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A Study on the Effect of Freezing and Thawing Repetition on the Tunnel in Cold Region

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ABSTRACT

Cold region is exposed to poor freezing conditions such as average number of snow days and freezing days, because of its geographical and climatic characteristics. It causes many problems in maintenance of the lining and road surface due to freezing and thawing. In particular, in the case of Gangwon area where are mountainous, construction of tunnels for local development is inevitable. The number of tunnels requiring maintenance due to freezing damage is continuously increasing. Therefore, it is essential to develop a method for reducing the freezing damage of road tunnel entrance and exit in cold regions such as Gangwon area. In order to secure the quality and performance of the new method and to improve the understanding of practitioners, it is necessary to establish maintenance measures that must be followed for the continuous condition and performance management of the method.

1. INTRODUCTION

In this study, the preliminary indices are selected considering the characteristics of the materials used in the new method and the environmental factors. The Delphi questionnaire was conducted twice for experts in the field of tunnels, and the construction and maintenance indexes were derived. Its indexes that are selected are intended to develop construction and maintenance guidelines and to develop safety maintenance and reinforcement processes that take into consideration the environmental characteristics of cold regions.

2. STATUS OF TUNNEL FREEZING DAMAGE IN KOREA

According to a domestic tunnel freezing case study related to freezing-thawing of cold zones (Kim, 2013), for the area like Daegwallyeong (Gangwon), it was generally

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observed the phenomenon where drain pipes had frozen if daily mean temperature remains below about -7°C for 2~3 days, and it was reported that the phenomenon, where icicles melt down, occurs repeatedly if ambient air becomes above 0°C after icicles form by ascending from the sidewall floor of construction joints to the ceiling in particular. And the calculation temperature referred to the freezing-thawing test standard of Ireland (freezing: two days or more at -7°C, thawing: three days or more at 6°C). In order to calculate the freezing damage environment standard, the evaluation method referred to the performance-focused evaluation manual by facility type (2016) to analyze the effects of freezing-thawing based on the Korea Meteorological Administration's data of Gangwon (Wonju, Daegwallyeong), Seoul, Busan and Gwangju areas in winter season (November 1 ~ March 31) over the past 40 years.

Table 1 The grading system of freeze-thaw cycle(F)

Grade	Freeze-thaw cycle(F)	Explanation
A	F < 3	Best condition without freeze-thawing
B	3 ≤ F < 15	No significant impact but exiting minor influence on auxiliary member due to freezing-thawing
C	15 ≤ F < 30	Simple maintenance and reinforcement are necessary because of prevention for durability degradation with freeze-thawing
D	30 ≤ F < 50	Need to repair and reinforcement of urgent heat insulation degradation with freeze-thawing
E	50 ≤ F	Need to do maintenance techniques such as heat etc.for tunnel with freeze-thawing

As a result of analyzing with the number of freezing-thawing repeated days as the following Table 1, Gangwon area was a D region, which was classified into a region where had the greatest number of freezing-thawing repeated days (F) compared to Seoul, Busan and Gwangju areas.

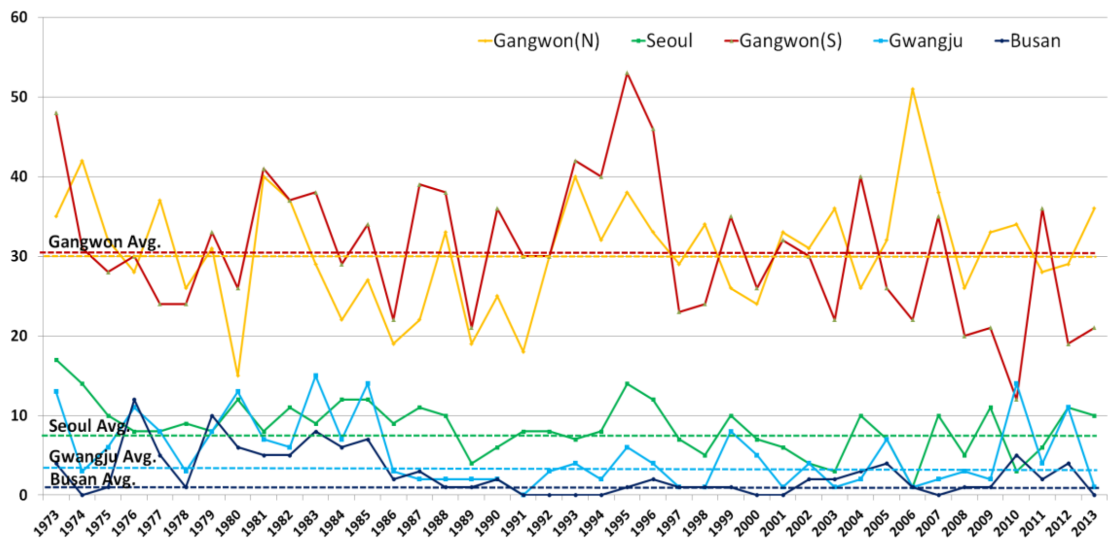

Fig 1 Comparison of freeze-thaw cycle(F) for 40 years with regions in S.KOREA

In other words, as Fig. 1 of the result that calculated the number of freezing-thawing repeated days (F) to plot, the number of freezing-thawing repeated days (F) in Gangwon area was calculated more than about 2~3 times compared to other areas in Korea. And the class was mostly C~E, which should be classified into cold tunnels rather than general tunnels, and it is judged that repair and reinforcement for improving tunnel durability should also prepare a maintenance system considering cold area's environmental characteristics corresponding to regional environment characteristics.

In fact, the report on precision safety diagnosis of road tunnel located in Gangwon area of S. Korea shows that the most defects occur around the entrance and exit. It is considered that the deterioration of the tunnel lining has progressed rapidly due to the influx of outside air. In applying the new method, it is necessary to designate an appropriate range for the entrance and exit sections.

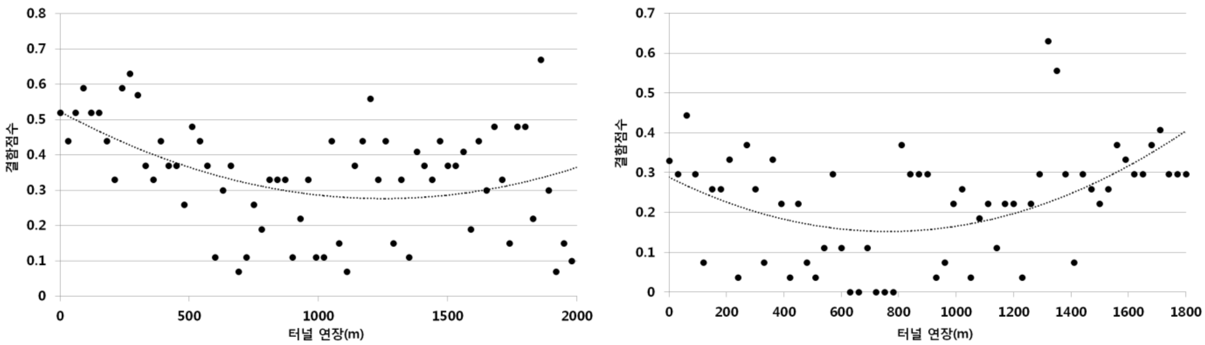

Fig 2 Defect distribution by tunnel extension

As a technology applied to the lining and road surface of the entrance and exit sections, the technology under development for reducing freezing damage of road tunnel is divided into lining insulation improvement technology, lining leakage prevention technology and road surface freezing prevention technology.

Tunnel lining is a structure that plays a very important role in securing the safety of users and should not be damaged by the application of technology, and should be a technology that enables visual inspection in safety diagnosis. Therefore, we developed a technology that can suppress the groundwater freezing by using the lining back surface using the adiabatic paint. Also, to prevent lining leakage, the existing leakage prevention technology was supplemented to improve performance maintenance period and redesigned to facilitate induction drainage in cold regions. In order to prevent the adverse effects caused by the use of snow removers such as calcium chloride, road surface freezing prevention technology has inserted carbon nanotubes, which are heating elements, on the road surface to prevent freezing of roads due to heavy snowfall and leakage.

Considering the material characteristics of the freezing damage reduction technology and the environmental characteristics, we want to develop the construction and the maintenance guideline to be implemented by the construction worker and the manager to maintain its performance continuously. Therefore, the Delphi questionnaire was conducted for experts in the tunnel field, and appropriate construction indicators and maintenance indexes were derived.

3. RESEARCH MATHOD

Delphi survey was utilized to derive indices of construction and maintenance for each tunnel freezing damage reduction technology. Delphi survey has an advantage in that different opinions derives an agreement as the number of times being surveyed is repeated by carrying out repetitive surveys for the same panel and sharing the result derived from respective panels.

This study carried out twice Delphi surveys to derive an agreement of the panel composed of experts in tunnel field. In order to utilize Delphi survey, a preliminary evaluation index was derived through the existing precedent studies and literature search, and the first Delphi survey with a mixture of open and closed types was carried out to collect various opinions of experts.

The second Delphi surveys analyzed the expert group's opinions about the importance between respective performance indexes through closed type questions to derive the final performance evaluation index. For a Delphi survey, expertise and sincerity etc. were considered to organize an expert panel. In order to maximize the reliability of Delphi analysis, the number of panel should be 10 or more at least (Ewing, 1992), and a panel of just only 10~15 persons could obtain useful results (Ziglio, 1996).

The first Delphi questionnaire was prepared with a mixture of open and closed types. The open-type questions tried to collect additional opinions of experts for the evaluation index, and the closed-type questions were organized to assess whether the evaluation index derived from the literature data review corresponded to the index for performance evaluation. The expert opinions by the first Delphi survey were organized as closed types when preparing the second to carry out the surveys.

Table 2 Minimum CVR by Respnders

Respondent	CVR	Respondent	CVR
10	0.62	20	0.42
11	0.59	25	0.37
12	0.56	30	0.33
13	0.54	35	0.31
14	0.51	40	0.29
15	0.49	-	-

The expert opinions of the closed type questionnaire were reflected to select the first performance evaluation index and verify the content validity for reflecting in the second Delphi survey.

The content validity is verified by using the content validity ratio (CVR). A CVR value suggests the minimum value according to the number of panels, and it is determined that there is content validity on experts' opinions when it becomes above the minimum value. The content validity is calculated by the following equation (1) (Lawshe, 1975).

$$CVR = \frac{n_e - \frac{N}{2}}{\frac{N}{2}} \tag{1}$$

where, $n_e$is the number of panels who responded as valid, and Nmeans the number of the entire Delphi panels participating in the study. If the number of panels who responded as an evaluation index being valid for performance evaluation is 100%, 50% and less than 50%, the CVR value is represented as 1.0, 0 and a negative number, respectively.

In other words, if the number of panels who responded as valid is 50~100%, the CVR value is located on 0~1.0, and such a CVR value could determine the minimum value as Table 2 according to the number of panels with the data presented by Schipper (Lawshe, 1975). Average, standard deviation, median, mode and CVR values were calculated for the second Delphi analysis, and the agreement was evaluated to assess the items' validity and whether the panel's opinions converge or not. The agreement is a method that verifies how much agreement is reached between respondents by using quartile deviation and median to schematize a value between Q3 and Q1, and it is said that the ratio of inter-quartile range and median is 0.3 if the agreement is 0.7, which means that the interval of intermediate 50% respondents exists in the range of 0.3×median around the median.

If the agreement of A is 0.9, it means intermediate 50% respondents exist in the range of 0.1×median, which could be determined that 0.9 has responses of the people surveyed being more agreed than 0.7. The agreement is calculated by the following equation (2) (Kim, 2015).

$$1-\frac{Q_3-Q_1}{M_d} \tag{2}$$

where, Q3, Q1 and Md are 3/4 fractile, 1/4 fractile and median, respectively. Interquartile (IQR) is calculated by equation (3) which is a measure representing the deviation of panel responses around the median, and it is generally considered that agreement is reached if it is 1.0 or less (Upton, 1996).

$$IQR = Q_3 - Q_1 \tag{3}$$

The results of the second Delphi survey were analyzed and the construction and maintenance indices of each freeze damage reduction technology were derived. Each of the indicators derived from the Delphi survey was categorized according to the type and characteristics.

4. DERIVING THE CONSTRUCTION AND MAINTENANCE INDEX

In order to derive the preliminary indices for the construction and maintenance of the freezing damage reduction technology, we reviewed the construction standard and the maintenance items related to the cold region by literature studies. We examined the requirements to develop the required performance considering the material characteristics of the development technology and the environmental characteristics of the cold region. A total of 49 preliminary indicators were derived by analyzing domestic and foreign literature data and expert consultation. The freeze damage mitigation technology is classified as lining insulation improvement technology, lining leakage prevention technology and road surface freezing prevention technology, and among them, the leakage prevention technology has the largest number of indicators to be taken into consideration when constructing. In the case of maintenance indices, a total of 7 indices were derived.

In this study, a panel of 14 persons had responded to the survey, and the resulting content validity (CVR value) was based on 0.51 and more. As previously explained, the first Delphi survey was organized by mixing closed and open type questions for 56 preliminary evaluation indices derived through literature analysis. As a result of carrying out the survey, it was represented that 9 additional evaluation items were derived as Table 3~6 in the open type survey result, a closed type survey was carried out for a total of 65 preliminary evaluation items in the second Delphi survey.

As a result of carrying out the second Delphi analysis for 65 preliminary evaluation indexes selected through the first Delphi survey, 39 items satisfied the content validity, and for the agreement, the panel's opinions were agreed in 43 items.

The conducting result of second Delphi survey to select construction and maintenance indices for freezing damage reduction technology shows that 7 indices for road surface freezing prevention technology, 10 indices for lining insulation improvement technology, 16 indices for lining leakage prevention technology and 6 indices for maintenance were selected.

Table 3 Result of 2nd Delphi survey (Road surface freezing prevention technology)

Construction Method		Construction Index	Result Responses	CVR	Agreement (less than 1)
Road surface freezing prevention technology	Construction Plan	Administrative matters for construction (licensing procedures, etc.)	78.6%	-0.29	2
		Bypass roads and blockade plans for existing road construction	78.6%	0.29	2
		Secure operating system (control box) installation location and space	NEW	0.14	1.75
	Construction (Procedures and Instructions)	Prior work related to construction site	92.9%	0.71	1
		Obtain equipment, tools and facilities necessary for installation (installation)	78.6%	0.14	2.75
		How to install the packaging side	85.7%	0.57	0.75
		Tolerance and quality standards	78.6%	0.71	1.5
		Additional construction for operation after system configuration	78.6%	0.14	1
	Materials	Compatibility of Materials (CNT) and Parts	100.0%	1.00	0
		On-site processing, assembly and installation of materials used (drawings and installation flowchart)	85.7%	0.71	0
		Performance test items and methods of used materials and parts	NEW	0.43	1.75
	Construction inspection	Performance test items and methods after construction, evaluation criteria	100.0%	0.86	0
		Types of Construction data, Items	85.7%	0.43	1.75
		Maintain Performance	92.9%	1.00	0

Table 4 Result of 2nd Delphi survey (Lining insulation improvement technology)

Construction Method		Construction Index	Result Responses	CVR	Agreement (less than 1)
lining insulation improvement technology	Construction Plan	Ensure work safety and traffic safety	78.6%	0.29	2
		Secure operating system (control box) installation location and space	NEW	0.14	1
	Construction (Procedures and Instructions)	Prior work related to construction site	92.9%	0.57	1
		Obtain equipment, tools and facilities necessary for installation (installation)	92.9%	0.57	1
		Minimized lining damage and interference with pre- and post-work	92.9%	0.86	1.5
		Influence of the existing structure by applying the method	85.7%	0.29	2
		Installation and reinstallation of facilities attached to existing structures	85.7%	0.71	1
		Possible secondary damages of existing structures	92.9%	0.71	1
		Tolerance and quality standards	92.9%	0.86	0.75
		Additional construction for operation after system configuration	85.7%	0.00	1.75
	Materials	Compatibility of materials (CNT, insulation) and parts	92.9%	0.86	0
		On-site processing, assembly and installation of materials used (drawings and installation flowchart)	100.0%	0.86	1
		Toxicity of adhesive material	78.6%	0.14	1
		Attachment strength of adhesive material	92.9%	0.43	1.75
		Performance test items and methods of used materials and parts	NEW	0.57	1
	Construction inspection	Performance test items and methods after construction, evaluation criteria	100.0%	0.86	0
		Types of Construction Data, Items	85.7%	0.14	2

Table 5 Result of 2nd Delphi survey (Lining leakage prevention technology)

Construction Method		Construction Index	Result Responses	CVR	Agreement (less than 1)
Lining leakage prevention technology	Construction Plan	Administrative matters for construction (licensing procedures, etc.)	78.6%	-0.29	2
		Ensure work safety and traffic safety	78.6%	0.43	1.75
		Connectivity with the preceding method	85.7%	0.43	1.5
		Secure operating system (control box) installation location and space	NEW	0.14	1
	Construction (Procedures and Instructions)	Prior work related to construction site	92.9%	0.71	1
		Obtain equipment, tools and facilities necessary for installation (installation)	92.9%	0.26	2
		influence of the existing structure by applying the method	92.9%	0.57	0.75
		Appropriateness of installation area of drain pan according to leak amount and leakage range	85.7%	0.71	1
		Installation and reinstallation of facilities attached to existing structures	85.7%	0.43	0.75
		Tolerance and quality standards	92.9%	0.86	1.5
		Leak prevention method securing the function of preventing freeze damage by itself	78.6%	0.57	1
		minimized lining damage and interference with pre- and post-work	85.7%	0.71	1
		Prevention of freezing of connection area between induction drain pipe and existing drainage system	92.9%	0.86	0.75
		Facility limit of tunnel (building limit)	NEW	0.43	1.75
	Materials	On-site processing, assembly and installation of materials used (drawings and installation flowchart)	85.7%	0.71	0.75
		Suitability of drainage system configuration by construction site and area	92.9%	0.57	1.5
		Suitability of product according to site and scale	85.7%	0.71	1
		Applicability of Hottey-Gell for preventing leakage of water	92.9%	0.57	1
		Specification of Inductive Drainage Pipe by Leakage Rate	85.7%	0.57	1
		Toxicity of adhesive material	78.6%	0.00	1
		Attachment strength of adhesive material	92.9%	0.71	1
		Performance test items and methods of used materials and parts	NEW	0.57	1
	Construction inspection	Performance test items and methods after construction, evaluation criteria	100.0%	0.71	1
		Types of Construction Data, Items	78.6%	-0.29	1
		Check for leaks after construction	92.9%	1.00	1

Table 6 Result of 2nd Delphi survey (Maintenance for freezing damage reduction technology)

Construction Method		Construction Index	Result Responses	CVR	Agreement (less than 1)
Road Tunnel freezing damage reduction technology	Management Plan	Items for inspection cycle, inspection items and inspection procedure	100.0%	1.00	1
		Measuring tools and spare parts, procurement of consumables	78.6%	0.14	1
		Construction drawings and facilities	NEW	0.57	1
	Maintenance	identify and evaluate performance (functionality) maintenance	100.0%	1.00	0.75
		Performance (function) maintenance inspection procedure	85.7%	0.71	1
		Performance evaluation and soundness criteria	92.9%	0.71	1
		Maintenance data classification and retention period	NEW	0.14	1.75
	Maintenance reinforcement	Maintenance, storage and management of construction records	100.0%	0.29	3
		How to repair and reinforce damaged areas	92.9%	0.71	1.75

4. DEVELOPMING A REINFORCEMENT PROCESS AND MAINTENANCE STRAGY

In this study, to develop a reasonable maintenance system considering the environmental characteristics of the cold region tunnels, we developed the freezing damage reduction technology and derived its construction and maintenance index to maintain its performance continuously.

In addition, according to the characteristics of the local environment, the road tunnel is classified into general and cold tunnel, and a reasonable construction and maintenance system is prepared. To accomplish this, a total of 65 preliminary evaluation indexes were derived from the analysis of related literature and previous studies. In order to derive the final index, 14 experts who are engaged in research institute, academia, Delphi survey was conducted and a final agreement was reached.

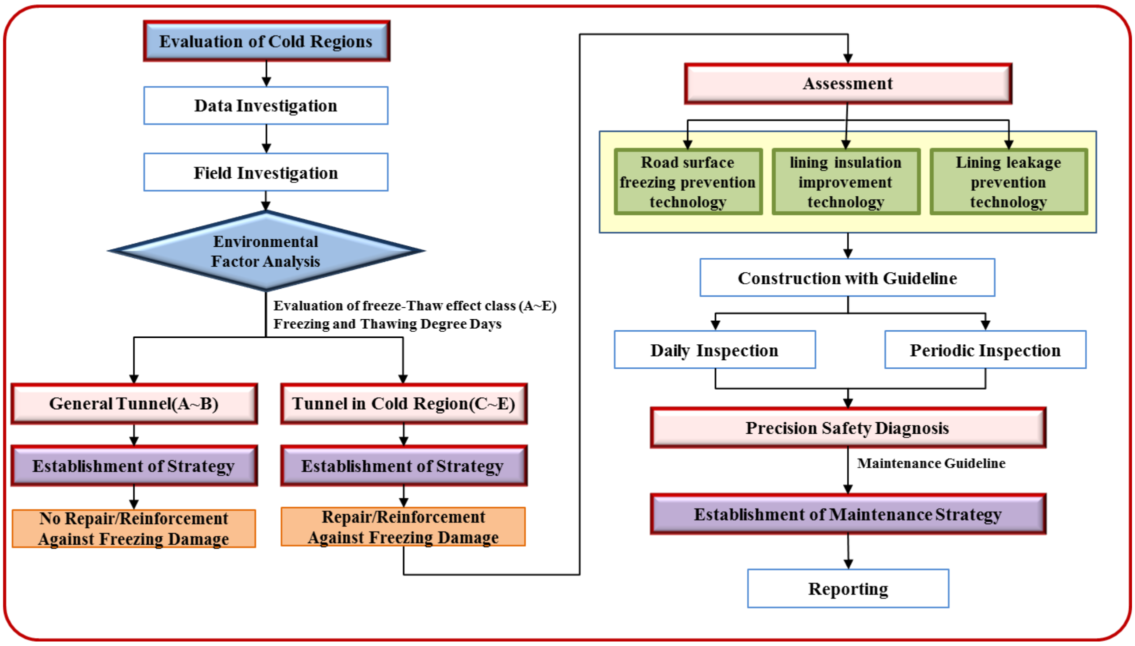

Fig 3 Construction and Maintenance Process

Based on the construction and maintenance indexes derived from this study, it will be possible to support reasonable decision-making and management system in establishing repair, reinforcement and maintenance management system of tunnel in cold region.

5. CONCLUSIONS

Freezing and thawing of a tunnel is caused by leakage of groundwater and moisture contained in the outside air. Therefore, appropriate technology for reducing freeze damage such as drainage, leakage prevention, insulation and heat generation is necessary.

In this study, the indices to maintain the performance are derived for efficient construction and maintenance considering the material characteristics of the freeze damage reduction technology and the environmental characteristics of the cold region. Also, according to the characteristics of local environment, it is classified into general tunnel and tunnel in cold region, and a reasonable construction and maintenance system is provided.

A total of 65 preliminary indices were derived through domestic and foreign literature review and related expert consultation. Two times expert Delphi survey were conducted among 14 experts working in research institutes, academics and industry. As a result, a total of 39 indices were finally selected.

The indices derived from this study will be used to develop guidelines for construction and maintenance of freeze damage reduction technology. Based on this, it could be utilized to support rational decision - making when establishing construction and maintenance system for tunnels located in cold regions. Therefore, it is possible to maximize the understanding and efficiency of practitioners such as tunnel construction engineers and maintenance companies. Also, it will be able to use as a basis for revision of national construction standards.

6. ACKNOWLEDGMENTS

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