ON THE DETERIORATION TENDENCY OF BRIDGE SLABS AFTER REPAIR WORK (IN THE CASE OF A LOCAL AUTONOMY)

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ABSTRACT

The life cycle cost of bridge structures is generally calculated on the assumption that the same bridge member deterioration curves apply to all the years in question. If the curves differ before and after repair work, then post-repair versions must be introduced – a task that requires further data accumulation and is expected to take over 10 years. This paper outlines a study on pre- and post-repair deterioration curves with a focus on bridge slabs. The two kinds of repair work considered here are replacement of all slabs and partial repair. Based on local-government data, it was found that while deterioration curves do not change after total slab replacement, a transformation to steeply descending curves is seen after partial repair.

Keywords: bridge slab, deterioration curve, total slab replacement, partial repair

1. INTRODUCTION

To raise social awareness for the importance of bridge maintenance and repair, it is necessary to determine how bridge-dependent road networks function in disaster conditions and to highlight the cost-effectiveness of maintaining such networks. Cost-effectiveness can be clarified based on calculated life cycle costs (LCCs). Conventional bridge treatment essentially involves either 1) wholesale removal and reinstallation when bridges deteriorate to a certain degree, or 2) corrective maintenance. Meanwhile, it is also considered possible that preventive maintenance may reduce overall costs considerably over a span of 50 to 100 years. This approach is seen as highly effective in gaining the consensus of taxpayers, and negative responses to LCC figures determined in this way tend to be limited. In this regard, the concept of LCC has achieved a certain degree of positive social recognition.

Determining LCC requires calculation of deterioration curves for the individual components constituting a bridge and repair costs depending on the degree of component deterioration. A formula that enables statistical processing of past and present data is basically used to calculate repair costs, although unknown factors are included due to future technological trends.

It is assumed that each component is repaired several times during the LCC calculation period. In the past, the use of deterioration curves similar to pre-repair curves for the period after repair was considered unavoidable due to a lack of accumulated inspection data.

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This study involved the construction department of a local government in charge of managing more than 5,000 bridges in its area. The department conducted first and second rounds of periodic inspections from 2000 to 2005 and from 2006 to 2010, respectively. Repair records had been kept, but were incomplete. The tendencies of deterioration progress in post-repair bridge components could be clarified using repair data and these two sets of inspection data. Although the tendencies for seven parts (i.e., superstructure elements (main girders, subcomponents), slabs, foundations, bodies, shoes, expansion devices and bridge surfaces) were examined in the study (Saito 2011), this paper focuses on concrete slabs, which account for 98% of all slabs. The data referred to here are from a bridge information system.

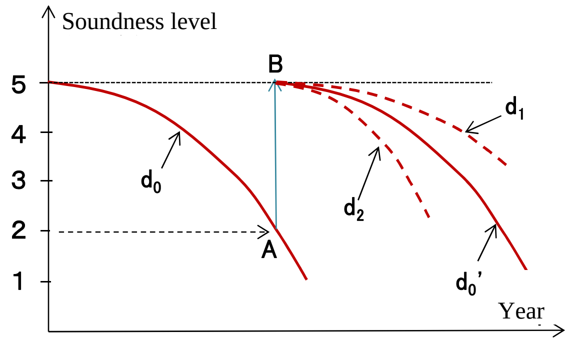


Fig. 1 Repair and deterioration curves

2. RELATION BETWEEN DETERIORATION CURVES AND REPAIR

Figure 1 shows the relationship between the deterioration curves and repair of a component. It was assumed that the inspection results were evaluated on a scale of 1 (bad) to 5 (good). First, the degree of aging deterioration was calculated using the deterioration curve d_0. For example, it was assumed that repair was conducted when this component's soundness level became 2, which is shown as Point A in the figure. Conventionally, the soundness level was assumed to return to 5, and the deterioration curve d_0', which was the same as the initial curve d_0, was used to calculate the degree of deterioration. These assumptions present two problems: 1) whether the soundness level actually returns to 5 (Point B in the figure), and 2) whether deterioration progresses with the same slope as that of the initial deterioration curve. In regard to the former, although some argue that the level may be higher than 5 depending on how repair is implemented, it is safe to assume that the value returns to 5 after repair because the initial value itself is not reached even with strict performance evaluation. Post-repair performance is also included in the slope of the deterioration curve after repair. Deterioration should be slow if the repair is good and fast if it is not. Figure 1 highlights the problem of what the actual condition of d_1 or d_2 is. As it is considered difficult to determine these values theoretically, post-repair deterioration was examined based on actual floor slab data in this study. The soundness level on the vertical axis of the figure is used to represent the degree of deterioration.

The data adopted for this study were obtained from a bridge information system managed by a municipal construction department as detailed in the introduction, and were used to examine post-repair condition. The detail of the data is omitted here.

3. PAST REPAIR RESULTS

This section presents results relating to previous repairs implemented by the construction department.

Since 1973, the number of spans on which component repair or reinforcement have been conducted is 4,790 in total.

This study focused on slab repair, which was roughly divided into three types (partial repair, full-length replacement and other types) for comparison. Other types include steel slab installation (2 cases) and reinforcement (32 cases), but these are not included in the examination of post-repair soundness changes detailed below.

Partial slab repair includes partial replacement, patch repair, crack repair and bridge surface waterproofing.

Figure 2 shows years and the number of spans (379 in total) on which partial slab repair has been conducted since 1987. The details of slab repair were not recorded before this time. The number increased dramatically from 2007.

In the figure, blue shading represents the number of spans for which results from the first and second rounds of inspection were found. The red and green areas indicate those for which only results from the first or second round, respectively, were found. Purple represents spans for which no inspections had been conducted since recent repair.

Figure 3 shows years and the number of spans (28 in total) in which full-length slab replacement has been conducted since 1987. No yearly characteristics are seen, presumably because the work was conducted for reasons other than slab deterioration response. The color-coding of the bars in the figure is the same as that for Fig. 2.

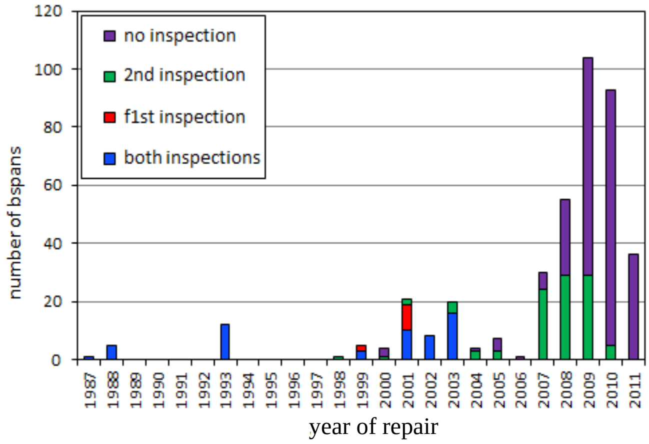
4. POST-REPAIR SLAB DETERIORATION CURVES

This section discusses the examination of post-repair slab deterioration curves based on inspection results. First, the following equation was used to calculate deterioration curves (Kiuchi 2011):

$$r(t) = 5 - 4\left(\frac{t}{T}\right)^{f} \qquad (0 \le t \le T) \qquad \text{(1a)}$$

$$r(t) = 1 \qquad (t > T) \qquad \text{(1b)}$$

Here, r(t) is the soundness level after t years of service, T is the service life, and f is the shape factor. The soundness level is an index representing the degree of component soundness, and has years values from 1 (the most deteriorated state) to 5 (the soundest state). Service life is the number of



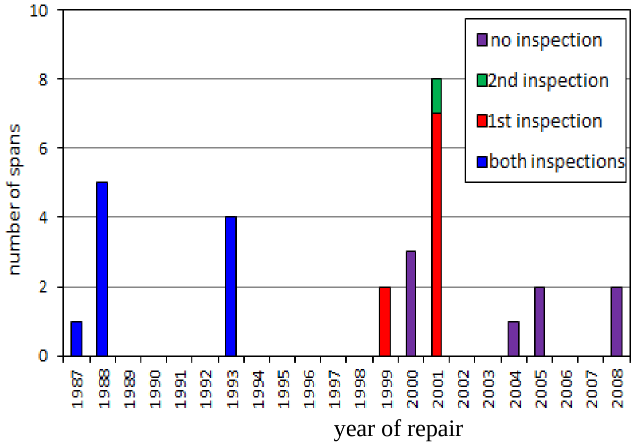


Fig. 2 Years and number of spans (379 in total) with partial slab repair since 1987

Fig. 3 Years and number of spans (28 in total) with full-length slab repair since 1987

years from the commencement of service until the soundness level reaches 1. Higher values represent slower deterioration. If the number of years in service t is greater than the service life T, the soundness level becomes 1 as shown by Eq. (1b). The shape factor f, which is a parameter determining the shape of the deterioration curve, was assumed to be f = 2 in this study .

First of all, the standard slab deterioration curves used for LCC calculation are shown before the post-repair deterioration curves.

Figure 4 shows the slab deterioration curve found from the results of the first round of inspections with data on 6,468 spans. Figure 5 shows curves found in the same way from the results of the second round with data on 6,378 spans. The green dots indicate individual data samples, and the red dashed lines were found using the least squares method on the data. The two curves show almost the same tendency.

Figure 6 shows slab deterioration curves found from the results of inspection after full-length slab replacement. The purple ◇ symbols represent inspection data; the corresponding number of spans

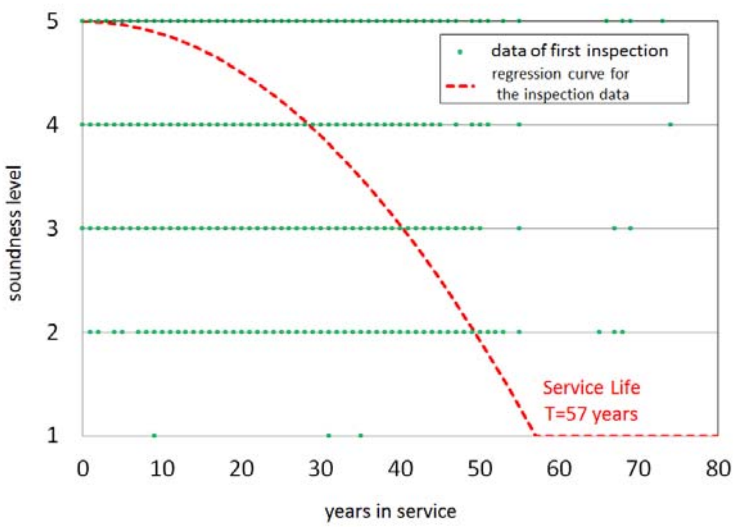


Fig. 4 Deterioration curve using the first round inspection (6,468 data)

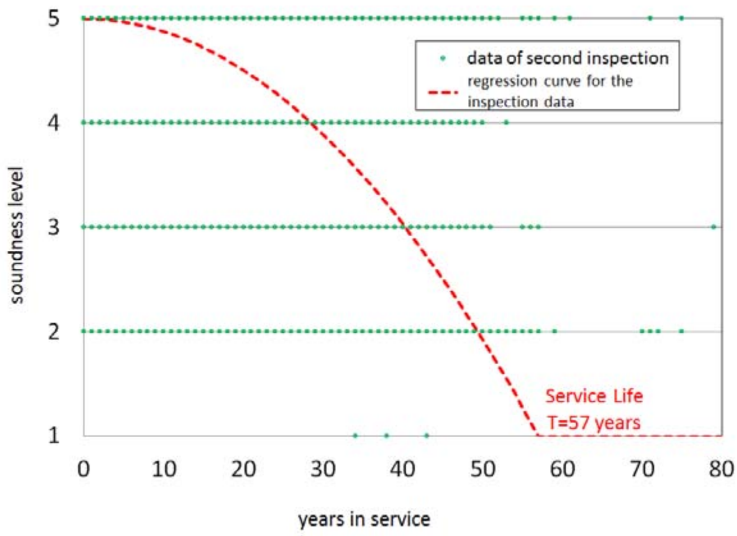


Fig. 5 Deterioration curve using the second round inspection (6,378 data)

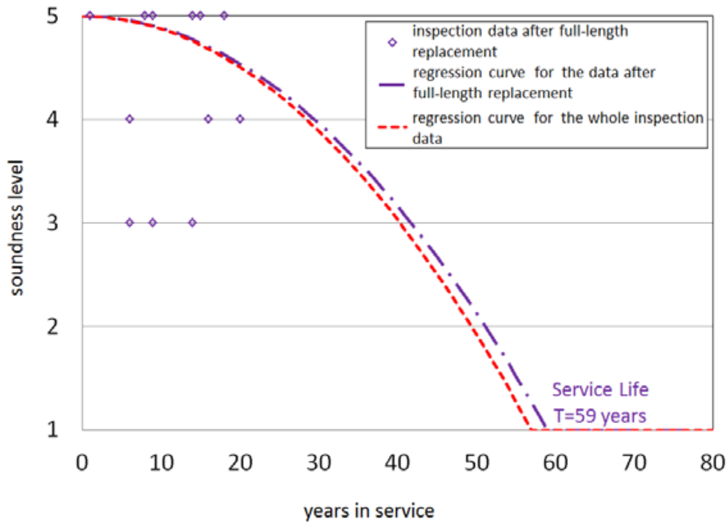


Fig. 6 Deterioration curves using the inspection data after full-length replacement (31 data)

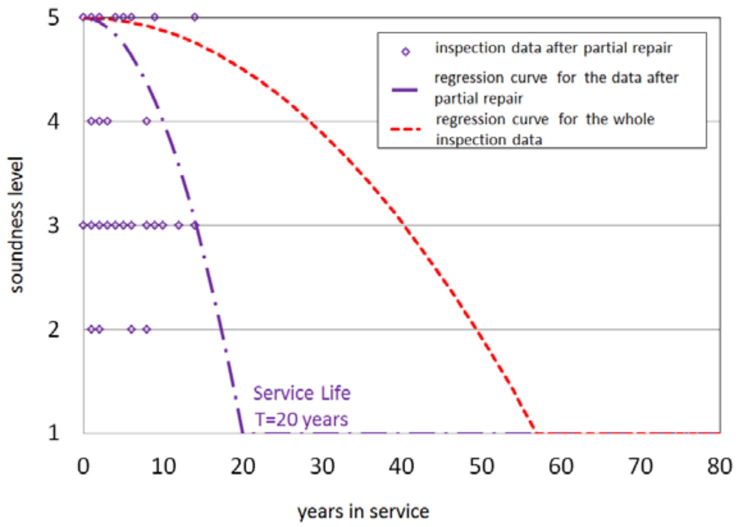


Fig. 7 Deterioration curves using the inspection data after partial replacement (177 data)

is 21. However, as the spans inspected in both the first and second rounds were counted twice, there were actually 31 data samples. The purple dashed-dotted lines indicate curves found using the least squares method. As seen in the figure, the lines exhibit almost the same tendency as the standard curves shown in figs. 4 and 5. This suggests that with slab repair based on full-length replacement, post-repair deterioration will show a tendency of progress similar to that of the standard slab deterioration curves.

Figure 7 shows slab deterioration curves found from the results of inspection after partial repair. The purple ◇ symbols represent inspection data. The number of data samples is 177 for 132 inspected spans for the reason outlined above. The purple dashed-dotted line indicates the curve found using the least squares method. Compared to that for full-length replacement, the deterioration curve indicates a much faster rate of decline. While the number of years until the soundness level reaches 1 is approximately 57 on the standard deterioration curve, it is 20 years after partial repair (approximately a third of the standard), indicating that deterioration progresses three times as quickly.

5. CONCLUSION

Among the problems to be addressed for more rational LCC calculation is clarification of changes in post-repair deterioration curves. If there is no change after repair, there is no problem; however, any change seen should naturally be reflected in the calculation. This may also affect the selection of repair methods.

The authors analyzed repair and inspection data selected from a data set managed by a municipal construction department to study changes in bridge component deterioration curves at the post-repair stage. From the results obtained, this paper outlines the outcomes of bridge slab analysis. The study produced results of inspection item evaluation corresponding to repair work (rather than simply comparing repair and inspection outcomes) in order to provide a basis for post-repair tendency clarification, and these outcomes are outlined here. Full-length replacement resulted in a level of performance similar to that seen with new slabs. However, with partial repair, dramatic acceleration of the deterioration curve decline was seen, and the level of performance decreased to almost a third of that observed with new slabs.

This highlights the challenges posed by bridge slab repair work and the feasibility of selecting an appropriate repair method. It may be acceptable to leave damage unrepaired to a certain degree, monitor its condition and conduct full-length replacement at the right time.

REFERENCES

Yoshiyuki Saito, Naotaka Shibuya and Hiroyuki Sugimoto (2011). A study on deterioration curves of bridge components after repair, 66th Annual Conference of the JSCE, I-609, pp. 1217-1218.

Junji Kiuchi, Yoshiyuki Saito and Hiroyuki Sugimoto (2011). A study on optimum bridge maintenance planning considering variations in inspection results, Journal of Structural Engineering, Vol. 57A, pp. 155－168.