DURABILITY ANALYSIS OF POTHOLE PATCHING MIXTURE IN SNOWY COLD REGION

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***ABSTRACT*:** On the pavement in snowy cold region, water spray is often carried out as snow thawing and removing activities in winter. Therefore in most cases, pavement surface is in wet condition, and it causes the generation of a lot of potholes. Usually, for the potholes, emergency repair is immediately conducted using patching mixtures. However under these circumstances, the patching mixture falls away soon due to the constraint in the repairing work. Consequently, as for the maintenance in snowy cold region, it is important to develop the optimal repair method or patching mixture material for such region. In order to provide the fundamental discussion of this issue, this study statistically evaluates the durability of the patching mixtures of potholes. Concretely, the generation process of potholes are modeled by the Weibull hazard model, and the durability performance of the patching mixtures is verified by estimating the hazard model based on the inspection data of actual potholes on the national road in snowy cold region and monitoring data after repairing them.

KEYWORDS: snowy cold region, pothole patching mixture, statistical durability analysis

1. INTRODUCTION

Paved Roads are required to (1) have sufficient surface properties so that vehicles can run safety and comfortably and (2) have high structural durability so that the roads can be used for a long term. However, as financial budgets are shrinking, it is extremely difficult to improve the efficiency of the maintenance and management of an enormous amount of road stocks. In this circumstance, asset management is attracting attention as a solution (Kobayashi), and we can recently see the significant advance of researches into statistical deterioration prediction based upon visual inspection data (Aoki et al., Tsuda et al.). Furthermore, lifecycle cost estimation methods (Kaito, et al.) based on the deterioration prediction have been proposed, and their applications to actual cases are expected.

However, the road pavement in snowy cold regions, which are managed by Kinki Regional Development Bureau, are almost always wet, because water is sprayed for thawing and removing snow during the winter season. Accordingly, these roads often get potholed. To cope with road surface abnormalities, such as potholes, emergency repair is conducted using repairing materials (patching mixtures), but the environments of snowy cold regions prevent them from fulfilling their primary performances, and such patching mixtures are peeled soon in many cases. Therefore, it is not appropriate to estimate the reduction of lifecycle cost based on the asset management method targeted at ordinary pavements. In addition, by taking countermeasures considering actual situations, it is possible to secure further safety for road users. With regard to potholes, the mechanism of the generation of a pothole has been already elucidated (Kamada and Yamada), but there have been no cases of statistical analysis of the actual situation of potholes in snowy cold regions and the durability of patching mixtures, as far as the authors know. It would be important to develop repairing methods and materials suited for snowy cold regions, based on the results of experimental analysis.

In this study, the authors statistically estimate the period from the repair of potholes generated in snowy cold regions with generally used patching mixtures to the peeling of them, based on actual inspection data, and analyze their durability empirically. In detail, the process of generation of potholes is expressed by the Weibull deterioration hazard model (Aoki et. al.), and then the period until the peeling of patching mixtures (durability) is estimated, by using the estimation results of the model. In this study, the authors do not develop or propose a repairing method or material for coping with potholes in snowy cold regions, but conduct fundamental discussions for developing a method for the maintenance and management of road pavement while taking into account the actual situation of snowy cold regions. Chapter 2 mentions the basic positioning of this study. Chapter 3 describes the Weibull deterioration hazard model. Chapter 4 empirically analyzes the durability of patching mixtures, using actual inspection data on general national roads in snowy cold regions.

2. BASIC POSITION OF THIS STUDY

2.1 Generation Mechanism of Potholes

A pothole is generated through the following processes: (1) After rain, snow, water spray, etc., the stagnant water on the road surface enters the pavement body from cracks, etc.; (2) repeated traffic loading forces the stagnant water to enter the space between aggregates and asphalt mortar; and (3) the bonding force inside the pavement weakens, aggregates flake, damaging the road. The mechanism of this stripping can be studied, by reproducing the stripping phenomenon in the immersion wheel tracking test (Kamada and Yamada). Actually, it was found, from the results of the immersion wheel tracking test, that potholes are generated due to the stripping under pavement, and the stagnant water around the lower surface of the pavement causes the generation of potholes. In addition, it is considered that the generation of potholes is caused by the following three factors: (1) repeated loading (due to large vehicles and the transverse slopes of lanes), (2) road configuration, etc. (curve sections and intersections), and (3) the stagnant water on paved roads (water condition, rainfall amount, water penetration conditions of concrete slabs and asphalt pavements). Among these three factors, the stagnant water is often remarkable. In general, stagnant water can be avoided, by designing appropriate drainage structures, installing drainage pipes, etc., but in the case of paved roads in snowy cold regions where water is sprayed to thaw snow, the stagnant water during the winter season is always problematic.

2.2 Patching Mixtures and Its Durability

The ordinary-temperature patching mixtures can be prepared at less than 100 degrees Celsius. In general, they can be classified into the mixture of coarse aggregate, fine aggregate, and emulsified asphalt, and the mixture of aggregates and cutback asphalt, which are mixed at room temperature. The ordinary-temperature asphalt material containing emulsified asphalt makes the pavement stable, because the decomposition of the water content of emulsified asphalt leads to an increase in strength. However, this material is difficult to store, and so it is prepared on the site, for example, for surface recycling. Meanwhile, the material containing cut-back asphalt makes the pavement stable due to the transpiration of the volatile content of asphalt, and so it is possible to store this material for a long time by shutting air. Therefore, most of the commercially available materials contain cut-back asphalt. The ordinary-temperature patching mixtures containing cut-back asphalt are easy to handle in storage and transportation, etc. compared with hot asphalt mixtures, and so these are broadly used for minor repair of potholes and bumps, etc. However, these are inferior to hot asphalt materials in early stability, durability, and water resistance. Recently developed materials include the materials blended with special resin, all-weather repair materials whose stability and durability have been increased by adjusting the particle size of aggregates, and repair materials composed of mainly the resin or cement that hardens reactively.

However, in snowy cold regions, it is difficult for ordinary-temperature repair materials to fulfill their specified performances. In other words, these patching mixtures are used in the severe environmental conditions, including the stagnant water on roads, and repair time is limited, because traffic should not be shut off for a long time. Therefore, there is a demand for ordinary temperature materials that can fulfill their functions as pothole patching mixtures even in snowy cold regions, but the statistical analysis data regarding actual durability of currently-used patching mixtures have not been accumulated to a sufficient degree. Obama et al. (2007) estimated the time from the repair of a pothole with patching mixtures to the regeneration of a pothole, using the accumulated inspection records of potholes on general national roads and the time-series data after the repair with ordinary-temperature patching mixtures, and proposed a method for evaluating the durability of them. In this study, the authors evaluate the durability of pothole patching mixtures based on the Weibull deterioration hazard model, using the method proposed by Obama et al. With the purpose of analyzing the factors that influence the durability of patching mixtures, while considering the study results of Obama et al., the authors introduced detailed structural conditions of the pavement and newly obtained the data regarding the conditions of repair work. The engineering value and practicality of this study exist, because the statistical analysis of durability of repair materials has been carried out from multifaceted perspectives.

3. WEIBULL HAZARD MODEL

3.1 Formulation of the model

In this study, the Weibull deterioration hazard model (Aoki et al.) is used, in order to express the processes of pothole generation. Although the details of the hazard model are mentioned in the reference (Lancaster), the outline of the Weibull deterioration hazard model is described in this paper, for readers' convenience.

Let us focus on the period from the repair of a pothole with a patching mixture to the regeneration of a pothole at the same spot in a certain road section. This period is the life span of a patching mixture. In this study, durability is evaluated based on this lifespan (endurance time). The lifespan of a patching mixture is expressed by random variable ζ , and it is assumed that ζ is subject to the probability density function $f(\zeta)$ and the distribution function (cumulative lifespan probability) $F(\zeta)$. Here, the domain of lifespan ζ is $[0,\infty)$. The probability of no generation of a pothole (survival of a pothole patching mixture) from the initial time to arbitrary time $t \in [0,\infty) : \widetilde{F}(t)$ (hereinafter called "survival probability") can be defined as the value obtained by subtracting the cumulative lifespan probability of the generation of a pothole (stripping of a pothole patching mixture) until time $t : F(t)$ from the whole event probability: 1.

$$\widetilde{F}(t) = 1 - F(t) \tag{1}$$

Here, the probability that a patching mixture survives until time t and the first pothole is generated during the period $[t, t + \Delta t]$ can be expressed by the following equation:

$$\lambda(t)\Delta t = \frac{f(t)\Delta t}{\widetilde{F}(t)} \tag{2}$$

Let the "hazard function $\lambda(t)$" mean the probability density that a patching mixture will survive until time t and a pothole is generated at the time t. The following equation can be obtained by differentiating both sides of Equation (1) with respect to t.

$$\frac{d\widetilde{F}(t)}{dt} = -f(t) \tag{3}$$

At this time, Equation (2) can be transformed into the following equation:

$$\lambda(t) = \frac{f(t)}{\widetilde{F}(t)} = \frac{d}{dt}(-\log \widetilde{F}(t)) \tag{4}$$

Here, Equation (4) is integrated, while considering $\widetilde{F}(0) = 1 - F(0) = 1$, to obtain the following:

$$\int_0^t \lambda(u)du = -\log \widetilde{F}(t) \tag{5}$$

Accordingly, by using the hazard function $\lambda(u)$, the probability that a patching mixture will survive until time $t : \widetilde{F}(t)$ can be expressed as follows:

$$\widetilde{F}(t) = \exp\left[\int_0^t \lambda(u)du\right] \tag{6}$$

Like this, by specifying the function form of the hazard function $\lambda(u)$, it is possible to derive the survival probability of a patching mixture $\widetilde{F}(t)$. In addition, by using the equation $\widetilde{F}(t) = 1 - F(t)$, it is possible to obtain the cumulative lifespan probability of a patching mixture $F(t)$. Here, let us discuss the following Weibull deterioration hazard function as a deterioration hazard function:

$$\lambda(t) = \theta\alpha t^{\alpha-1} \tag{7}$$

where θ is a constant parameter representing the frequency of the generation of a pothole. Under the assumption that θ can be expressed by characteristics that influence the structures of a road section and the damage of patching mixtures, θ can be expressed by the following equation, using the characteristic vector $\mathbf{x} = (x_1, \cdots, x_M)$:

$$\theta = \mathbf{x}\boldsymbol{\beta}' \tag{8}$$

where $x_m (m = 1, \cdots, M)$ represents the observed value of the m-th characteristic variable and $\boldsymbol{\beta} = (\beta_1, \cdots, \beta_M)$ denotes the unknown parameter vector. $(\ )'$ represents transposition. In addition, α in Equation (7) is the acceleration parameter that represents the rate of increase in hazard rate with time. When the Weibull deterioration hazard function is employed, the probability density function of the lifespan of a patching mixture: $f(t)$ and the survival probability of a patching mixture: $\widetilde{F}(t)$ can be expressed as follows:

$$f(t) = \theta\alpha t^{\alpha-1} \exp(-\theta t^{\alpha}) \tag{9a}$$

$$\widetilde{F}(t) = \exp(-\theta t^{\alpha}) \tag{9b}$$

3.2 Model estimation method

Let us discuss the estimation of the Weibull deterioration hazard function based on observed inspection data. The time of the start of use of each patching mixture is set as $t = 0$, and $\bar{t}_i$ represents the measured value of the duration of use of the patching mixture $i (i = 1, \cdots, n)$. The symbol $(-)$ represents a measured value. If a pothole is generated during the monitoring period and the lifespan of a patching mixture ends, the duration of use is equal to the lifespan, that is $\bar{t}_i = \zeta_i$. On the other hand, when a pothole has not been generated and the lifespan of a patching mixture has not ended, the duration of use of a patching mixture is equal to the observation period $\overline{T}_i$, and the lifespan of a patching mixture ζ_i is not observed. Then, let us introduce the following dummy variable $\overline{d}_i$, which expresses whether the lifespan of a patching mixture i exceeds the observation period.

$$\overline{d}_i = \begin{cases} 1 & \bar{t}_i = \zeta_i \leq \overline{T}_i \\ 0 & \zeta_i > \overline{T}_i = \bar{t}_i \end{cases} \tag{10}$$

At this time, the observation information of the patching mixture i can be expressed by $\boldsymbol{\xi}_i = (\overline{d}_i, \bar{t}_i, \overline{\mathbf{x}}_i)$. Here, let us define the unknown parameter vector of the Weibull deterioration hazard model as $\boldsymbol{\omega} = (\alpha, \boldsymbol{\beta})$. Furthermore, in order to clearly express that $f(t_i)$ and $\widetilde{F}(t_i)$ are the functions of patching mixture's characteristic data $\mathbf{x}_i$ and of unknown parameter vector $\boldsymbol{\omega}$, respectively, these are expressed with $f(t_i, \mathbf{x}_i : \boldsymbol{\omega})$ and $\widetilde{F}(t_i, \mathbf{x}_i : \boldsymbol{\omega})$. Supposing that there is the observed information $\overline{\boldsymbol{\xi}}_i = (\overline{d}_i, \bar{t}_i, \overline{\mathbf{x}}_i)$ regarding the patching mixture *i*, the conditional probability of pothole generation given the removal of the right side of the ζ_i distribution due to the monitoring period regarding the patching mixture *i* can be expressed by the following equation:

$$\ell(\overline{d}_i, \bar{t}_i, x_i : \omega) = f(\bar{t}_i, \bar{x}_i : \omega)^{\bar{d}_i} \widetilde{F}(\bar{t}_i, \bar{x}_i : \omega)^{1-\bar{d}_i} \tag{11}$$

where the first term in the right-hand side represents the probability that the observation period of a patching mixture will end due to the generation of a pothole and its lifespan will become $\bar{t}_i$, and the second term denotes the probability that the lifespan of a patching mixture will become longer than the observation period $\overline{T}_i$ (that is, duration of use $\bar{t}_i$). Supposing that the deterioration of each of n patching mixtures is independent of one another, the likelihood function can be expressed by the following equation:

$$\begin{aligned} L(\boldsymbol{\omega} \mid \overline{\boldsymbol{\xi}}) &= \prod\nolimits_{i=1}^{n} \ell(\overline{d}_i, \bar{t}_i, \bar{x}_i : \omega) \\ &= \prod\nolimits_{i=1}^{n} f(\bar{t}_i, \bar{x}_i : \omega)^{\bar{d}_i} \widetilde{F}(\bar{t}_i, \bar{x}_i : \omega)^{1-\bar{d}_i} \end{aligned} \tag{12}$$

where $\overline{\boldsymbol{\xi}} = (\overline{\boldsymbol{\xi}}_1, \cdots, \overline{\boldsymbol{\xi}}_n)$. In the maximum likelihood method, the parameter value $\hat{\boldsymbol{\omega}}$ that maximizes the logarithm of the likelihood function (12) is obtained as the maximum likelihood.

4. EMPIRICAL ANALYSIS

4.1 Outline of the empirical analysis

In order to analyze the durability of patching mixtures, this study is focused on the national roads under the control of the national road maintenance office in the vicinity of the Ministry of Land, Infrastructure, Transport and Tourism. The potholes generated naturally on these roads during the period from June 2007 to the end of February 2008 were repaired with ordinary-temperature patching mixtures, and then the conditions of the patching mixtures were observed. Before applying the Weibull deterioration hazard model, the conditions of potholes were analyzed based on inspection records, observation data after repair, and basic information on paved roads (observed road length: 71.1 km; the length of roads equipped with the device for spraying water to thaw snow: 22.1 km). **Tables 1** and **2** show the analytical results. **Table 1** is focused on structural conditions, while **Table 2** is focused on repair work conditions. These tables tabulate the number of potholes and the average lifespan of patching mixtures. During the target period, a total of 123 potholes were generated, and the average lifespan of patching mixtures was 39.1 days. The database of such information has been already produced.

Firstly, let us discuss how the differences of

Table 1 Overview of the Spots of Potholes (structural conditions)

Lane	Total number	Frequency	Average lifespan
Inbound lane	51	1.50	45.0
Outbound lane	67	1.72	33.8
Center	5	1.25	49.8

Rut	Total number	Frequency	Average lifespan
Inside rut	118	1.64	33.9
Outside rut	5	1.00	61.3

Structure	Total number	Frequency	Average lifespan
Earthwork	102	1.50	36.2
RC slab	21	2.33	52.8

Surface material	Total number	Frequency	Average lifespan
Fine-graded pavement	100	1.72	30.2
Discharge pavement	23	1.21	77.5

Water-spray device for thawing snow	Total number	Frequency	Average lifespan
Installed	90	1.76	25.2
Not installed	33	1.27	76.8

Total	123	1.60	39.1

Table 2 Overview of the Spots of Potholes (repair work conditions)

Removal of water	Total number	Average lifespan
Removed	8	116.5
Not removed	54	14.8
No water	61	50.4

Removal of dirt	Total number	Average lifespan
Removed	3	156.0
Not removed	62	16.0
No dirt	58	57.7

Water spray for thawing snow	Total number	Average lifespan
Sprayed	18	16.6
Not sprayed	105	42.9

Tamping method	Total number	Average lifespan
Human power	1	109.0
Pressurization with vehicles	60	63.1
Machines	62	14.7

Total	123	39.1

structural conditions influence the number of potholes. It was found that the number of potholes significantly depends on ruts, structure (earthwork parts or RC slabs), surface material (fine-graded pavement or drainage pavement), and the device for spraying water to thaw snow. Here, as for surface materials, the water-spray device was set on the road section of fine-graded pavement, and not set on the road section of drainage pavement, and so it cannot be concluded that surface materials influence the generation of potholes. The "frequency of generation of a pothole" in the tables means the number of times of the repeated generation of a pothole at the same spot. As this value is larger, potholes more tend to be generated. The frequency of generation of a pothole depends on structures, surface materials, and the water-spray device. For example, in the case of structures, the frequency of generation of a pothole is 1.60 on average, while that for RC slabs is 2.33 (earthwork parts: 1.50). In the case of surface materials, the frequency for fine-graded pavement is 1.72 (drainage pavement: 1.21), while the frequency for the roads equipped with the water-spray device is 1.76 (the roads not equipped with the water-spray device: 1.27). It is obvious from the average lifespan that the differences of road positions, surface materials, and the water-spray device cause the over twofold differences in durability of patching mixtures.

Next, let us discuss the repairing work conditions (**Table 2**). In this study, the removal of water, dirt, and dust, the existence of the water-spray device, and tamping methods were recorded (weather, air temperature, and pothole size, etc. were separately recorded). It was found that average lifespan more depends on repairing work conditions than structural conditions (**Table 1**). Especially, the durability of patching mixtures depends on whether or not water and dirt are removed during the repairing work. Therefore, the limited time of repairing work sometimes prevents patching mixtures from fulfilling their primary performances. On the other hand, when repairing work conditions are satisfactory, the currently-used patching mixtures can exert their durability to a sufficient degree in snowy cold regions.

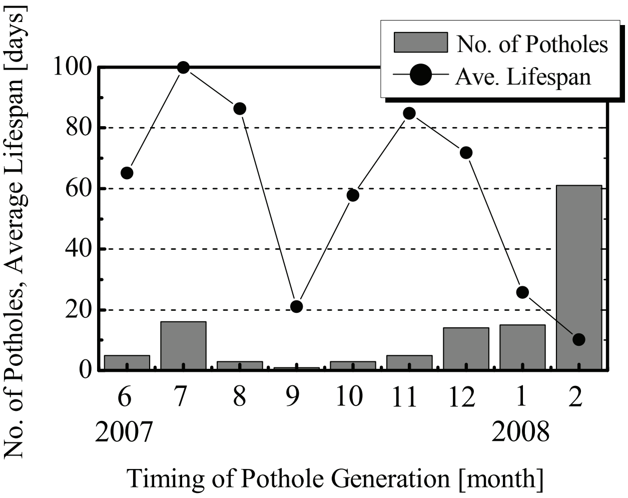

Figure 1 No. of Potholes Generated and Average Lifespan of Patching Mixtures in Each Month

In addition, **Figure 1** shows the number of potholes and average lifespan in each month. During the winter season from Dec. to Feb., potholes are generated, and the lifespan of patching mixtures is short. For example, comparing the data of Jan. and Jul., the numbers of potholes are the same, but there is a significant difference in average lifespan. The primary performances are the snowfall during the winter season and the subsequent water spray for thawing snow. This indicates that water influences the generation of a pothole and the durability of a patching mixture. The average lifespan in Sep. was short, while only one pothole was generated in the spot where the frequency of generation is high.

4.2 Analytical results

Based on the above database, the Weibull deterioration hazard model is estimated. Considering the previous research results (Obama et al.) and **Tables 1** and **2**, the candidate variables (characteristic vector **x**) that would influence the generation of a pothole include (1) the repeated generation of potholes: x_2^1, (2) surface material: x_2^2, (3) existence of the water-spray device: x_2^3, (4) water

Table 3 Estimation Results of the Weibull Deterioration Hazard Model

(Whether or not a pothole is generated repeatedly: $\beta_2{}^1$)

	α	$\beta_1{}^1$	$\beta_2{}^1$
Max. likelihood estimator	0.579 (8.88)	0.0387 (2.98)	0.0759 (2.71)
Log likelihood	-252.0		

Note) The value in each parenthesis represents *t*-value.

Table 4 Estimation Results of the Weibull Deterioration Hazard Model

(Surface material: $\beta_2{}^2$)

	α	$\beta_1{}^2$	$\beta_2{}^2$
Max. likelihood estimator	0.588 (8.86)	0.0156 (1.71)	0.0607 (3.16)
Log likelihood	-252.1		

Note) The value in each parenthesis represents *t*-value.

removal from a pothole during the repairing work: x_2^4, (5) removal of dirt (dust): x_2^5, (6) tamping method: x_2^6, and (7) large vehicle traffic amount: x_2^7. Among them, the repeated generation of potholes and almost become qualitative parameters. Although the repeated generation of potholes can be handled as a quantitative parameter, this is used as a qualitative parameter in this analysis, because the repeated generation than the number of times is important for analyzing the factors related to durability. In addition, there is a possibility that some of adopted explanatory variables are highly correlative.

$$x_2^1 = \begin{cases} 1\text{: A pothole was generated repeatedly.} \\ 0\text{: A pothole was not generated repeatedly.} \end{cases} \tag{13}$$

$$x_2^2 = \begin{cases} 1\text{: Fine-graded pavement} \\ 0\text{: Discharge pavement} \end{cases} \tag{14}$$

$$x_2^3 = \begin{cases} 1\text{: a water-spray device for thawing snow} \\ 0\text{: no water-spray devices for thawing snow} \end{cases} \tag{15}$$

Table 5 Estimation Results of the Weibull Deterioration Hazard Model

(Whether or not there is a water-spray device: $\beta_2{}^3$)

	α	$\beta_1{}^3$	$\beta_2{}^3$
Max. likelihood estimator	0.619 (9.00)	0.0140 (1.95)	0.0673 (3.34)
Log likelihood	-247.5		

Note) The value in each parenthesis represents *t*-value.

Table 6 Estimation Results of the Weibull Deterioration Hazard Model

(Removal of water from potholes: $\beta_2{}^4$)

	α	$\beta_1{}^4$	$\beta_2{}^4$
Max. likelihood estimator	0.613 (8.49)	0.0372 (2.73)	0.0598 (2.63)
Log likelihood	-254.1		

Note) The value in each parenthesis represents *t*-value.

Table 7 Estimation Results of the Weibull Deterioration Hazard Model

(Removal of dirt (dust) from potholes: $\beta_2{}^5$)

	α	$\beta_1{}^5$	$\beta_2{}^5$
Max. likelihood estimator	0.608 (8.43)	0.0379 (2.66)	0.0504 (2.51)
Log likelihood	-255.1		

Note) The value in each parenthesis represents *t*-value.

$$x_2^4 = \begin{cases} 1\text{: Water has not been removed.} \\ 0\text{: Water has been removed.} \end{cases} \tag{16}$$

$$x_2^5 = \begin{cases} 1\text{: Dirt (dust) has not been removed.} \\ 0\text{: Dirt (dust) has been removed.} \end{cases} \tag{17}$$

$$x_2^6 = \begin{cases} 1\text{: The tamping method was} \\ \quad\text{the pressurization with a vehicle.} \\ 0\text{: The tamping method was} \\ \quad\text{human power or machinery.} \end{cases} \tag{18}$$

All of these explanatory variables could nullify the hypothesis regarding power of explanation with the *t*-test of 5% significance level (*t*-value is over 1.96). Actually, the lanes and structures shown in **Table 1** could not nullify the hypothesis with the *t*-test, and

Table 8 Estimation Results of the Weibull Deterioration Hazard Model (Tamping method: β_2^6)

	α	β_1^6	β_2^6
Max. likelihood estimator	0.613 (8.66)	0.0928 (3.51)	-0.0577 (-2.72)
Log likelihood	-253.8		

Note) The value in each parenthesis represents *t*-value.

Table 9 Estimation Results of the Weibull Deterioration Hazard Model (Large vehicle traffic amount: β_2^7)

	α	β_1^7	β_2^7
Max. likelihood estimator	0.571 (8.77)	0.172 (2.79)	-2.91E-05 (-2.13)
Log likelihood	-256.7		

Note) The value in each parenthesis represents *t*-value.

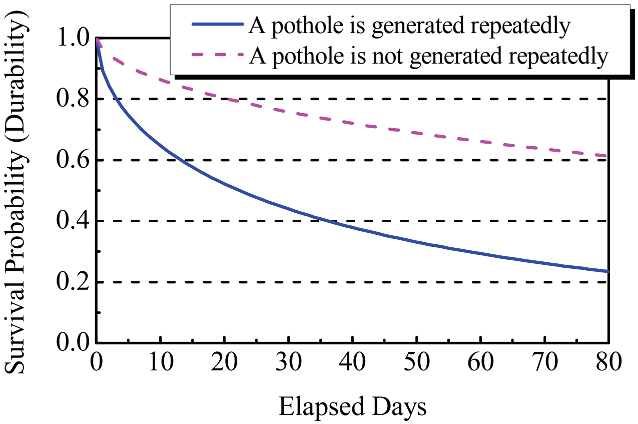

Figure 2 Survival Probabilities of Patching Mixtures (in the cases where a pothole is generated repeatedly and where a pothole is not generated repeatedly)

so these are not included in analysis items. In addition, x_1 is a constant term, and so $x_1 = 1$. **Tables 3** to **9** show the estimation results of the Weibull deterioration hazard model.

Firstly, let us focus on the repeated generation of a pothole shown in **Table 3**. Since β_2^1 is a positive value: 0.0759, the hazard function for the spot where a pothole was generated repeatedly becomes larger than that for the spot where a pothole was not generated repeatedly (that is, the lifespan shortens). In other words, once a pothole is generated at a spot, a pothole tends to be generated at the same spot. This indicates that the generation of a pothole is not a random event, but depends on road surface conditions, structural characteristics, and repairing work conditions. This also indicates that the currently used patching mixtures and methods cannot achieve sufficient effects and performance, under the severe road conditions, such as snowy cold regions. In addition, the value of acceleration parameter α is 0.579. Namely, the probability of pothole generation decreases with time, after the repair with patching mixtures. **Table 4**, etc. also show the same characteristics. It was found from *t*-value and log likelihood that the durability of patching mixtures depends on the existence of the water-spray device as a structural condition and tamping methods rather than the removal of water or dirt as a repairing work condition.

Next, in order to understand the above things visually, let us calculate the survival probability of a patching mixture in Equation (9b) (**Figures 2-6**). The horizontal axis in the figure represents the number of days since the repair with patching mixtures. Since the acceleration parameter α is less than 1 ($\alpha < 1$), the decrease rate of survival probability becomes lower with time, in every case. There is a possibility that this indicates the characteristics of two extreme cases—in one case, the durability of patching mixtures is extremely low; in the other case, patching mixtures can be used permanently. In addition, let us check durability in each condition. **Figure 2** shows the survival probability of a patching mixture that depends on whether a pothole is generated repeatedly. When a

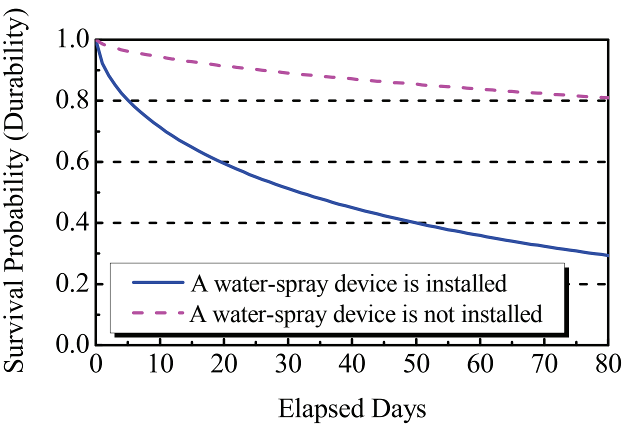

Figure 3 Survival Probabilities of Patching Mixtures (in the cases where a water-spray device is installed and where it is not installed)

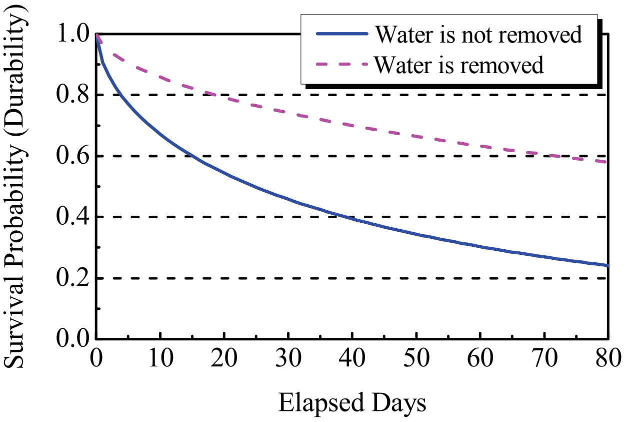

Figure 4 Survival Probabilities of Patching Mixtures (in the cases where water is removed during repair work and where water is not removed)

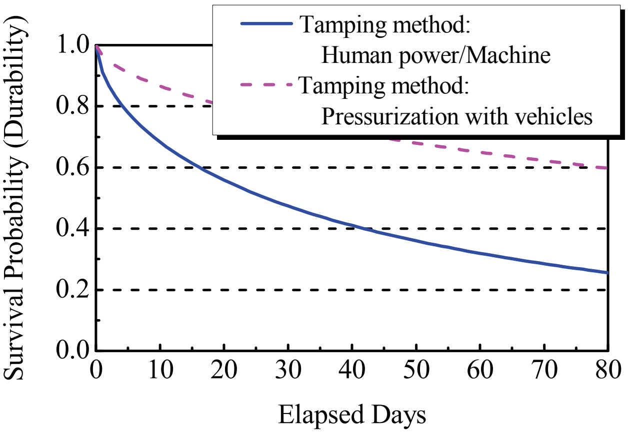

Figure 5 Survival Probabilities of Patching Mixtures (tamping methods during repair work)

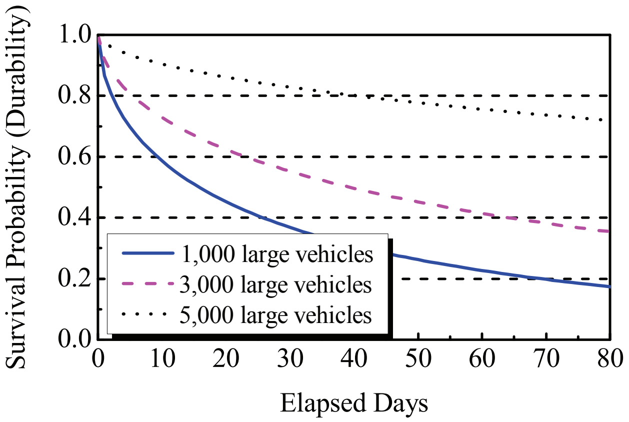

Figure 6 Survival Probabilities of Patching Mixtures (Large vehicle traffic amount)

pothole is generated repeatedly, the survival probability 10 days after repair is about 65%. When a pothole is not generated repeatedly (a pothole is generated for the first time), the survival probability is about 85%. The repeated generation of a pothole is considered due to underlying structural or constructional factors. In any case, it is obvious that the durability of a patching mixture is low. **Figure 3** shows that when the water-spray device is installed, the survival probability 10 days after repair is about 70%, and when the water-spray device is not installed, the survival probability is over 90%. Especially, when the water-spray device is not installed, the survival probability is still about 80% even 80 days after repair. Comparing this data with that for the case where the water-spray device is installed, it can be concluded that the durability of patching mixtures strongly depends on whether or not there is the water-spray device. In addition, it is noteworthy that the number of days elapsed until the survival probability becomes 50% differs from the average lifespan shown in **Table 1**. Namely, the simple average of samples, such as the average lifespan shown in **Table 1**, is strongly influenced by singular values, and it is difficult to do accurate analysis. On the other hand, the comparison of **Figures 4** and **5**, which show repair work conditions, indicates that the survival curves for the case in which water was removed and for the case in which the road was compacted by vehicles show almost the same tendency. Meanwhile, when repair construction is not enough, the durability of patching mixtures becomes lower. In addition, from **Figure 6**, which shows the survival probability for each large-vehicle traffic amount, it was found that durability increases as the large vehicle traffic amount is larger. It can be considered that locally generated potholes are strongly influenced by other factors, as large vehicle traffic amount is measured in a certain road section. This can be understood, also from the fact that the *t*-value of β_2^7 of large vehicle traffic amount shown in **Table 9**.

5. CONCLUSION

In this study, the authors statistically analyzed the durability of patching mixtures used for coping with road abnormalities, such as potholes, with the purpose of streamlining the maintenance and management of paved roads in snowy cold regions and improving the durability of the pavement. For the analysis, the processes of the generation of potholes were expressed with the Weibull deterioration hazard model, and then it was found that most of patching mixtures deteriorate for a short period of time at the spot where potholes are repeatedly generated, the road equipped with the water-spray device, and the place where repair work is insufficient. This indicates that the currently-used patching mixtures cannot fulfill their primary performances under the severe conditions, such as snowy cold regions, especially roads with stagnant water, and that it is indispensable to develop patching mixtures and methods suited for snowy cold regions.

The following passages summarize the future study themes, based on the findings of this study. Firstly, let us discuss the development of patching mixtures suited for snowy cold regions. It is necessary to develop patching mixtures that can tolerate severe road conditions, such as snow thawing and water spray. In addition, in order to offer safe, comfortable services to road users, it is necessary to develop patching mixtures with high workability that can exert sufficient durability after time-limited repair. Secondly, let us discuss the development of an appropriate evaluation model for analyzing the performance of patching mixtures, such as durability. A variety of patching mixtures suited for snowy cold regions have been developed, and it is expected that new patching mixtures will emerge. In order to install them properly at appropriate places, it is essential to design quantitative scheme for comparative analysis based on a uniform performance evaluation method.

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