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ANALYSIS OF ROAD SURFACE DRAINAGE SECTION CAUSED BY ROAD CROSS SLOPE USING ROAD SURVEY VEHICLE WITH SEVERAL SENSORS

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ABSTRACT

Proper road drainage is an important factor in terms of road safety. Though maintaining a safe water level on the road is of utmost priority for highway authorities, it may not be identified before the rainfall. If the drainage problem sections are predicted before rainfall, traffic accident concerns about water on the road surface could be addressed. Especially, once the automated vehicle travel the road, the road surface condition would be crucial. The inadequate road surface drainage may have several reasons such as pavement distress, drainage facilities and road geometry. Among the several reasons of excess water on the road surface, the geometric characteristics were considered to find out the drainage problem.

In order to analyze the drainage problem, the cross slope, which is related with drainage, was measured using a road survey vehicle with several sensors such as GPS(Global Positioning System) and an INS(Inertial Navigation System) and cameras. Then the excess water causes were identified from the analysis result of cross slope. We also propose an algorithm for the road sections with actual drainage problems and suggest countermeasures regarding the relevant sections. It was found that the results may be applied to identify the drainage problems that may have been caused by the road geometry.

Keywords: *GPS, INS, Road Drainage, Road Survey Vehicle, Laser, Road Geometry*

I. INTRODUCTION

The drainage problems are related to safety as well as the highway structure on a road. Especially, because poor drainage during the winter may be related to road freezing problems, road drainage is an important factor in terms of safety. It was determined that the ponding-sections on the road surface and high traffic accident occurrence sections coincided by 75% in some highway sections and the key factors of the highway drainage problems were represented by pavement rutting, inadequate drainage facility locations and superelevation sections (Kang, 2010).

Because the drainage problems are recognized as an important factor in terms of road safety, the highway agency and road experts are performing many tasks and efforts to recognize the ponding-sections on the road surface prior to problems occurring.

Most of the ponding-sections can be identified only during rainfall, but cannot usually be done under normal conditions. The drainage problems are related to several factors including the road grade, cross slope, pavement distress and inadequate drainage facilities.

This study presented a methodology to automatically measure the cross slope using a van equipped with a GPS and INS on the actual drainage problems road section with a focus on the cross slope out of those factors, and suggested alternatives in order to provide a solution for such problems.

II. EXISTTING METHOD TO MEASURE CROSS SLOPE

In general, the highway geometric information such as horizontal, vertical and cross alignment is acquired through highway drawings. However, the highway drawings do not exist for every road and even when they are available, the drawings sometimes differ from the actual roads in the case of the cross slope due to road overlay. In this case, common methods to measure the cross slope are represented by a total station or a survey using a GPS.

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The existing measurement methods make an accurate measurement possible, whereas the surveyors move the survey equipment along the road edge, many problems may occur, in terms of safety conditions, in addition to high amounts of time and cost.

In order to solve such problems, using a GPS real time kinematic survey, Korea's Seo, et al.(2002) identified the superelevation through measuring the central line on a road and the road shoulder on both ends over a newly constructed 2km-road consisting of a circular and spiral curve. In this test, the information can be acquired while running a handcart equipped with a GPS on a new pre-opened road.

Lee, et al.(2004) identified the cross slope using 3-D digital photogrammetry. Awuah-baffour, et al.(1997) installed a cross-shaped platform on a road and then measured the cross slope and vertical slope using the GPS height gap by installing a GPS on each edge. IOWA DOT(2003) in the U.S.A. measured the grade and cross slope on a road using the information acquired through Lidar.

III. DEVELOPMENT OF ALGORITHM TO ANALYZE CROSS SLOPE

The existing cross slope-measurement methods were difficult to apply to operating road sections or required a significant amount of time in the post processing of data acquired.

So this study, in order to analyze a cross slope quickly and safely in an operating road, developed the algorithm that is able to analyze the cross slope using a van equipped with a GPS and INS and applied these results to the field.
The procedures to analyze a cross slope are as follows:

3.1 Data Collection and Choice

The data acquired from a GPS and INS is represented by the coordinate information on the vehicles (x, y and z) and the attitude information (roll, pitch and heading).

The GPS can acquire positional information such as (x, y, z) and has a high position accuracy over a long period of time and also provides uniform accuracy which is independent of time. However it has low measurement output rates. On the other hand, an INS can acquire attitude information such as the roll, pitch and yaw (heading) and has a relatively high position accuracy over a short period of time, but has accurate attitude information. However, it produces cumulative errors over time. The integration of both a GPS and an INS provides high position accuracy and attitude information.

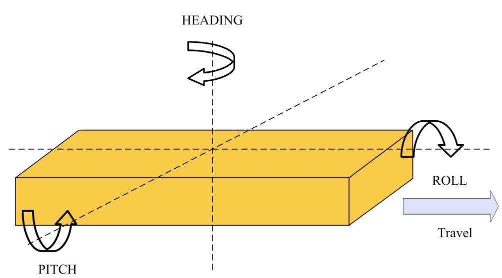

Figure 1. Attitude of Vehicle

Since a GPS/INS Integrated system can obtain the position and attitude of vehicle, it can be used to analyze the highway geometric information including the cross slope. Amongst the data acquired from the vehicle, because the Roll data was related to the cross slope, the Roll value was used to analyze the cross slope in this research.

3.2 Comparison of RST for Each Road Segmentation

While using the roll value to analyze a cross slope, the procedure of a cross slope from real-world coordinates is as follows;

(1) Data Collection and Choice
(2) Elimination of unwanted data noise from acquired data
(3) Identification of a cross slope transition section
(4) Modeling of a cross slope transition section
(5) Calculation of length of transition section
(6) Decision of normal crown section and superelevation section

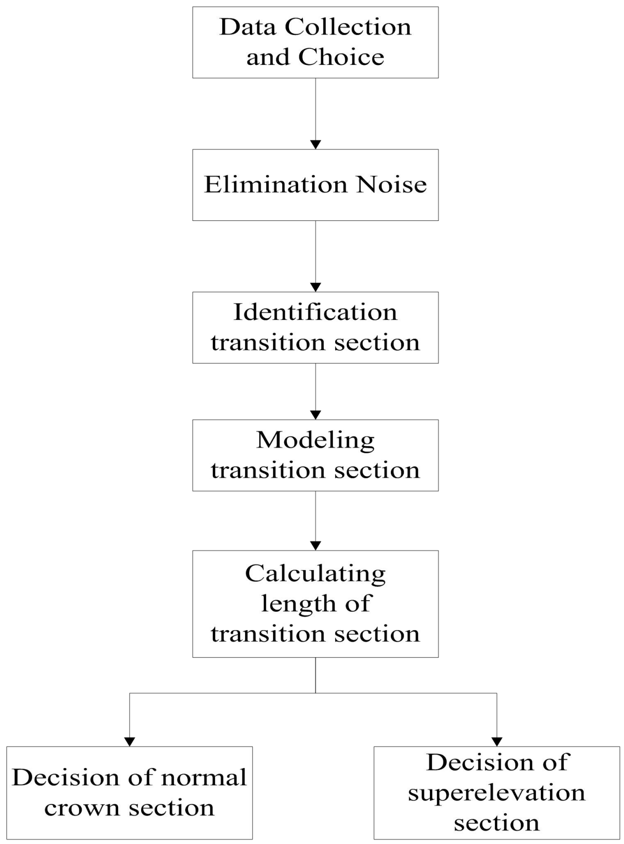

Figure 2 Flowchart of Cross Slope Analysis

3.3Eliminating Unwanted Noise from Acquired Data

The raw data from the vehicle contained data noise due to vehicle vibration. Therefore, the elimination of noise was required to ensure only valid data was used. In order to eliminate data noise, a smoothing method was used. There are several kinds of smoothing methods such as Moving average, Lowess and loess, and Savitzky-Golay filtering. Among these smoothing methods, the moving average is a well-known and simplest method, therefore in this research the moving average method was used.

The moving average formula is as follows;

$$y_s(i) = \frac{1}{(2N+1)}(y(i+N)+(y(i+N-1)+\cdots\cdots+y(i-N)) \tag{1}$$

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where,
$y_s(i)$: ith smoothed data by Moving average
2N+1: span

In deciding the span of the moving average, a weakness may occur in that the bigger the span range, the better the noise removal, but raw data distortion can occur, and the smaller the span range, the raw data distortion does not occur but the noise cannot be removed effectively. Accordingly, in order to decide the span range, applying 11, 31, 51, 71, 91 and 101 to the raw data as in Figure 3, this study compared the raw data and the slope. It could be known the biggest span value, which did not distort the slope of the raw data, was 51 as shown in Table 1. So this study used the span of moving average as 51.

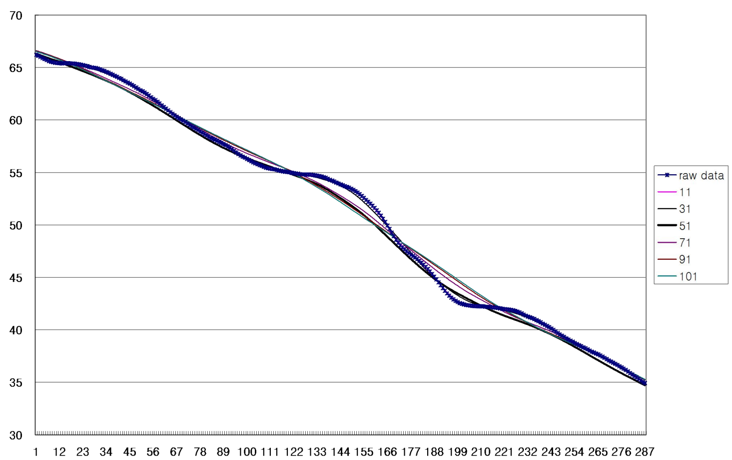


Figure 3 Application of Results of Different Spans of the Moving Average

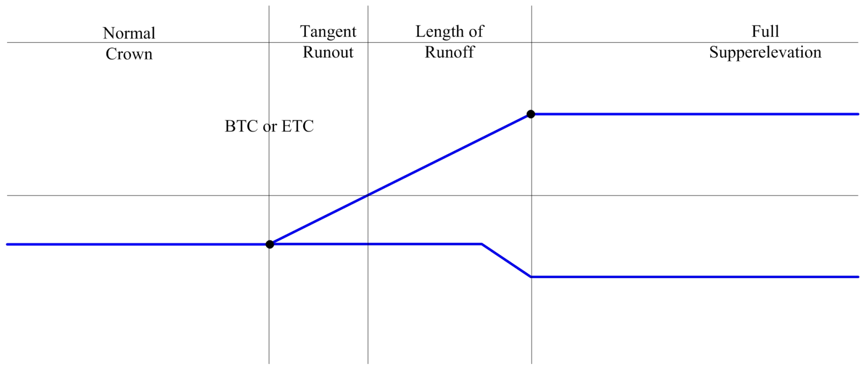
Table 1. Linear Regression Results at Each Moving Average Span Range

Spanraw data	Slope	R^2	Slope Difference with Raw Data
	-0.116	0.9866	
5	-0.116	0.9867	0.000
11	-0.116	0.9871	0.000
21	-0.116	0.9881	0.000
31	-0.116	0.9895	0.000
41	-0.116	0.9910	0.000
51	-0.116	0.9940	0.000
71	-0.115	0.9950	0.001
91	-0.115	0.9964	0.001
101	-0.115	0.9967	0.001

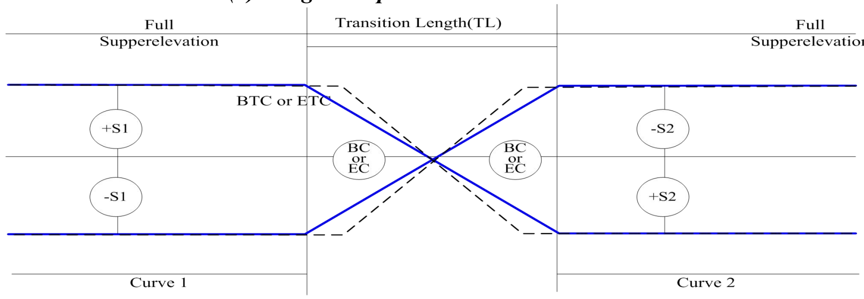
3.4 Calculating Cross Slope

The cross slope is composed of a normal crown and superelevation as shown in of Figure 4 (a) and in between exists the transition section. In general, the transition section refers to the section with a changing crown and is mostly equivalent to a spiral curve in a horizontal alignment. Figure 4 (b) represents a cross slope diagram of an S-shape curve section continued with reverse curves; the drainage problems mostly occurs in the transition section of a cross slope.

This study, in order to identify the cross slope changing section, from the constant cross slope section such as the normal crown and superelevation sections, the cross slope transition section was differentiated.



(a) Tangent - Spiral Curve - Circular Curve



(b) Circular Curve 1 - Transition Section - Circular Curve 2
Figure 4. Diagrammatic Profile of Cross slope

$$e(\%) = -\tan(Roll) \times 100\% = -\tan(\theta) \times 100\% \quad (2)$$

3.5 Identification of Cross Slope Transition Section

In order to identify the normal crown section and superelevation section, the change rate of two consecutive cross slopes were used. If the change rate is greater than 0.01%, it may be roughly considered that the cross slopes changed, or else the cross slopes did not change.

$$if \begin{cases} | e_i - e_{i+1} | \geq 0.01 : e_{ch} \\ | e_i - e_{i+1} | < 0.01 : e_{con} \end{cases} \quad (3)$$

where,

e_i, e_{i+1} : i, i+1th cross slope

e_{ch} : cross slope changing section

e_{con} : cross slope constant section

If the length of a cross slope changing section is greater than 20m, this section was considered as a cross slope transition section. Although the length is greater than 20m, if the change rate of cross slope over an entire analysis section is less than 1%, it is assumed that it is not a cross slope transition section but a simple deformation of the road surface.

The identification procedure of a cross slope transition section is as shown in Figure 5.

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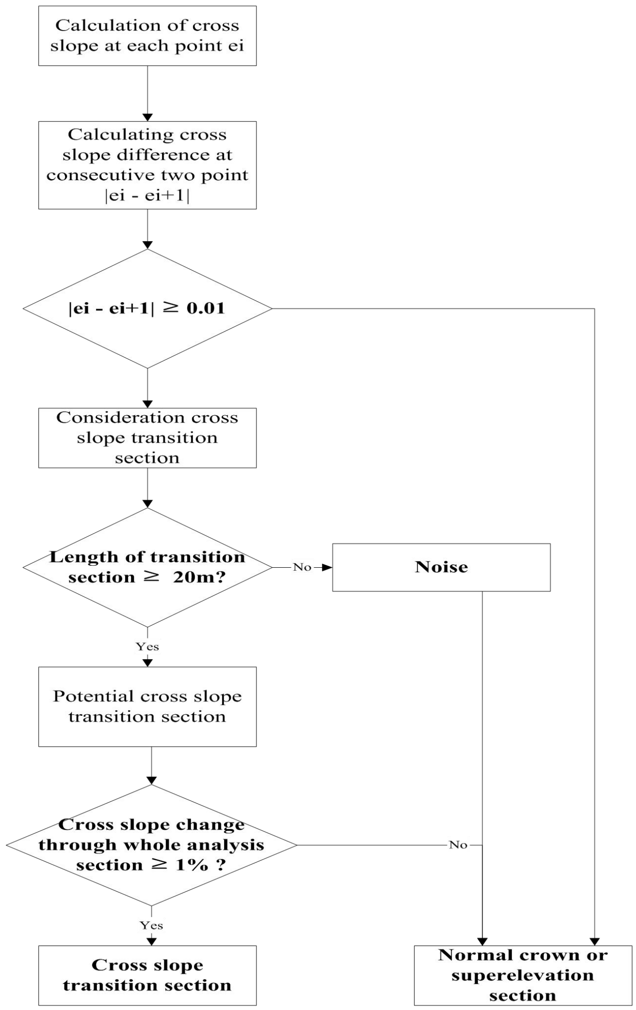

Figure 5. Procedure for identification cross slope transition section

In the previous step the approximate cross slope transition section was selected. In order to decide an accurate cross slope transition section, mathematical models were used. A normal crown section can be expressed and cross slope transition section can be modeled by a linear function as shown in Figure 6.
In Figure 6, the equation and parameters are as follows;

$$e_{NC} = a(\%) \tag{4}$$

$$e_{SE} = b(\%) \tag{5}$$

$$e_{TL} = \alpha x + \beta \tag{6}$$

where,

e_{NC} : Normal Crown,

e_{SE} : Superelevation

e_{TL} : Equation of cross slope transition section

α, β : Parameter of equation,

x : Distance from beginning point

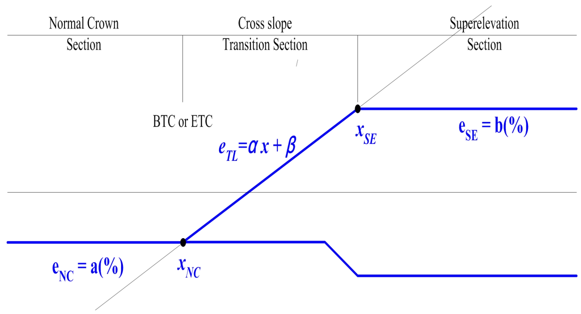

Figure 6. Decision of cross slope transition section

The x_{NC}, x_{SE} is the accurate beginning and ending point of a transition section and can be acquired by calculating the intersection points of Equation (4), (5) and (6). Equation (7) and (8) show the beginning and ending point of a transition section.

$$x_{NC} = \frac{a-\beta}{\alpha} \qquad (7)$$

$$x_{SE} = \frac{b-\beta}{\alpha} \qquad (8)$$

IV. APPLYING THE DEVELOPED ALGORITHM TO THE FIELD

4.1 Overview of the Field Application

The algorithm was evaluated by analyzing the cross slope analysis in this study. There exists a design drawing regarding the targeted section however, in order to identify an accurate cross slope due to pavement deformation on a road; the analyzed cross slope was compared through the drawing and this study using a laser scanner.Composing the information acquired in the laser scanner at the right angle to road lateral at 10m-interval, the cross slope was identified using the group of points, called point-clouds, included in each section.

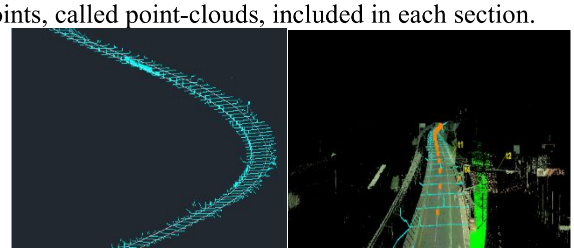

Figure 7. Figure addressed in the form of DXF after acquiring the section at every 10 m

In this study, it is assumed that the cross slope information from the laser scanner is more accurate than the drawings. Therefore the cross slope results from the laser scanner are regarded as a true cross slope value. The analysis results of the differences amongst the cross slope, laser scanner, drawing and INS in each measurement method are as shown in the following Table 2.

The root mean square error (RMSE) with the laser scanner in the algorithm developed in this study showed 0.373, so it was known well that it reflected the cross slope on an actual road.

Table 2. Difference Between Cross Slope by Measurement Method and Laser Scanner

no.	Measured Result			Difference with Laser Scanner	
	Laser Data	drawing data	INS data	Laser-Drawing	Laser-INS
1	-4.94	-4.59	-4.68	0.354	0.260
5	-2.07	-2.00	-1.31	0.067	0.760
9	-1.69	-2.00	-1.44	0.309	0.255
13	0.00	0.00	0.71	0.000	0.715
17	1.70	2.00	2.53	0.297	0.824
21	3.11	3.33	3.56	0.218	0.449
25	3.91	4.00	4.11	0.087	0.199
29	4.09	4.00	4.06	0.093	0.028
33	3.93	4.00	4.09	0.073	0.167
37	4.05	4.00	4.32	0.047	0.270
41	4.01	4.00	4.05	0.014	0.033
45	3.80	4.00	3.98	0.202	0.183
49	4.07	4.00	4.66	0.065	0.594
53	3.88	4.00	4.49	0.118	0.610
57	4.08	4.00	4.88	0.075	0.802
61	2.69	2.50	2.86	0.187	0.170
65	1.00	0.50	1.46	0.495	0.467
69	-0.97	-1.50	-0.56	0.527	0.412
73	-3.12	-3.50	-2.85	0.378	0.268
77	-4.55	-5.00	-4.30	0.453	0.243
81	-4.60	-5.00	-4.44	0.404	0.161
85	-4.52	-5.00	-4.19	0.484	0.327
RMSE				0.225	0.373

This study has discussed the accuracy and the reasons that cause errors in the GPS/INS integrated system; the method to measure the superelevation on the road which was constructed quickly and safely and is now under use. In other words, it was analyzed the accuracy of the measurement method using GPS-INS through comparing to superelevation acquired through the existing measurement method after acquiring data through operation of the van equipped with GPS/INS run on the curved sections of a general road.

V. ANALYSIS PROCEDURE

5.1 Overview on Analyzed Sections

This study identified the drainage problem sections produced by the cross slope on a road out of various drainage problems and then focused on the arrangement of improvements regarding the results.Accordingly, using a van equipped with GPS/INS, this study analyzed the cross slope over 8 sections having real drainage problems out of about a 38km section between 150.68 and 188.69km, based on the starting point of the No. 50 Expressway in Korea. The analyzed highway section was located in a mountainous area; a two-way four-lane road with a design speed of 100km/h. The sections with drainage problems have vertical grade and a continuous plane curve. Most of those sections were represented by a cross slope transition section (TL) as in Figure 4 (b), as spiral curve sections. Then this study, in order to solve the drainage problems, analyzed the adequacy of length on the cross slope transition section and presented the improvement methods.

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Table 3. Information on Drainage Problem Sections

no.	Distance from starting point (km)	Grade (%)	cross slope(%)-measured		Transition Length
			max	min	
1	Sta. 150.68~150.55	-5.0%	5.17	-1.47	120
2	Sta. 166.65~166.51	-3.7%	4.3	-1.98	140
3	Sta. 166.26~166.16	-3.0%	2.28	-2	100
4	Sta. 165.99~165.79	-2.0%	2	-2	200
5	Sta. 165.21~165.10	-5.0%	2.3	2	110
6	Sta. 173.48~173.24	+4.0%	4	-2.27	240
7	Sta. 189.33~189.22	-1.2%	2.19	-2.14	110
8	Sta. 188.88~188.69	-2.5%	2.69	-1.94	190

5.2Review on Superelevation Rate

The cross slope transition section is considered along with the spiral curve and the cross slope is required to be installed on the entire section across the spiral curve. That is, the length of the spiral curve is designed over the length to completely change the cross slope.

TL, the length of spiral curve section in Figure 4 (b), can be calculated through Equation (9).

$$Ls = \frac{B\Delta i}{q} \quad (9)$$

Where,
Ls : length of spiral(m)
B : length of tangent runout(m)
Δi : normal cross slope rate(%)
q : design superelevation rate(%)
In general, each nation's superelevation rates are as shown in Table 4.

Table 4. Design Superelevation Rate (%)

Country \ Design Speed(km/h)	120	110	100	90	80
KOREA	1/200	1/185	1/175	1/160	1/150
AASHTO (USA)	1/250	1/238	1/222	1/210	1/200
JAPAN	1/200	-	1/175	-	1/150

This shows the value to consider the comfort of a drive; if the superelevation rate is large, the vertical angular velocity is bigger, so the driving comfort would worsen. On the other hand, if the superelevation rate is large, or the cross slope change is small across the long section, drainage problems may occur. So the minimum superelevation rate in Korea is limited to 1/250 in consideration of the drainage.

5.3Comparison between Minimum and Maximum Cross Slope Transition Section

Given the drive comfort, the maximum superelevation rate should be defined and TL as in Figure 8 and should be over the minimum length. Meanwhile, given the drainage factors, the minimum superelevation rate should be defined and the maximum length of TL as in Figure 8 is limited.

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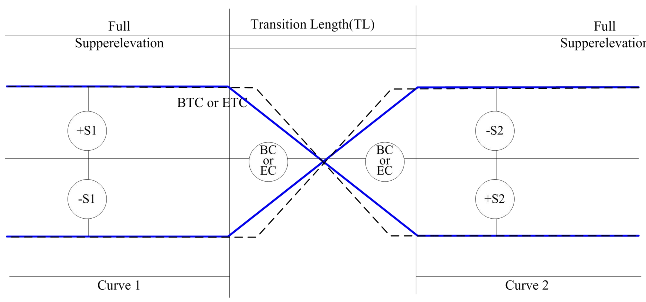

Figure 8. Diagrammatic Profile of Cross slope for S-Shape Curve Section

TL should be located between TL Min in consideration of driving comfort and TL Max in consideration of drainage.

$$if\begin{cases} TL\_\min \ \leq\leq TL \leq T\_\max & : \text{Adequacy} \\ TL\_\max \ \leq\leq TL & : \text{Poor drainage} \\ TL \leq L \leq \ \min & : \text{Poor drive comfortability} \end{cases} \quad (9)$$

Where,
TL : cross slope transition section length
TL_min : Minimum TL in consideration of driving comfort (superelevation rate : 1/175 design speed when 100km/h)
TL_max : Maximum TL in consideration of drainage (superelevation rate : 1/250)

That is, if TL is over the TL Max, it can be considered to have drainage problems.

5.4Analysis Results on Cross Slope Transition Section and Preparation of Improvement

The maximum and minimum cross slope transition sections were calculated for each section and the real cross slope transition sections were analyzed through a van equipped with a GPS/INS. The results are as shown in Table 5.

Table 5. Analysis Results on Cross Slope Transition Sections

no.	Distance from starting point (km)	TL_min (m)	TL_max (m)	Length of spiral curve (m) (Acquired from drawing)	Length of Cross slope transition section (m) (measured from vehicle)
1	Sta. 150.67 ~150.55	95m	136m	125m	120m
2	Sta. 166.65 ~166.51	90m	129m	122m	140m
3	Sta. 166.26 ~166.16	61m	88m	122m	100m
4	Sta. 165.99 ~165.79	57m	82m	185m	200m
5	Sta. 165.21 ~165.10	62m	88m	182m	110m
6	Sta. 173.48 ~173.24	90m	129m	192m	240m
7	Sta. 189.33 ~189.22	62m	89m	175m	110m
8	Sta. 188.88 ~188.69	66m	95m	220m	190m

As an analysis result, it can be known that the TL in 3 - 8 sections was larger than the TL Max considering drainage. The spiral curve lengthens in the combination of a circular curve and spiral curve, the superelevation rate lowers and then the surface drainage in low slope sections is not efficient, so the superelevation rate should be raised in these sections. That is, it is necessary to shorten the TL.

In the case of analyzed sections, the rotation axis of a cross slope is a two-lane road from the center line, and when applying the normal cross slope of 2.0%, the spiral curve length comes out 80cm more as in Table 6, so it is recommended to reduce it by 80cm.

Table 6. Improvement of Cross Slope Transition Section

no	Distance from starting point (km)	Existing TL (measured)	Adjusted TL (m)
3	Sta. 166.26~166.16	100m	Sta. 166.26~166.18
4	Sta. 165.99~165.79	200m	Sta. 165.99~165.87
5	Sta. 165.21~165.10	110m	Sta. 165.13~165.10
6	Sta. 173.48~173.24	240m	Sta. 173.48~173.32
7	Sta. 189.33~189.22	110m	Sta. 189.33~189.30
8	Sta. 188.88~188.69	190m	Sta. 188.80~188.69

Table 7. Spiral Curve Length by Normal Crown with Lanes

	Normal Crwon 1.5%	Normal Crwon 2.0%
2-lane	60m	80m
3-lane	75m	100m
4-lane	90m	120m

On the other hand, the No. 1 and 2 sections are placed on TL_min ≤ TL ≤ TL_max in TL; so it met the drainage conditions. These sections need to consider pavement deformation or drainage facility problems rather than the cross slope. Then, it is found that to reduce the TL close to a cross slope transition section is also helpful to solve drainage problems.

In case the TL would be reduced to minimum, the cross slope changes quickly in an S-shape curve section, so a sharp inflection point may be produced. In order to solve these problems, it is needed to secure efficient surface conditions through circularly handling the edge parts of such inflection points.

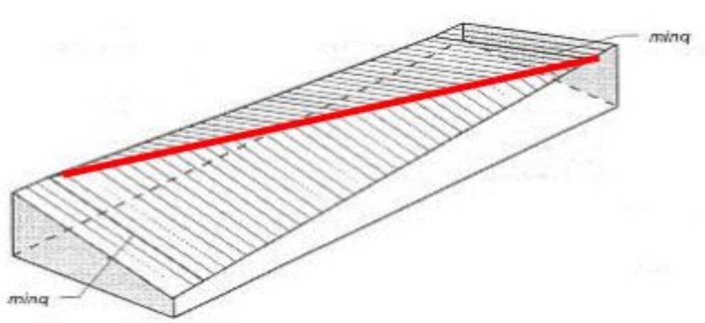

Figure 9. Treatment of cross slope in inflection points (RAS, 1996)

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VI. CONCLUSION AND FURTHER STUDY

This study attempted to identify drainage problems caused by a cross slope, road geometry factors regarding drainage problems, including pavement, drainage facilities and road geometry.

Also, in order to quickly measure the cross slope without any traffic disturbances to grasp the drainage problems caused an inadequate cross slope, this study developed an algorithm to analyze the cross slope using a van equipped with a GPS/INS.

Thereafter, operating the vehicles on a real road with drainage problems using the developed algorithm, this study grasped the sections where the cross slope transition section was installed inadequately to the curved sections.
It was found that most of the drainage problem sections occurred when the cross slope was near 0% on a transition section between the circular curves of an S-shape curve and it was therefore recommended to solve the drainage problems through securing the section length with a low cross slope, as the minimum cross slope transition section to secure the driving comfort.

This study analyzed only the effect of a cross slope out of various drainage factors, but if it were to consider the crossslope along with pavement conditions and the vertical slope, it was determined that it could identify more accurate problems and present improvement methods.

In conclusion, the road surface condition is important of vehicle maneuver. In the era of automated vehicle, the information of road condition should be provided to the vehicle for safe behavior. Therefore in this research, the hazardous road segmentation was identified caused by cross slope for autonomous vehicle and it will be applied for the cooperated autonomous vehicle.

VII. ACKNOWLEDGEMENTS

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