Special edition paper

Research on Prediction of Peeling/Spalling of Concrete from Viaducts

We measured thickness of cover concrete of reinforcements and investigated concrete degradation on railway viaducts. From that, we confirmed that degradation proceeds more rapidly as the thickness decreases. We therefore propose a method of predicting the minimum thickness of cover concrete of reinforcements, which is expected to be applied to predict where peeling/spalling of concrete might occur.

**Keywords:** Thickness of cover concrete of reinforcements, Corrosion of reinforcement, Investigation of reinforcement

1 Introduction

Pieces of concrete falling from railway viaducts could pose a danger to people. We have hitherto extracted places where spalling might occur by visual checks and inspections using infrared cameras and taken measures to prevent spalled concrete from falling, such as by striking deteriorated concrete off in advance and covering concrete with fiber sheets. However, there still are some cases where pieces of concrete fall off from viaducts.

It is known that corrosion of reinforcement, one of the causes of spalling of concrete, often occurs at points where thickness of cover concrete of reinforcement is small. In this research, we therefore studied to establish a method of predicting places (spans, etc.) where corrosion of reinforcement could easily occur. That was done by calculating the expected minimum thickness of cover concrete of reinforcement from the average and standard deviation of sample thickness measurement data.

2 Measurement of Cover Concrete of Reinforcements

For noise barriers of viaducts of the Joetsu Shinkansen aged more than 30 years in Niigata and Gunma prefectures, we conducted measurement of the thickness of cover concrete of reinforcements and a survey of blistering and peeling (“abnormalities”) due to corrosion of reinforcements.

Viaduct noise barriers have a wall on the track side (“inner wall”) and a wall on the exterior side (“outer wall”). In the measurement, we investigated main (vertical) rebars using an electromagnetic radar in the direction from the inner wall to the outer wall. We also carried out visual checks of abnormalities of outer walls due to corrosion of reinforcement that might affect people due to pieces of concrete falling.

Fig. 1 shows some of the results of surveys on the thickness of inner and outer cover concrete of individual vertical rebars arranged longitudinally. The thickness varied greatly, and even thickness less than the design thickness (30 mm) was found at some points.

Fig. 2 shows the relation between thickness of inner and outer wall cover concrete and outer abnormalities (with antirust treatment applied after striking deteriorated concrete off). We found a tendency where thickness of outer wall cover concrete was smaller at points where thickness of inner wall cover concrete was larger. The correlation confirmed between the thickness of inner and outer wall cover concrete suggests that the thickness of inner wall cover concrete can be used to predict the thickness of outer wall cover concrete. Furthermore, Fig. 2 shows that outer wall abnormalities occurred at points where the thickness of cover concrete was small. So, we sorted out the rate of abnormalities according to the thickness of outer wall cover concrete and confirmed that the rate of abnormalities is greater at points where thickness of cover concrete is smaller, as proved in a past paper (Fig. 3). This indicates the possibility that level of risk of spalling can be predicted from the thickness of cover concrete of reinforcement even at points where no abnormality is found yet.

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However, measuring thickness of cover concrete of reinforcement for all noise barriers would involve a huge amount of labor. We therefore studied formulating the variation of thickness of cover concrete and calculating the expected minimum thickness.

3 Analysis of Thickness of Cover Concrete

3.1 Calculation of Expected Minimum Thickness
On the premise that thickness of cover concrete of reinforcement follows logarithmic normal distribution, we sought a theoretical relation between average thickness, standard deviation, the minimum thickness.

Presume that random variable $x$ follows logarithmic normal distribution $f(x)$.

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma(x)} \exp \left( -\frac{1}{2} \left( \ln(x) - \lambda \right)^2 \right)$$

Here, $\zeta$ and $\lambda$ are parameters. When average value $\mu$ and standard deviation $\sigma_x$, with which random variable $x$ is the statistic of number of samples $n$, are known, those parameters can be obtained in the following equation.

$$\zeta^2 = \ln \left( 1 + \frac{(\mu_x)^2}{\mu^2} \right), \quad \lambda = \ln(\mu_x) - \frac{1}{2} \zeta^2$$

Next, the minimum value of random variable $x$, which follows logarithmic normal distribution, follows the Weibull distribution $g(x)$ shown below.

$$g(x) = \frac{m}{\beta} \left( \frac{x}{\beta} \right)^{m-1} \exp \left( -\frac{x}{\beta} \right)^m$$

Therefore, the parameters for logarithmic normal distribution are

$$\beta = \exp(\lambda - \zeta A), \quad m = \frac{1}{\zeta} B$$

Here,

$$A = \frac{2\ln(n) - \frac{1}{2}\ln(\ln(n)) - \ln(2\sqrt{n})}{\sqrt{2\ln(n)}}, \quad B = \frac{1}{\sqrt{2\ln(n)}}$$

As explained above, if the average value and standard deviation of random variable $x$, which follows logarithmic normal distribution, are known, the expected minimum thickness of cover concrete of reinforcement can be estimated in the following equation using the parameters of the Weibull distribution.

$$\mu_w = \beta \Gamma \left( 1 + \frac{1}{m} \right)$$

3.2 Estimation Using Actual Measurement Data
We verified whether the measurement data samples of thickness of cover concrete of reinforcement follow logarithmic normal distribution. Fig. 4 shows a comparison between the histogram of the actual thickness data measured for the viaduct used in Fig. 1 and the logarithmic normal distribution.

As the thickness of cover concrete of reinforcement of inner walls agrees with the logarithmic normal distribution, we assume it can be expressed using logarithmic normal distribution. In contrast, the thickness of cover concrete of reinforcement of outer walls does not agree with the logarithmic normal distribution as well as the data of inner walls does. One of the probable causes is the effect of the fact that aspects such as the thickness of cover concrete of reinforcement of outer walls have changed since the construction of noise barriers because safety measures such as striking deteriorated concrete off are more carefully taken with outer walls than with inner walls in light of risk to the public.

4 Future Issues
Investigating reinforcement from the inner side using electromagnetic radar, we could efficiently measure the thickness of cover concrete of reinforcement of the inner and outer walls of noise barriers and obtain the following results from the large amount of measurement data.

- We confirmed that the rate of abnormalities of concrete due to corrosion of reinforcement was higher at points where thickness of cover concrete of reinforcement was smaller.
- We proposed a method formulating variation of thickness of cover concrete of reinforcement by logarithmic normal distribution to calculate the expected minimum thickness of cover concrete.

The results of this research suggests that places (spans) where corrosion of reinforcement can easily occur can be predicted, even if no abnormality is found yet, based on the expected minimum thickness of cover concrete of reinforcement that can be calculated from the thickness measurement data. We will therefore conduct further research on the following subjects.

- The minimum amount of sample measurement data to calculate the minimum thickness of cover concrete of reinforcement
- Consideration of factors of corrosion of reinforcement (becoming wet, level of neutralization of concrete, etc.)
- A method of estimating thickness of cover concrete of reinforcement of outer walls based on that thickness of inner walls

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