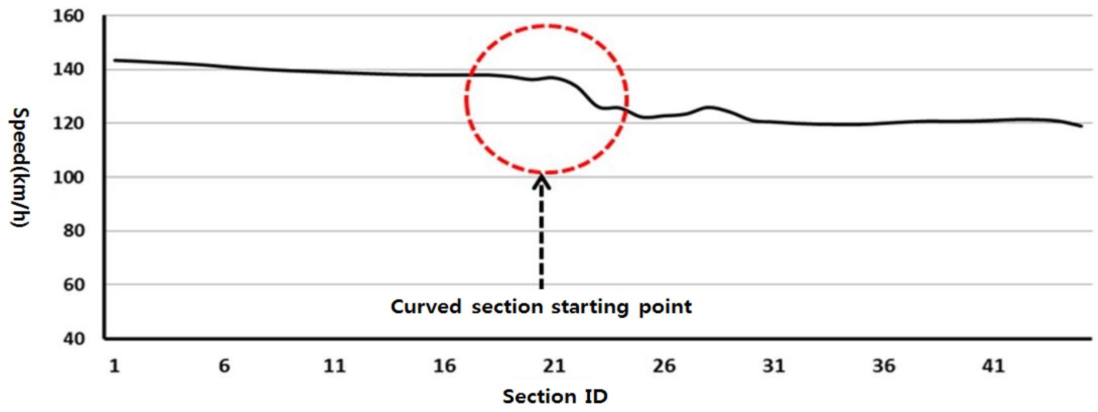

Figure 10. Speed about R=1,400m

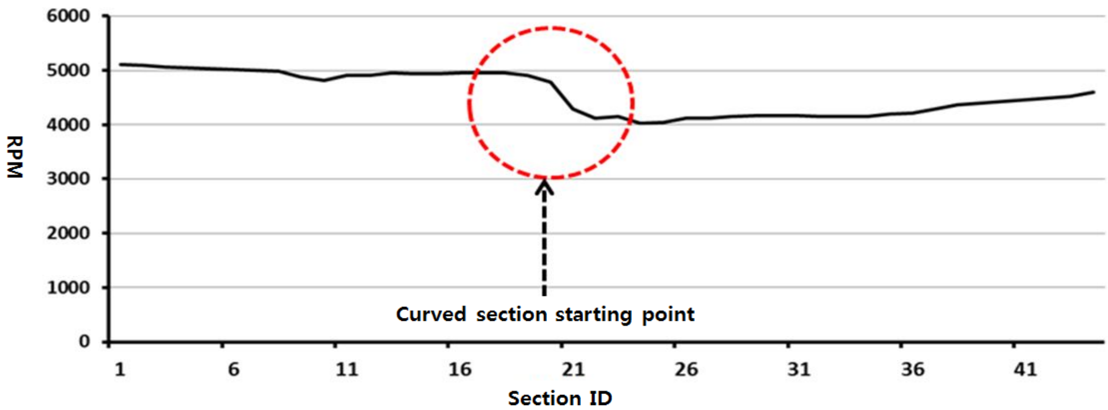

Figure 11. RPM(Revolution Per Minute) about R=1,400m

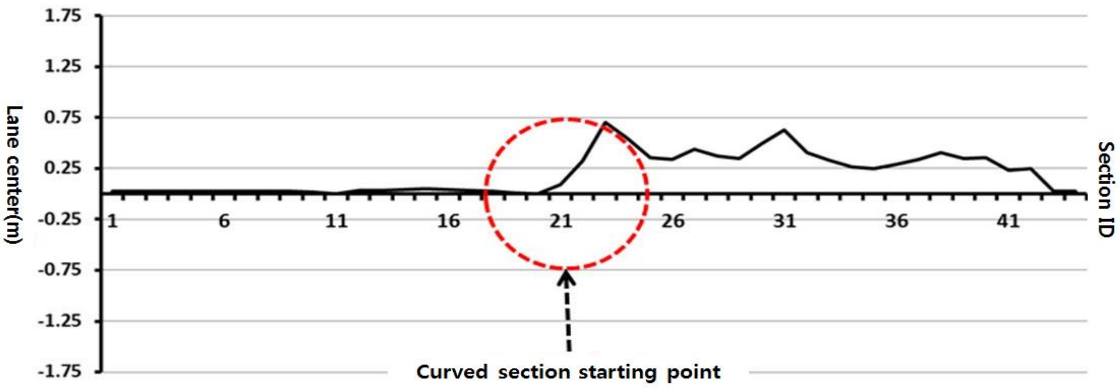

Figure 12. Lane Placement about R=1,400m

4.3.2 Driving attitude when curve radius R=2,000m

As a result of analyzing the running speed, subjects started to reduce speed from the curved section start point, and then accelerated again, and kept mid-120km/h until termination. RPM(Revolution Per Minute) also dropped from 5,000s to 4,000s when entering the curved section, and then was a little accelerated to 4,500, and kept this level until termination. LanePlacement had almost no change until curved section entering, and then started to increase from the curved section entrance, and the increase of change width after this point is thought to be an effort to stay in the center of the lane.

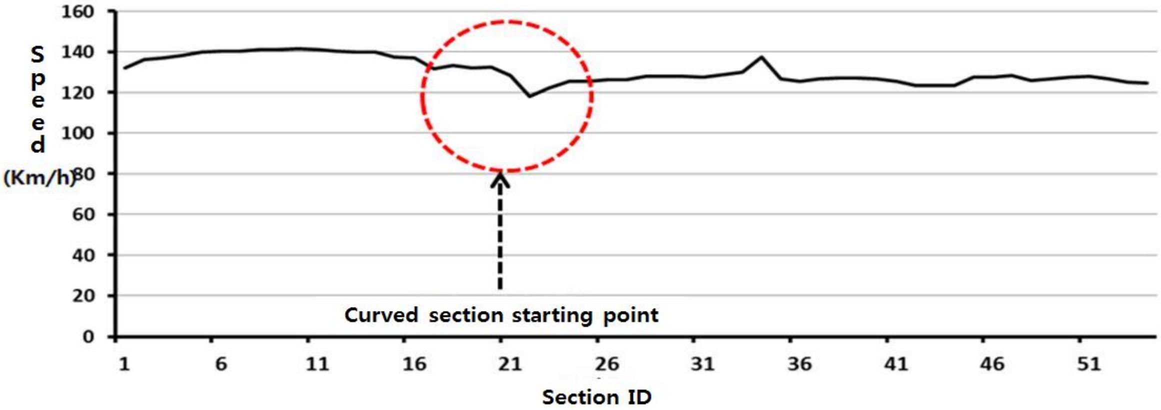

Figure 13. Speed about R=2,000m

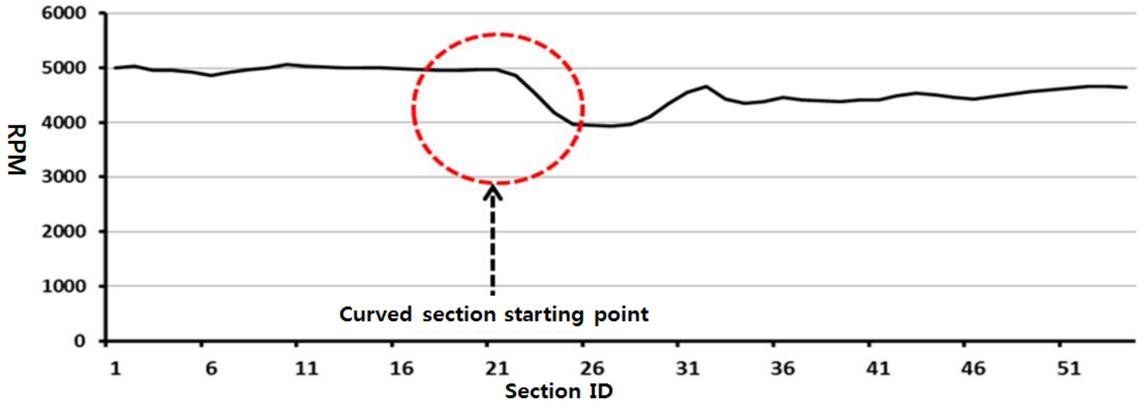

Figure 14. RPM(Revolution Per Minute) about R=2,000m

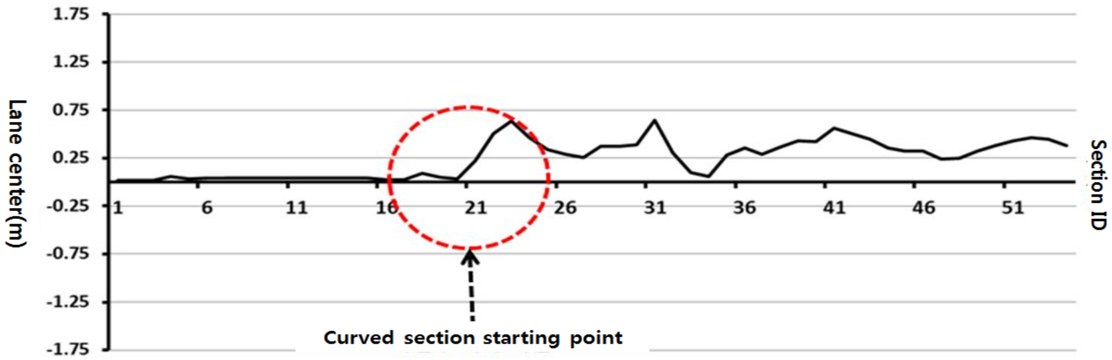

Figure 15. Lane Placement about R=2,000m

4.3.3 Driving attitude when curve radius R=3,000m

The running speed change appeared smaller than when R=2,000m, and there was no big change of speed. It is thought that subjects drove more safely than when driving on the curve radius, similar to when driving on the tangent section. There was almost no RPM change, and it showed a delicate change on the curved section start point, and then showed value of 5,000s constantly.

Lane Placement also represented more stable results than when the curve radius was below R=2,000m, and the lane center deviation width was kept at 0.25m (2.5cm), which is thought to be a stable value compared to when driving curve radius of R=1,400m and R=2,000m.

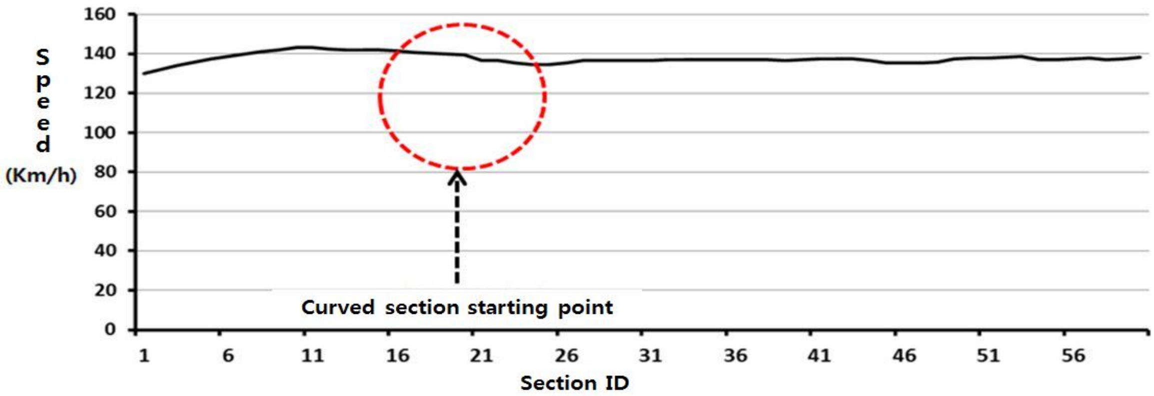

Figure 16. Speed about R=3,000m

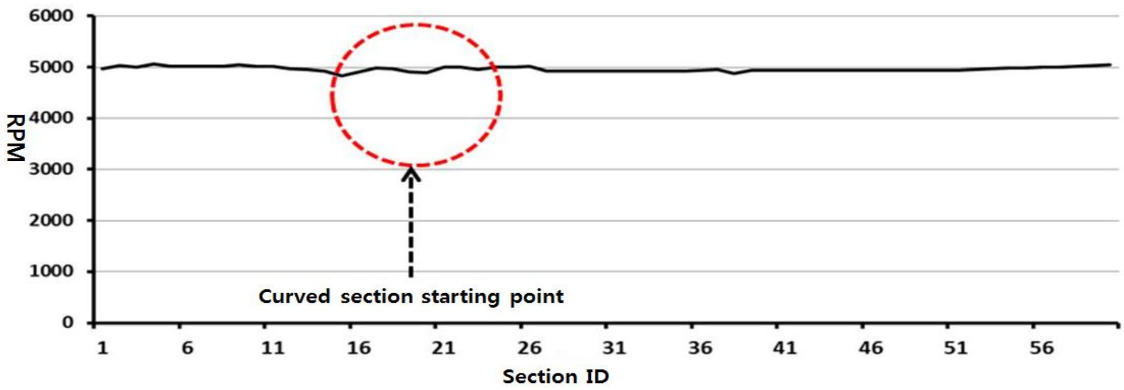

Figure 17. RPM(Revolution Per Minute) about R=3,000m

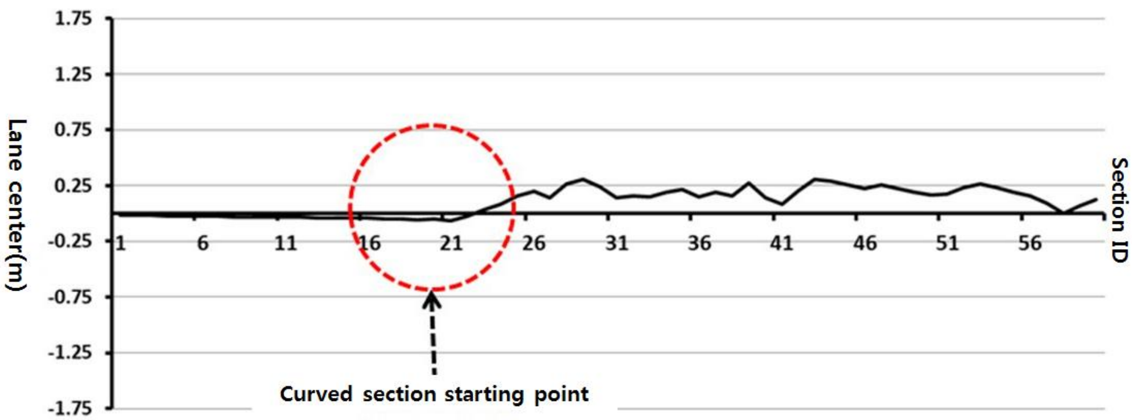

Figure 18. Lane Placement about R=3,000m

The summary of the running speed, RPM, and Lane Placement when the curve radius R=1,400m~ R=6,000m is as below.

Table 3. Comparison of interval of Initial Driving and Curve entrance section

Radius of Curve	Speed	RPM	Lane Placement
R=1,400m	O	O	O
R=2,000m	O	O	O
R=3,000m	X	X	X
R=4,000m	X	X	X
R=5,000m	X	X	X
R=6,000m	X	X	X

O = Difference of initial driving section(2km) and curve entrance
X = Non-difference of initial driving section(2km) and curve entrance

5. CONCLUSION

As a result of analyzing the tangent section drowsiness EEG occurrence point, the drowsiness EEG increased on 9.6km point, and as a result of conducting t-test analysis on the average of EEG difference between initial driving 1km section and drowsiness occurrence point 1km section, it showed statistical difference at the 95% confidence level. As a result of analyzing data of curved section driving on the curve radius, there was no big deal on the running speed, but as a result of analyzing RPM and LanePlacement, drivers' driving attitude appeared similar to tangent section driving attitude when radius of curve is over R=3,000m.

In conclusion, when drivers drove long tangent that only consisted of tangent sections, drowsiness EEG appeared on 9.6km point, and curved section driving attitude appeared when the curve radius was below R=2,000m, and tangent section driving attitude appeared when curve radius was over R=3,000m.

According to the result of this study, when the design speed is elevated to over 120km/h, the size of curve radius should be designed almost close to a tangent line. The problem that can arise from this point is that drivers could easily feel boredom, which may have drivers asleep at the wheel causing huge danger when driving at high speed. Therefore, the total length of tangent section plus curved section over R=3,000m should not exceed 9.6km when building super-highway.

ACKNOWLEDGEMENTS

This research was supported by a grant from The SMART Highway Geometric Funda mental Study (R&D 07 Technology Innovation A01) funded by the Ministry of Land, Transport and Maritime Affairs of the Korean government.

REFERENCES

Yoon, Byoung Jo (2010), Analysis Study on the Microscopic Characteristics of Freeway Flow Speed.

Kim, Young Suk, Jo Woun Boum(2004), An Observational Study on the Dirver Vehaviorus at Long Tangent Sections Followed by Sharp Horizontal Curve.

Jeong, Jun Hwa(2000), Analysis of the Driver's Behavior at Horizontal Curves.

Son Young Tae, Kang Jae Won, Eu Na Won (2009), Studies on the change of driver brain wave according to road type.

Kim, Jung-young, (1999), The tangent section of the highway operator physiological reaction analysis.

Hwang, Min-Chul, Yu, En-kyung, Kim, Chul-Jung (1997). Brain wave characteristic of Visual Emotion change.

Kim, Sun-Wung, (2003). Development of Evaluation Method of Driver's Fatigue by Physiological Signal.

Cooper, R., Osselton, J.W., and Shaw, J.C (1980), EEG Technology, 3rd edition, Butter worths & Co Ltd; Cuild ford & London.

Goran Kecklund and Torbjorn Akerstedt (1993), Sleepiness in long distance truck driving; an ambluatory EEG study of right driving, *Ergonornics*, vol. 36, No. 9.