Influence of Anti-freezing layer on the Frost Penetration Depth for Paved Road Design

Influence d'une couche anti-gel sur la profondeur de pénétration du gel dans la conception des chaussées

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ABSTRACT : Design of pavement in seasonal freezing areas should consider the environmental conditions in case of design and construction for pavement thickness. There are a lot of conditions of climate, soil, and material among the environmental conditions. One of that is caused from effect of these conditions is frost heaving. The frost penetration depth of paved road in Korea is usually estimated from the freezing index that made temperature data analysis of 30 years period and decided the thickness of anti-frost layer. It may be caused of over-design for pavement design with using the current estimation method of the frost penetration depth. Therefore, this study analyzed the depth of frost penetration for pavement design and the depth of frost penetration of paved road using field monitoring data. This paper presents the field monitoring results of frost penetration depth with anti-freezing layer and without anti-freezing layer. The analysis on the influence of anti-freezing layer to the pavement road was presented for the region of South Korea.

RÉSUMÉ : La conception des chaussées dans les régions connaissant des périodes de gel doit tenir compte des conditions environnementales. Parmi les conditions environnementales, nombreuses sont celles relatives au climat, au sol et aux matériaux. Mais l'une d'entre elles est causée par l'impact de toutes ces conditions, c'est le déchaussement. En Corée du Sud, la profondeur de pénétration du gel d'une route goudronnée est généralement évaluée à partir de son indice de gel. Celui-ci repose sur une analyse de données de température sur une période de 30 ans, et sa valeur détermine l'épaisseur de la couche anti-gel. La méthode de calcul actuelle de la profondeur de pénétration du gel peut néanmoins provoquer une exagération de la profondeur des chaussées. Cette étude analyse le phénomène à l'aide de données de surveillance obtenues sur le terrain. L'article présente également les résultats de la surveillance sur terrain de la profondeur de pénétration du gel sur des routes ayant une couche d'anti-gel et sur des routes n'en ayant pas. Les résultats de l'analyse de l'action de la couche d'anti-gel sur une route correspondent au cas de la Corée du Sud.

KEYWORDS : Field Frost Penetration Depth, Frost Index, Frost Penetration Map, Pavement, Air Temperature

1 INTRODUCTION

Desing of pavement in seasonal freezing areas should consider the environmental conditions including climate, soil, and moisture content of soil. One of that is caused from effect of these conditions is frost heaving. Jiang and Tayabji(1999) studied on the influence of in-situ moisture content on the seasonal monitoring site. Tomasz(2009), Wu, Zang and Liu(2010) evaluated the factors influenced on the freezing point in the soil water system and long-term thermal effect of the asphalt pavement.

The frost penetration depth of paved road in Korea is usually estimated from the freezing index that made temperature data analysis of 30 years period and decided the thickness of anti-frost layer. It may be caused of over-design for pavement design with using the current estimation method of the frost penetration depth. Therefore, this study analyzed the depth of frost penetration for pavement design and the depth of frost penetration of paved road using field monitoring data.

2 FIELD MONITORING SYSTEM

2.1 Measuring instruments and their position

Field monitoring system is a system that measures field environmental parameters such as moisture and temperature. Purpose of field monitoring system is to measure the moisture content and temperature of the pavement automatically, continuously and objectively. Sensors of field monitoring system are shown in Fig. 1. Temperature sensors measure the internal temperature of the pavement and moisture sensors measure the moisture content of the roadbed.

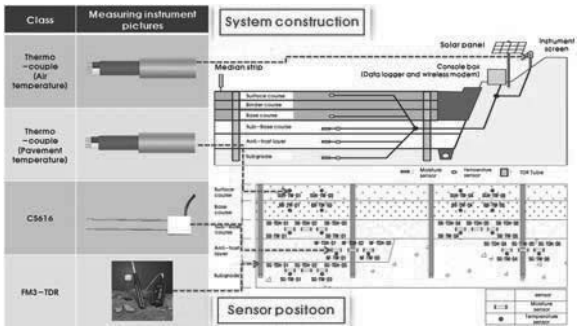


Figure 1. Field monitoring system and sensors

2.2 Field monitoring region

The field monitoring region is divided into three regions by freezing index 550~650°C·day, 450~550°C · day, and 350~450°C · day. Each region has three-section of road pavement such as cutting area, boundary area of cutting and banking, and lower area of banking. A total 25 sections for three regions (9 section in cutting area, 9 section in boundary area of cutting and banking, and 7 section in lower area of banking) were constructed as tabulated in Table 1.

Table. 1. Field monitoring system section

Freezing index (℃·day)		Cutting section	Boundary section	Banking section
550 - 650	No. 1	1	1	1
	No. 2	1	1	1
	No. 3	1	1	1
450 – 550	No. 4	1	1	1
	No. 5	1	1	-
	No. 6	1	1	1
	No. 7	1	1	1
350 – 450	No. 8	1	1	-
	No. 9	1	1	1
	No. 10	1	1	1
200 – 350	No. 11	1	1	1
	No. 12	1	1	-
	No. 13	1	1	1
Below 200	No. 14	1	1	-
	No. 15	1	1	1
Total		15	15	11

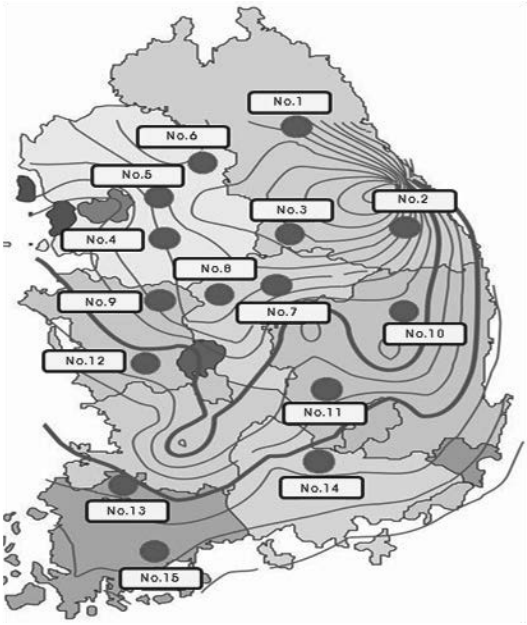


Figure 2. Field monitoring region

2.3 *Process of Field monitoring system construction*

The placement of measurement sensors accompanies the calibration of sensors before the placement. To construct a field measurement system as shown in Fig. 3, the measurement sensors were laid at the center of each layer. After the placement is completed and then installed modem, battery, solar panel and data logger, consecutively, to collect data through wireless communication in console box. Fig. 4 shows the view of the installation of automatic mea

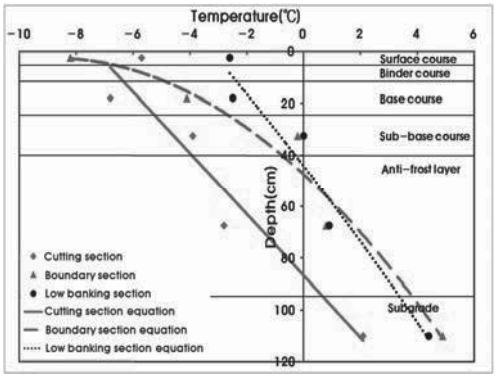
Figure 3. Placement of measuring instrument on the compacted roadbed materials

Figure 4. Construction of field automatic monitoring system

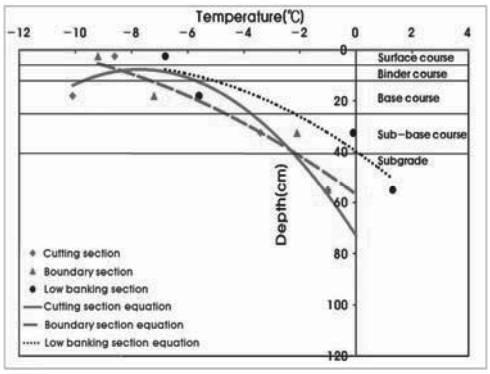
3 FROST PENETRATION DEPTH OF PAVED ROAD WITH FIELD MONITORING DATA

3.1 *Analysis of frost penetration depth for the region with freezing index 550~650 ·day*

The analytical study of temperature distribution along the paved road profile was carried out by using the measured lowest daily temperature in the field. Figure 5 shows the temperature variations and correlation for pavement section for three areas with anti-frost layer existence and non-existence.



(a) Existence of anti-frost layer



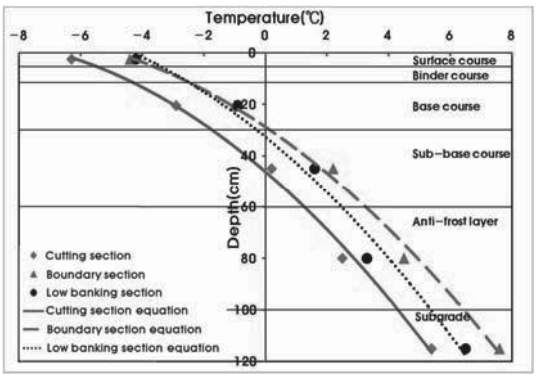
(b) Non-existence of anti-frost layer

Figure 5. Frost penetration depth of No.1 region

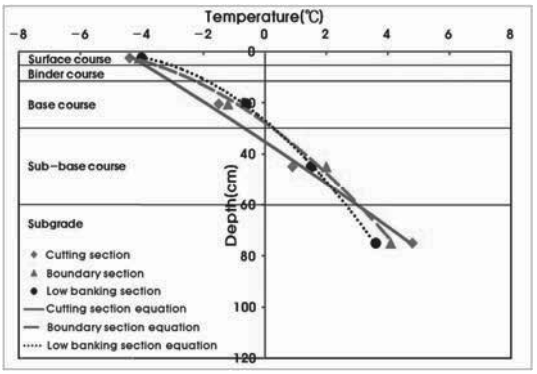
3.2 *Analysis of frost penetration depth for the region with freezing index 450~550 ℃day*

The analytical study of temperature distribution along the paved road profile was carried out by using the measured lowest daily temperature in the field. Figure 6 shows the temperature variations and correlation for pavement section of three areas with anti-frost layer existence and non-existence. The temperatures of No.4 or No.5 cases went down below 0℃ to subbase course and base course regardless of anti-frost payer

existence or non-existence, and temperature of subgrade of No. 6 case went down below 0℃ in non-existence of anti-frost layer.



(a) Existence of anti-frost layer

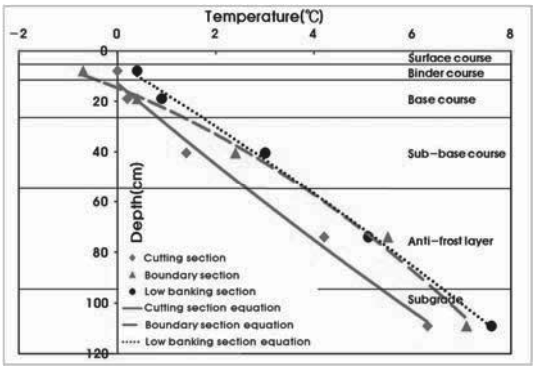


(b) Non-existence of anti-frost layer

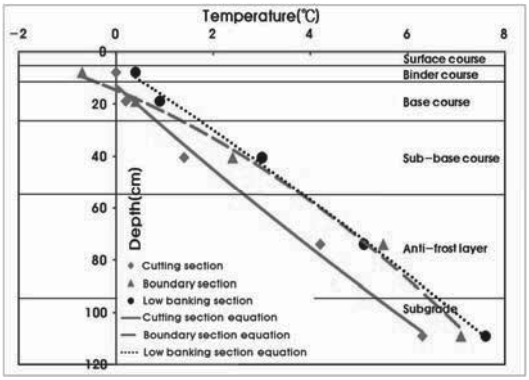
Figure 6. Frost penetration depth of No.4 region

3.3 Analysis of frost penetration depth for the region with freezing index 350~450 ℃·day

The temperatures at No.7, No.8 and No. 9 regions went down below 0℃ to subbase course and base course regardless of anti-frost payer existence or non-existence.



(a) Existence of anti-frost layer



(b) Non-existence of anti-frost layer

Figure 7. Frost penetration depth of No.9 region

3.4 Analysis of frost penetration depth according to regional

In this study, analysis of temperature distribution along the paved road profile was carried out with the measured the lowest daily temperature. Table 2 describes the frost penetration depth of cutting section with anti-frost layer for three years.

Table 2. Estimation results of frost penetration depth for three years

Region \ Year	2009~2010 (cm)	2010~2011 (cm)	2011~2012 (cm)
No. 1	110	More than 110	70
No. 2	120	More than 130	More than 130
No. 3	92	100	100
No. 4	80	80	50
No. 5	55	55	40
No. 6	103	More than 120	120
No. 7	28	50	22
No. 8	60	More than 60	45
No. 9	40	50	10
No. 10	70	50	50
No. 11	40	50	36
No. 12	17	17	17
No. 13	10	18	10
No. 14	18	37	29
No. 15	50	70	52

4 COMPARISON OF FROST PENETRATION DEPTH OF FIELD RESULTS WITH EXISTING THEORY

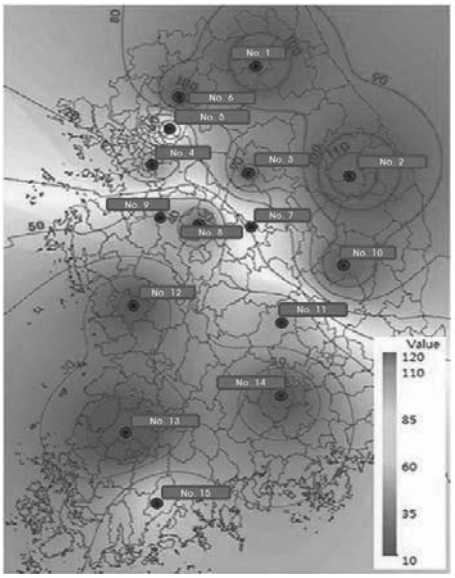
The empirical equations developed by the Korea Institute of Construction Technology (KICT) and Japan Road Association (JRA) were used to determine the frost penetration depth. The results of frost penetration depth measured in the field and estimated by the empirical equations are tabulated in Table 3. Generally the frost penetration depths determined by the empirical equations are greater than those of field measurement with the exception of No.1, No.2 and No.3 sites. In particular, the results calculated by the Japan Road Association show no significant differences among the regional category of frost index.

Table 3. Results of comparison for frost penetration depth

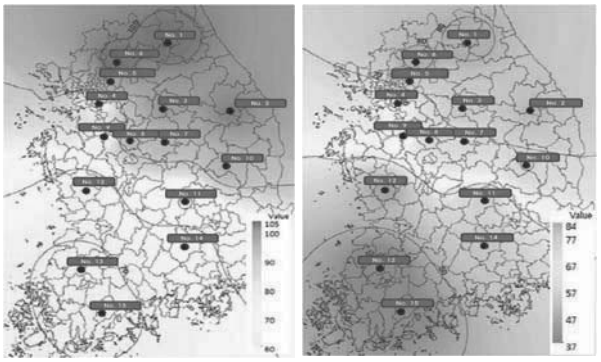
Region \ Research institute	Field data (cm)	U.S. Army Corps of Engineers (cm)	KICT (cm)	JRA (cm)
No. 1	110	95	105	85
No. 2	120	115	99	78
No. 3	92	110	96	74
No. 4	80	110	84	60
No. 5	55	104	94	72
No. 6	103	107	105	85
No. 7	28	90	92	69
No. 8	60	97	92	69
No. 9	40	94	84	61
No. 10	65	80	93	70
No. 11	60	70	80	56
No. 12	17	80	73	49
No. 13	10	71	61	38
No. 14	18	70	78	54
No. 15	50	67	54	40

5 MAPS OF FROST PENETRATION DEPTH WITH UING FIELD AND EMPIRICAL RESULTS

The maps of frost penetration depth were made based on 15 field monitoring datum using ArcGIS program. Interpolation method was adopted to make frost penetration maps with IDW (Inverse Distance Weighting). IDW is one of the most commonly used interpolation techniques. Fig. 8 shows the maps of the frost penetration depth made by using ArcGIS. Frost penetration depths by the field measurements show significantly different. However, the frost penetration depths using the empirical equation of KICT show a similar trend in lower frost index. In particular, the results by the empirical equation of JRA show no significant differences among the regional category of the frost index.



(a) Field measurements



(b) KICT (c) JRA

Figure 8. Maps of the frost penetration depth by field measurement and empirical equations

6 CONCLUSION

The frost penetration depth of paved road was determined by the field measurement. The moisture content and temperature are measured and stored the data through solar panel data transmission system and manual system, respectively. The results of field monitoring for determination of frost penetration depth are summarized as below.

(1) The paved road constructed with inclusion of anti-frost layer, the temperature at subgrade for five field regions does not go down below 0℃ with the exception of site No.1, No.2 and No.6. However, without inclusion of anti-frost layer, the temperature at subgrade with the region which has the frost index 550-650℃·day goes down below 0℃.

(2) The subbase and base courses are influenced by the temperature below 0℃ regardless of anti-frost layer is existed or not for all of the freezing index categories.

(3) Frost penetration depth of field shows significant difference by the regional frost index. However, the frost penetration depth estimated by the empirical equation proposed by KICT shows a similar trend in lower frost index. In particular, the results calculated by the JRA empirical equation show no significant differences among the regional category of frost index.

(4) Based on the analysis of field frost penetration depth measurement, the reasonable design concept can be available for road design.

7 ACKNOWLEDGEMENTS

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