Department of Rural Roads
Ministry of Transportation
Kingdom of Thailand

Kingdom of Thailand
The Project for Bridge Master Plan and Bridge Maintenance Ability in Rural Area

Report 3
Long-term Bridge Maintenance and Management Plan Development Manual

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Table of Contents

1. Examination of the Long-term Maintenance Plan

1.1. Planning Flow and Examination Items

Long-term maintenance planning is intended to prepare plans concerning preventive repairs and planned rebuilding with the aims of extending the service life of bridges and reducing bridge maintenance costs.

Figure 1.1.1 shows the examination items and flow of long-term maintenance planning of DRR-managed bridges.

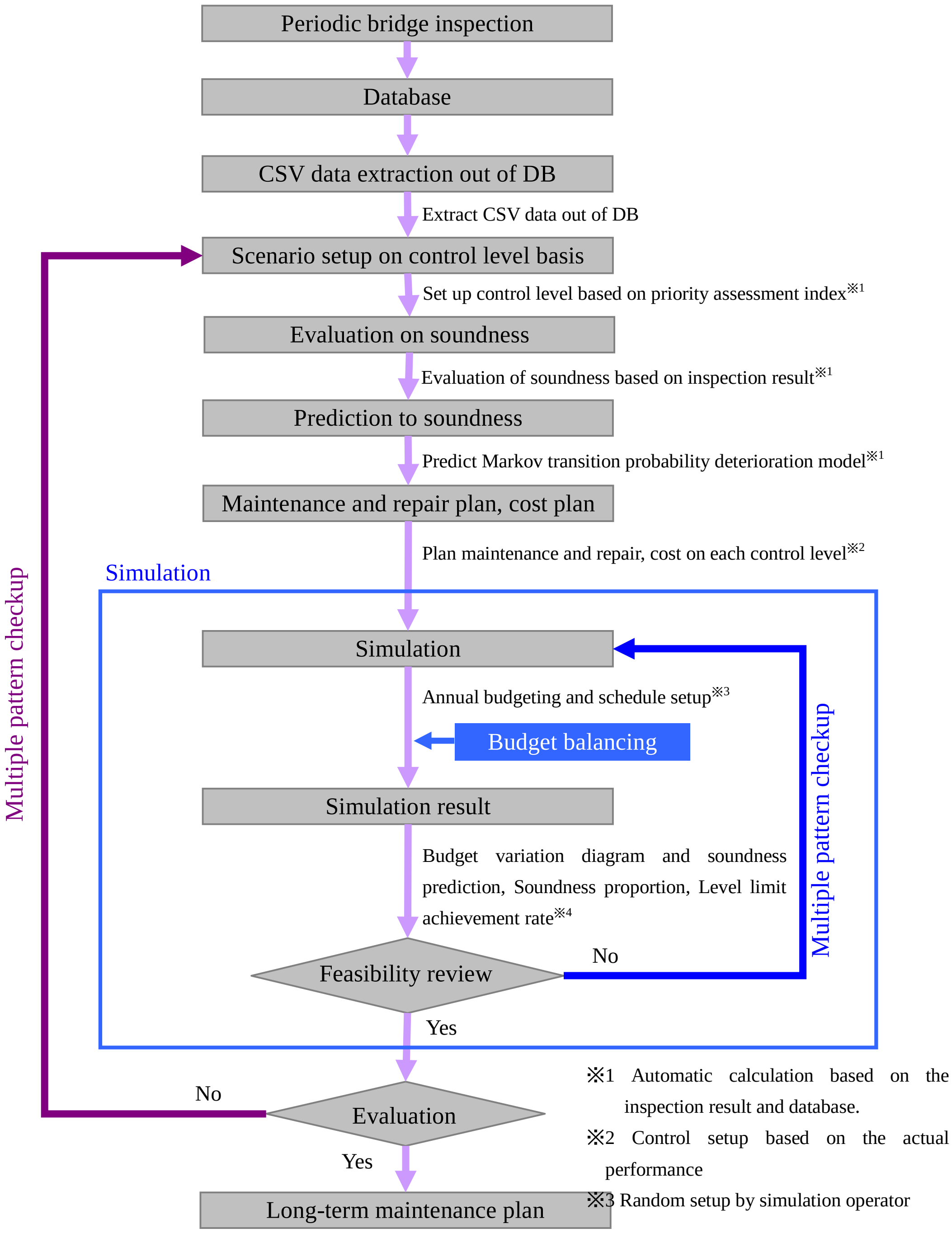


Figure 1.1.1: Long-term maintenance plan flow and examination items

Table1.1.1: Description of examination items in long-term maintenance plan

Item	Description
Periodic bridge inspection	Periodic bridge inspection according to Bridge inspection and evaluation manual
Scenario setup on control level basis	Assess priority of every bridge and set control level up. Schedule planning of maintenance and repair to keep control level as set ahead.
Evaluation on soundness	Evaluate soundness by 100 point-based scoring system on every member and span.
Prediction to soundness	Predict bridge degradation
Maintenance and repair plan and soundness prediction	Develop maintenance and repair plan for each member, and LCC estimation counts on it.
Priority assessment and set up	In budget balancing, maintenance and repair priority are put on bridge and its member.
Budget balancing	Based on the degree of damage and the priority of each member, select a target bridge considering the budget upper limit every year.
Feasibility review	Conduct simulation with the investment fund into multiple patterns and the management objective of bridges in rural area. Predict budget variation and soundness change, and assess control level achievement rate in all aspects, and then develop an actual plan reflecting the DRR status quo.
Evaluation	Evaluate stability, longevity, and cost-effectiveness with long-term bridge maintenance and repair plan.
Long-term bridge maintenance and management plan development	Develop bridge maintenance and repair or replacement plan.

1.2. Setting of Maintenance Scenarios based on Control Level

1.2.1. Necessity for Introduction of the Control Level

The bridges managed by DRR differ widely in terms of size of bridge, traffic volume, location conditions (emergency transport route, intersection, etc.) and conditions of use. Implementing maintenance of such bridges based on the same standard is an inefficient approach.

Accordingly, the concept of control level will be introduced as a means of effectively maintaining all of the bridges that are under DRR management. Through introducing the control level, it becomes possible to control each bridge corresponding to its level of importance, i.e. to prepare the maintenance scenario for each bridge.

The control level may be described as the maintenance goal, and this entails identifying a goal for “maintaining soundness of the bridge concerned at a certain level” and compiling a plan for attaining the said goal. Moreover, the act of setting a control level for each bridge is the act of setting the basic philosophy of DRR maintenance (deciding which bridge conditions should be prioritized) and is thus important in terms of fulfilling accountability.

Moreover, setting maintenance scenarios based on the control level entails setting the timing of maintenance and repair measures for each bridge, which is linked to establishing the order of priority of maintenance and repair measures.

For example, in the case where there are numerous bridges that have the same extent of damage (soundness of around 50), the bridges with a high control level will be those that have reached or exceeded the scheduled maintenance and repair time, and they will be deemed to require immediate measures, whereas the bridges with a low control level will be those that haven’t reached the scheduled maintenance and repair time, and it will be deemed permissible to leave them unattended for the time being. In the current situation where it is imagined there are numerous bridges with damage, through introducing the control level approach, it should be possible to rationally disperse the initial investment that is concentrated in the planning stage.

The following sections outline each control level.

1.2.2. Outline of Control Levels

(1) Control Level A

Control Level A refers to maintenance that aims for functional degradation of practically 0. In this approach, bridges are always maintained at a high level of soundness through frequently repeating preventive measures at low cost immediately after minor damages occur. It is desirable to apply this control level to bridges that have top level importance and for which it is unrealistic to rebuild in the future.

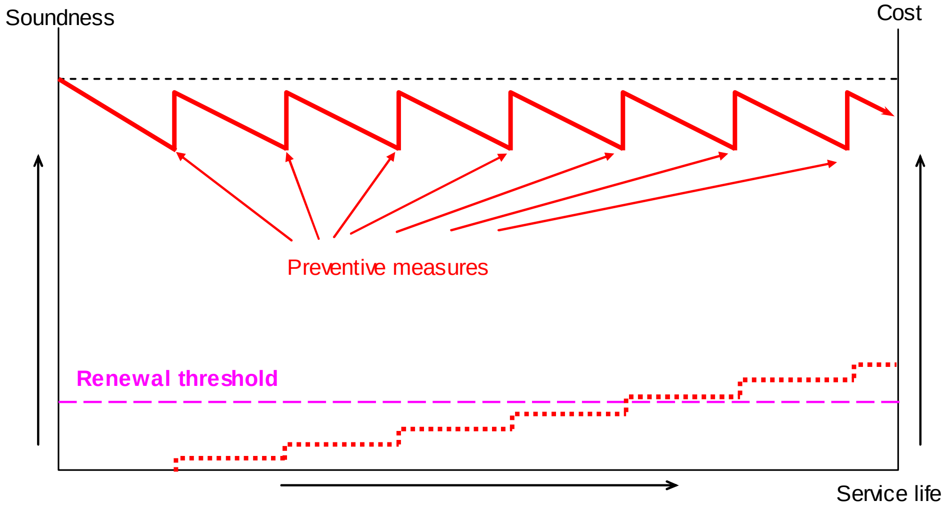


Figure 1.2.1: Image of maintenance and management according to Control Level A

(2) Control Level B

Control Level B refers to maintenance that aims for the planned restoration of degraded functions. In this approach, bridges are maintained at a relatively high level of soundness through repeating maintenance and repair measures at low cost with respect to minor damages. It is desirable to apply this control level to bridges that are relatively important and for which it is difficult to rebuild in the future.

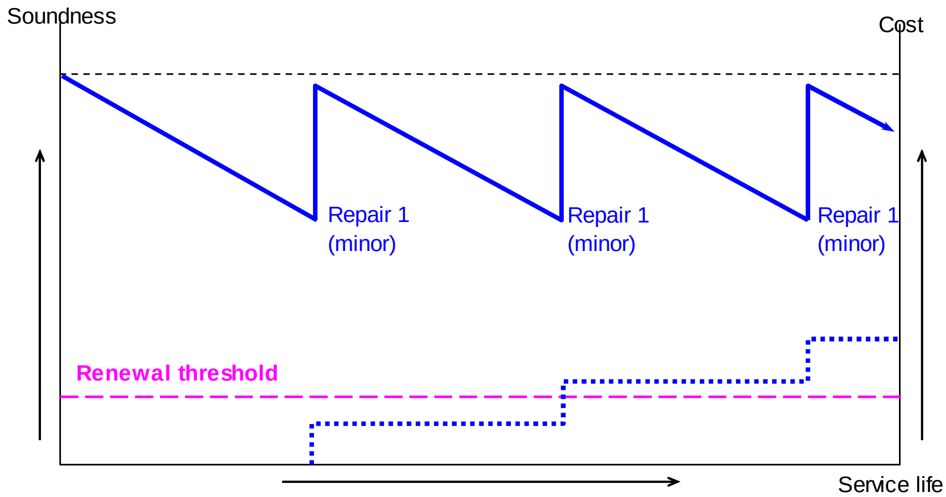


Figure 1.2.2: Image of maintenance and management according to Control Level B

(3) Control Level C

Control Level C refers to maintenance that aims for the planned restoration of degraded functions. In this approach, bridges are always maintained at a medium or higher level of soundness through conducting maintenance and repair measures at slightly higher cost with respect to damages that are slightly more serious than in Control Level B. It is desirable to apply this control level to bridges that have medium importance.

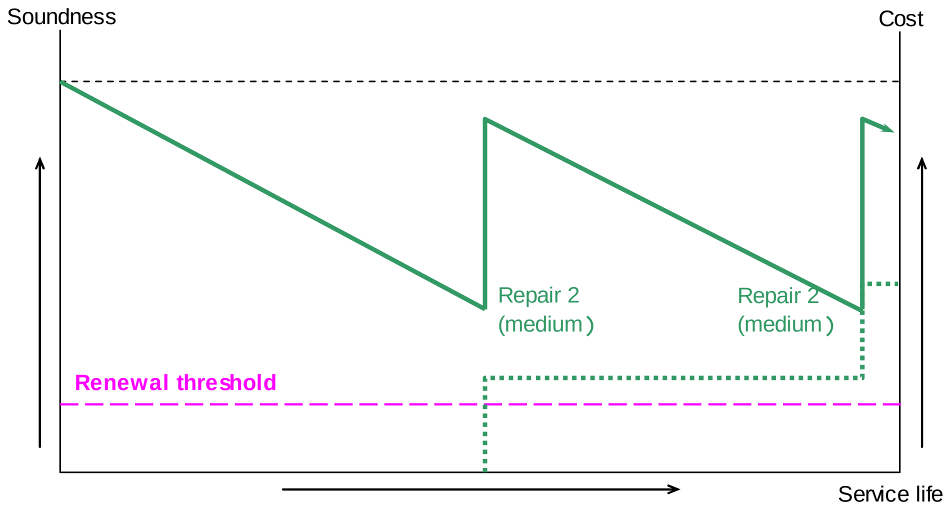


Figure 1.2.3: Image of maintenance and management according to Control Level C

(4) Control Level D

Control Level D refers to the approach whereby the minimum required soundness of bridges is maintained with the minimum of effort through leaving bridges unattended until just before the renewal threshold and implementing large-scale maintenance and repair measures before problems arise in usefulness. However, “leave unattended” here infers not going so far as taking countermeasures, while fully grasping damage conditions by means of regular inspections, etc. It is desirable to apply this control level to a few bridges with the lowest level of importance.

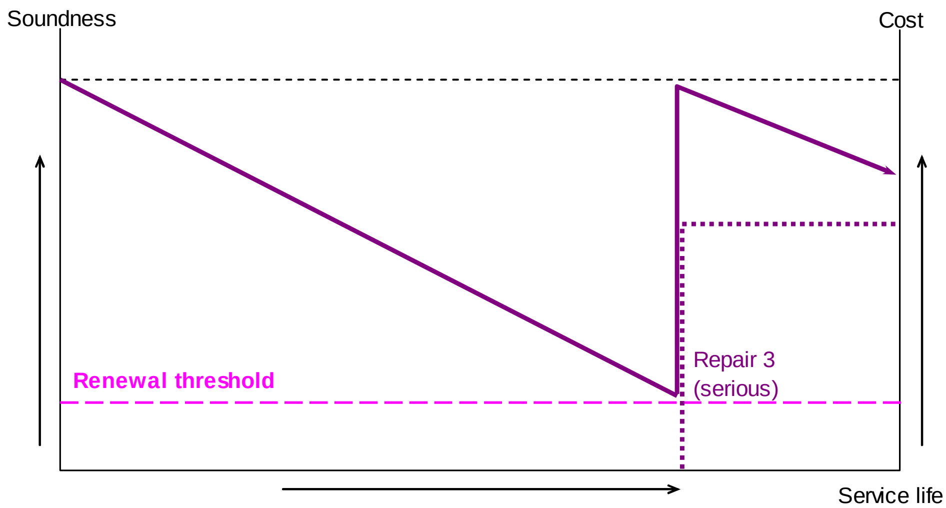


Figure 1.2.4: Image of maintenance and management according to Control Level D

(5) Overall Image of Control Level

Figure 1.3.5 shows the overall image of the aforementioned Control Levels A to D.

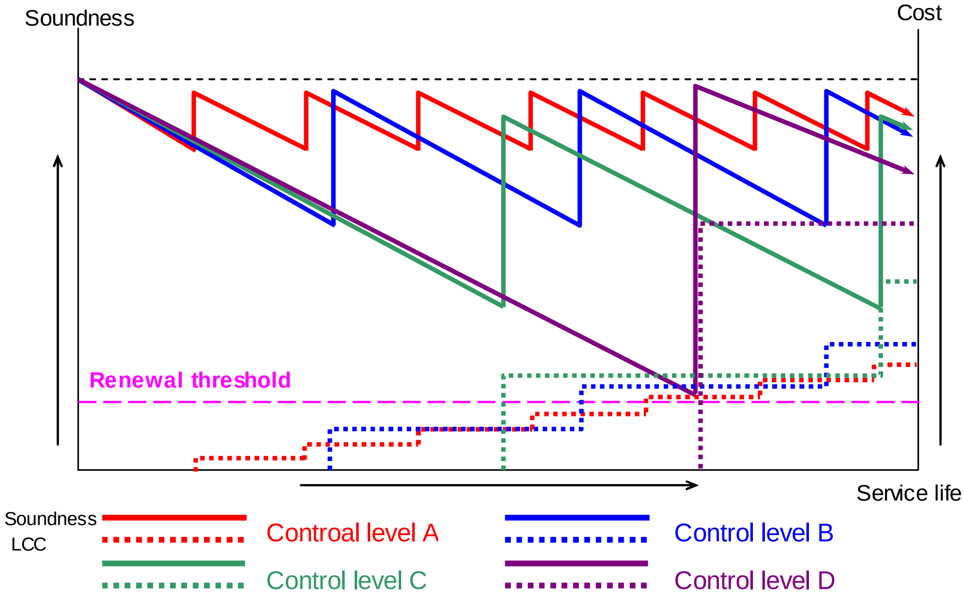


Figure 1.2.5: Image of Control level

As for bridges where it is deemed that "repairs are inappropriate because safety cannot be secured even if repairs are made and so on" as a result of bridge inspection, and bridges where it is deemed that "rebuilding is necessary" based on administrative judgment (functional conditions rather than the damage situation), the following scenario shall be set: "Conduct maintenance based on one of the control levels out of A~D following implementation of planned rebuilding."

1.2.3. Setting of the Control Level

It is necessary to set the control level of each bridge upon considering the social conditions, service conditions and environmental conditions and so on that the bridge is placed under.

When setting the control level of bridges managed by DRR, a method that allows the bridges to be quantitatively evaluated according to indicators (importance evaluation indicators) that reflect the importance of bridges.

Table 1.2.1 shows the importance evaluation indicators that are used in the project.

Table 1.2.1: Priority evaluation index set-up

Item	Priority coefficient	Limit and score (Max, 10 points and Min. 0)					
Roadway priority	**3**	0-10 score depending on the degree of priority to roadway					
		10-point coverted from calculation in other way					
Crossing state	**3**	railway	highway, motorway	local roadway	dam, valley	other	
		10	10	6	4	0	
Total traffic	**3**	≧20,000	≧10,000	≧3,000	≧2,000	≧500	＜500
		10	8	6	4	2	0
Heavy vehicle traffic	**2**	≧4,000	≧2,000	≧1,000	＜1,000		
		10	7	3	0		
Bridge length	**1**	≧400m	400m＞L≧15m		＜15m		
		10	Proportional distribution（10～0）		0		

The value calculated from the importance evaluation shall be called the "importance evaluation score." The importance evaluation score is calculated through multiplying the importance coefficient by the score for each indicator and deriving the total for each item.

*Priority evaluation point = Σ (priority coefficient * score)*

1.3. Soundness Evaluation

1.3.1. Definitions of Damage Classification and Soundness

In order to compile the long-term maintenance plan, it is important to quantitatively gauge the condition of bridges. Here, as the method for doing this, the soundness of bridges (members) shall be calculated.

Here, degree of damage and soundness are defined as follows.

Damage classification: This is an indicator of the level of seriousness of damage in member numbers that are the units of inspection indicated in the "Inspection Work and Evaluation Manual." The damage classification is expressed by the results of damage judgment obtained from inspection.

Soundness: This indicator expresses the functional maintenance level of members or bridges. Put another way, it is an indicator for gauging the overall condition of members or bridges upon considering the fluctuation or range of damage classification confirmed for each member number.

1.3.2. Thinking on Evaluation of Soundness

Thinking on the evaluation of soundness can broadly be divided into the following two directions.

Evaluate the overall condition upon focusing on the worst damage: safe-side evaluation

Generally evaluate the fluctuation or range of damage: mean evaluation

Table 1.3.1 shows the main features of each approach.

Table 1.3.1: Concept of general evaluation of soundness

Concept	Conservative evaluation (Worst damage focused)	General evaluation (Fluctuation or range of damage)
Advantage	- Worst damage is focused in making conservative evaluation on soundness and mitigating any risk.	- Each member or entire structure can be evaluated to take fluctuation or range of damage into account and put them into soundness. - LCC can be estimated at good accuracy so to help doing budget control. - Relative evaluation can be provided both locally and globally.
Disadvantage	- Fluctuation or range of damage is hard to be into soundness and LCC may be roughly estimated. - Hard to provide relative evaluation locally and globally. - Overestimated budget or inappropriate maintenance plan may be developed.	- Locally serious damage may be missed, and other risk mitigation steps are necessary.

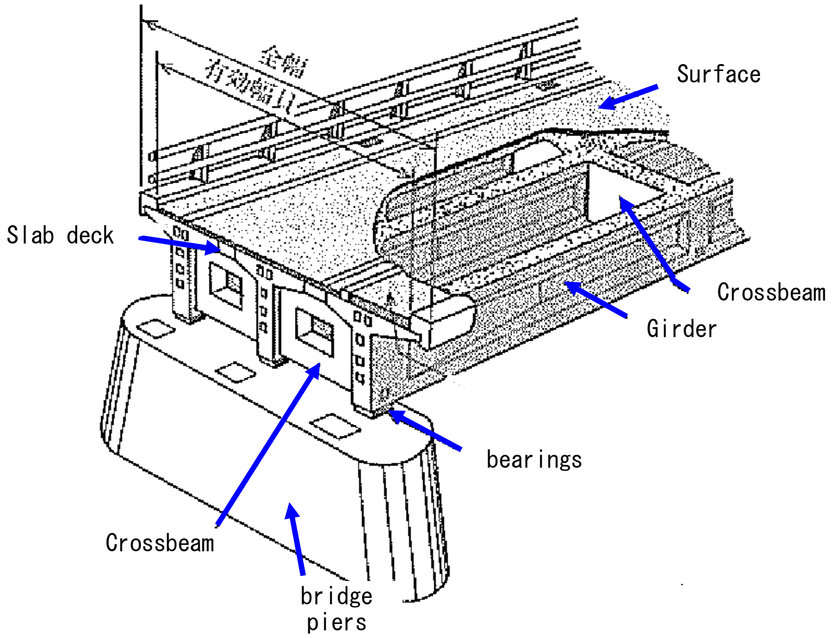
When compiling the long-term maintenance plan in DRR, the evaluation of soundness that "generally evaluates the fluctuation or range of damage" and makes it possible to conduct comparative evaluation of managed bridges and is suited to budget control will be adopted.

However, in this method which conducts mean evaluation, since it is possible that localized critical damage will cease to be conspicuous, it is important to also adopt risk aversion measures. Therefore, through taking the following risk aversion measures, the drawbacks of this approach will be augmented.

Separate evaluation of damages with a high priority for maintenance and repair (see section 1.2.6).

1.3.3. Selection of Members for Evaluation of Soundness

Bridges are composed of numerous members, and the degree of impact on bridge structural safety differs according to each member. Accordingly, members are classified into main members and other members according to the importance (Figure 1.3.2). Here, main members are defined as members which if left unattended may even make it necessary to rebuild the bridge concerned.



Key members

girder, crossbeam, slab deck, bridge piers, abutments, foundation

Others

bearings、 on-slab members(pavement, expansion joints, guide rail), drainage, inspection facility, ancillary attachment

Figure 1.3.2: Key members include in a bridge

The evaluation of soundness for compiling the long-term maintenance plan in DRR will target the following members.

Main girders, Crossbeams, Floor slabs, Bearings, Abutments, Bridge piers

[Reason for selecting members]

- Main members, which if left unattended may even make it necessary to rebuild the bridge concerned, are targeted.
- Out of the members that comprise bridges, bearings tend to become damaged relatively early. Bearings are targeted for evaluation of soundness in consideration of the facts that the damage changes over time, the maintenance and repair methods differ according to the conditions of damage, and the impact on cost is large.
- Among other members, there are those such as bridge deck members (paving, expansion joints, bridge railings, etc.) that have an impact on traffic safety. Damage to these bridge deck members can be dealt with by means of everyday maintenance such as paving repairs and the like, and changes in condition can be easily discovered by conducting routine road patrols; therefore, they are omitted from the evaluation of soundness.
- Concerning damage to abutments and bridge piers, damage that gets worse over time is targeted. Damages such as scouring and alteration caused by flooding and so on are not targeted because they require urgent attention and are not suited to scheduled maintenance and repair planning.
- The members targeted here refer to members that are subject to evaluation of soundness of the overall variation and scope of damage in the budget simulation; it does not indicate the members targeted in the actual long-term maintenance plan.

1.3.4. Soundness Calculation Policy

(1) Soundness Calculation Formula

The policy regarding soundness calculation is indicated below.

- Soundness is expressed by a score out of 100 points.
- The entirely sound state where there is no damage at all (for example, immediately after completion of the bridge) is given a score of 100, while the state where the impacts of damage hinder traffic and make it necessary to conduct load restrictions and traffic controls, etc. is given a score of 0.
- The overall state of damage of members is numerically expressed as the “Overall degree of damage,” and the soundness of members is calculated according to the following formula:

Soundness = 100 – Overall degree of damage

(2) Overall Damage Calculation Formula

The policy for calculating the overall degree of damage is indicated below.

- The damage evaluation classification of each element is numerically defined as a damage score, and the overall degree of damage is calculated in consideration of the ratio of damaged member numbers out of the total number of member numbers. Moreover, concerning the damage evaluation classification of each member number for which soundness is being calculated, data on inspection results will be used according to the Inspection Work and Evaluation Manual (hereafter referred to as the “Evaluation Manual”).

Table 1.3.2: Damage evaluation classification in inspection work and evaluation manual

Evaluation level	Damage
1	No damage
2	
3	
4	
5	Serious damage

Table 1.3.3: Damage evaluation classification and damage type in inspection work and evaluation manual

No	Damage	Evaluation	Remark
1	Foundation settlement, movement, displacement	1,5	-
2	Uneven surface	1,3,5	
3	Expansion joint malfunction	1,3,5	
4	Guard fence transformation	1,3,5	
5	Drainage malfunction	1,5	
6	Damaged sidewalk	1,5	
7	Ancilary facilities malfunction	1,5	
8	Abutment backside deformation	1,3,5	
9	Abutment bank protection deformation	1,3,5	
10	Scour	1,3,5	
11	Defect in PC anchorage detail	1,5	Damage of key members focused in long-term maintenance and management plan
12	Crack, leakage, freelime	1,2,3,4,5	
13	Concrete slab deck falling out	1,3,5	
14	Crack on slab deck	1,2,3,4,5	
15	Rebar exposure	1,2,3,5	
16	Bearing malfunction	1,3,5	

- The damage evaluation classifications prescribed in the Inspection Work and Evaluation Manual are stipulated as 1~5 and E and R, however, in order to conduct the future simulation, it is necessary to consider the interference to traffic if the 5 classifications are left unattended. Therefore, it has been decided to add a new classification of U (= Urgent) as the next level of damage after the five classifications. Moreover, the U classification is only a future simulation setting, i.e. it is an evaluation classification that isn’t inputted as a damage classification in inspections.

U classification: Extreme damage that has reached a level where traffic safety is hindered (as a result of future simulation)

- The damage score and overall degree of damage calculation formula are set as follows.

Table 1.3.4: damage evaluation classification and damage score point

Damage evaluation	Point
1	0
2	20
3	50
4	70
5	90
U	200

$D = 20 \times D_1 + 50 \times D_2 + 70 \times D_3 + 90 \times D_4 + 200 \times D_5$

Where, D : Overall degree of damage

D_1 : Ratio of member numbers of evaluation classification 2

D_2 : Ratio of member numbers of evaluation classification 3

D_3 : Ratio of member numbers of evaluation classification 4

D_4 : Ratio of member numbers of evaluation classification 5

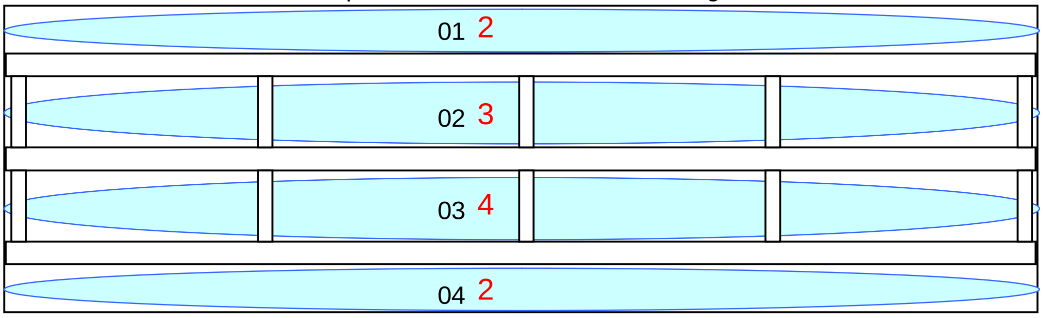
D_5 : Ratio of member numbers of evaluation classification U

The damage score is set while taking the following items into account:
Evaluation classification 2 occurs in all member numbers: soundness score 80
Evaluation classification 3 occurs in all member numbers: soundness score 50
Evaluation classification 4 occurs in all member numbers: soundness score 30
Evaluation classification 5 occurs in all member numbers: soundness score 10

Since Evaluation classification U, which is separately set for conducting simulation of future conditions, targets damage that is serious enough to impede traffic safety, its damage score is set at 200 in consideration of its importance and in order to thoroughly ensure that risk is averted.

1.3.5. Example of Soundness Calculation (Slab deck)

Inspection result of slab deck damage



Damage degree calculation

Damage evaluation	Point	No. of member	Rate	Total No of member	Total damage degree
1	0	0	0.00	4	40.0
2	20	2	0.50		
3	50	1	0.25		
4	70	1	0.25		
5	90	0	0.00		
U	200	0	0.00		

Soundness degree calculation at inspection

Soundness degree
＝100-40.0
＝60.0

Overall degree of damage: D＝20×0.50＋50×0.25＋70×0.25＋90×0.0＋200×0.0＝40.0

Floor slab soundness : 100 - 40.0 = 60.0

1.3.6. Soundness Evaluation Method of Damage that Requires Urgent Attention and Damage having a High Level of Priority for Maintenance and Repair

In cases of damage classed as 5, which is the most advanced state of damage, in the periodic inspection, the results of inspection are reevaluated by expert engineers from the viewpoint of risk aversion. As a result of the re-evaluation, the damage classification 5 is classified into three types as shown in Table 1.2.5.

Table 1.3.5 Damage classification in damage classification 5

Classification		Definition of Classification	Evaluation
[Classification1]	Emergency repair is necessary	Emergency repair is necessary to recover damage in the short time to provide service as normal.	「E」
[Classification2]	maintenance and repair for damage with high priority	maintenance and repair for damage with high priority	「R」
[Classification3]	Other damages, excluded in Classification 1 and 2.	Other damages, exclueded in Classification 1 and 2.	「5」

Here, out of the classified damage levels, concerning Classification 1 which refers to damage that requires urgent attention, and Classification2 which refers to damage with a high priority for maintenance and repair, evaluation methods in the long-term maintenance plan are indicated below.

(1) Classification 1: damage that requires urgent attention (E)

Since traffic is already hindered due to bridge collapse and so on, urgent attention is needed. Accordingly, in the long-term maintenance plan, this is not targeted for evaluation of soundness, and the following handling is conducted in the simulation:

Members that are evaluated as “E” following re-evaluation of the inspection results are omitted from simulation.

Assuming that the members evaluated as “E” undergo complete maintenance and repair countermeasures under urgent response in three years from the day of inspection implementation, they will be reverted to simulation from the fourth year onwards. Soundness at the time of reversion will be 100 points.

(2) Classification 2: damage with high priority for maintenance and repair (R)

Within damage classification 5, this refers to damage that is deemed to have particularly high urgency and to carry a risk of critically impacting bridge safety by expert engineers. Accordingly, the soundness of members experiencing damage having a high maintenance and repair priority (R) is calculated as follows.

■ Damage with a high maintenance and repair priority (R)

Soundness = 10 (total soundness = 90)

Moreover, if damage having a high maintenance and repair priority (R) occurs in even one member number, the soundness of members is evaluated as 10.

(2) Example of evaluation of the soundness of members in which damage having a high maintenance and repair priority (R) occurs

Ex) RC slab deck

Inspection result

Image of damage in member number 03

Soundness estimation without consideration of high priority for repair

Damage evaluation	Point	No. of member	Rate	Total No of member	Total damage degree
1	0	0	0.00	4	45.0
2	20	2	0.50		
3	50	1	0.25		
4	70	0	0.00		
5	90	1	0.25		
U	200	0	0.00		

Soundness degree
＝100-45.0
＝55.0

Soundness estimation with consideration of high priority for repair (concept in this plan)

Total damage degree is equal to 90 points.

Damage evaluation	Point	No. of member	Rate	Serious damage	Total No of member	Total damage degree
1	0	0	0.00	0	4	90.0
2	20	2	0.50	0		
3	50	1	0.25	0		
4	70	0	0.00	0		
5	90	1	0.25	1		
U	200	0	0.00	0		

Soundness degree
＝100-90.0
＝10.0

1.4. Method for Future Prediction of Soundness

1.4.1. Thinking on Degradation Prediction

In order to compile a preventive maintenance plan for taking measures that are based on the medium- to long-term viewpoint, it is necessary to gauge the future state of degradation of bridges (what state of damage is reached, and when).

However, currently, since no technology for predicting bridge degradation has been established but it is still in the research stage, it is currently difficult to quantitatively and accurately predict the condition of damage at points in the future. As is shown in Table 1.6.1, the degradation prediction methods that are currently used are broadly divided into theoretical methods and methods based on data analysis. The most appropriate method for the project will be adopted upon identifying the characteristics of each.

Table 1.4.1: degradation prediction methods and comparison

Item	Theoretical method	Analytic method
Outline	Method on the basis of the knowledge and experience to date, which predict the deterioration theoretically.	Method to enable degradation prediction by collecting and analyzing the inspection data from an existing bridge.
Example	- Concrete slab deck degradation (salt damage, carbonation) - Fatigue in RC slab deck - Damage of painting on steel member	- Markov Transition Probability
Feature	Possible to predict the degradation state given limitation in the use of material and specific members.	- Direct measurement enables to figure out the degradation state at high accuracy during inspection work. - Many examples of inspection results obtained in the simple manner.
Problematic issues	- Limit to material, member, and degradation prediction or condition. - Require results of material test, sampling test, NDT, and structural calculation. - Prediction becomes different from practical result depending on construction and environmental situation.	- Lack of inspection result causes low qualified degradation prediction and the basis of prediction becomes unreliable. - Good qualified degradation prediction formula requires many inspection results by repeating inspection and it costs more to get enough data.
Past performance	- Part of Ministry of Land, Infrastructure, Transport and Tourism - Ehime prefecture	- PONTIS - Part of Ministry of Land, Infrastructure, Transport and Tourism

		- Kochi, Hyogo, and Wakayama prefectures - Hokkaido Development Department
Judgment	Unaccepted	Accepted - Available to apply it to initial data - Available to upgrade data with database development.

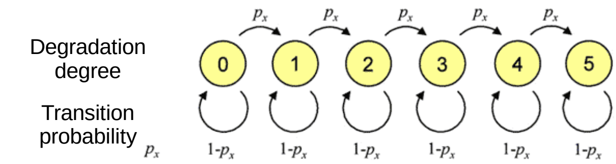
[Reason for selecting Markov's transition probability]

- Periodic inspections according to the Inspection Survey and Evaluation Manual are basically predicated on close visual inspection, and it is impossible to apply theoretical methods that require test values.
- Markov's transition probability is a soundness calculation method for gauging the condition of bridges in which all inspection data (degree of damage to each member number) are used to evaluate the degree of soundness of members overall upon considering the scale, scope and variance of damage. Through using this method, it is possible to effectively utilize the bridge inspection data that will be accumulated from now, appropriately evaluate the scope and variance of damage based on the weighted mean of all inspection data, and improve the accuracy of budget planning.
- In order to predict the soundness of bridges in the future, it is necessary to predict the scale, scope and variance of damage in the future. Out of the two degradation prediction methods mentioned earlier, the method of data analysis using Markov's transition probability is able to predict the scope and variance of damage (theoretical methods can predict the scale of damage but not the scope and variance of damage). Moreover, because Markov's transition probability is extremely easy to use, it is possible to compile accurate budget plans in consideration of "safety and peace of mind" through skillfully linking the degradation transition probability with the damage points in the soundness calculation.
- In consideration of the above points, it is recommended that data analysis using Markov's transition probability be adopted as the method for predicting degradation in the long-term maintenance planning of DRR.

1.4.2. Outline of Markov's Transition Probability

Markov's transition probability is a model for indicating the probability that one state of being will change to the next state of being. For example, assuming that only elements with probability of Px will move from degradation state 0 to degradation state 1 in a year, the remaining elements (1-Px) will remain at degradation state 0. By conducting this repetitive calculation once a year, it is possible to calculate the distribution of probability indicating the state of degradation.

Markov Transition Probability



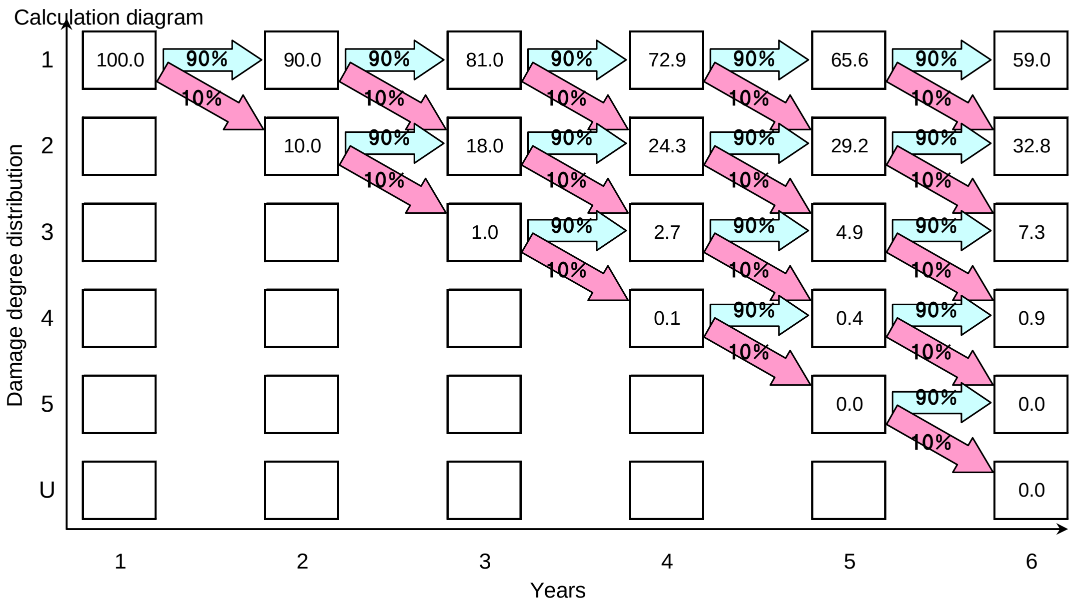
Application of degradation progress model converted from Markov-chain

Example of Markov Transition Probability Matrix

Degradation prediction formula From

To		1	2	3	4	5	U
	1	0.900	0.000	0.000	0.000	0.000	0.000
	2	0.100	0.900	0.000	0.000	0.000	0.000
	3	0.000	0.100	0.900	0.000	0.000	0.000
	4	0.000	0.000	0.100	0.900	0.000	0.000
	5	0.000	0.000	0.000	0.100	0.900	0.000
	U	0.000	0.000	0.000	0.000	0.100	1.000

Calculation diagram



1.4.3. Concrete Image of Degradation Prediction using Markov's Transition Probability

Markov's transition probability matrix is assumed to be as follows. (The transition probability matrix is appropriately calculated from the inspection results (described later)).

From

To	1	2	3	4	5	U
1	0.950	0.000	0.000	0.000	0.000	0.000
2	0.050	0.950	0.000	0.000	0.000	0.000
3	0.000	0.050	0.950	0.000	0.000	0.000
4	0.000	0.000	0.050	0.950	0.000	0.000
5	0.000	0.000	0.000	0.050	0.975	0.000
U	0.000	0.000	0.000	0.000	0.025	1.000

Note) The above table shows the transition probability matrix where 5% of the member numbers that are evaluated with an "a" classification this year move to the "b" classification next year, while the remaining 95% of member numbers remain in the "a" category.

Using the above transition probability matrix, the formula for predicting the distribution of damage after "t" years can be expressed as shown below.

Damage distribution after t years

One-year transition probability matrix   Damage distribution at present

$$
\begin{pmatrix}
0.950 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.050 & 0.950 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.000 & 0.050 & 0.950 & 0.000 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.050 & 0.950 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.000 & 0.050 & 0.975 & 0.000 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.025 & 1.000
\end{pmatrix}^{t}
\times
\begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ U \end{pmatrix}
=
\begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ U \end{pmatrix}
$$

1.4.4. Policy for Calculating the Degradation Prediction Formula

In order to predict degradation with high accuracy, needless to say the method whereby the unique degradation prediction formula is calculated for each bridge member is ideal. Moreover, since only bridges that undergo inspection are targeted for long-term maintenance planning, it is possible to obtain inspection results for all the bridges targeted by the planning. Therefore, the degradation prediction formula will be calculated based on the method for calculating the unique degradation prediction formula for each member of each bridge.

In calculating the degradation prediction formula, the ideal approach is to conduct reverse calculation of the unique degradation predication formula of each member of each bridge using the results of a number of inspections that have been implemented in recent years. However, DRR does not have such multiple sets of inspection results. Accordingly, regarding the conditions at the time of completion as hypothetical inspection results, the unique degradation prediction formula for each member of each bridge derived from the inspection results here and the years of service shall be calculated. Figure 1.6.1 shows the concrete image of degradation prediction.

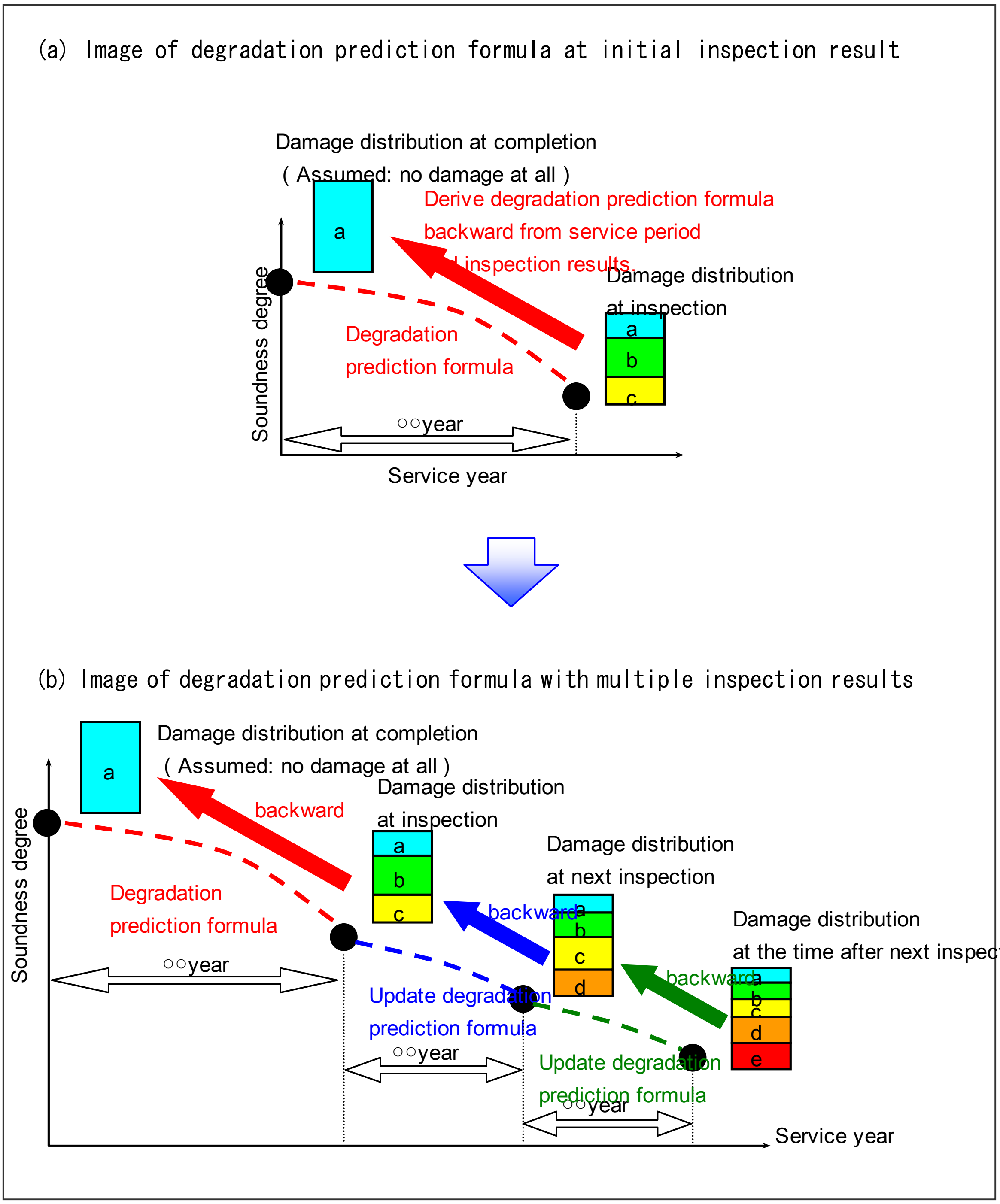


Figure 1.4.1: Image of deriving degradation prediction formula

1.4.5. Method for Calculating the Degradation Prediction Formula

The following figure shows the image of the method for calculating the degradation prediction formula.

One-year transition probability matrix

Damage distribution at present

Damage distribution after t years

$$\begin{pmatrix} X_{11} & X_{12} & X_{13} & X_{14} & X_{15} & X_{16} \\ X_{21} & X_{22} & X_{23} & X_{24} & X_{25} & X_{26} \\ X_{31} & X_{32} & X_{33} & X_{34} & X_{35} & X_{36} \\ X_{41} & X_{42} & X_{43} & X_{44} & X_{45} & X_{46} \\ X_{51} & X_{52} & X_{53} & X_{54} & X_{55} & X_{56} \\ X_{61} & X_{62} & X_{63} & X_{64} & X_{65} & X_{66} \end{pmatrix} \times \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ U \end{pmatrix} = \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ U \end{pmatrix}$$

Degradation prediciton formula derivation

$$\begin{pmatrix} X_{11} & X_{12} & X_{13} & X_{14} & X_{15} & X_{16} \\ X_{21} & X_{22} & X_{23} & X_{24} & X_{25} & X_{26} \\ X_{31} & X_{32} & X_{33} & X_{34} & X_{35} & X_{36} \\ X_{41} & X_{42} & X_{43} & X_{44} & X_{45} & X_{46} \\ X_{51} & X_{52} & X_{53} & X_{54} & X_{55} & X_{56} \\ X_{61} & X_{62} & X_{63} & X_{64} & X_{65} & X_{66} \end{pmatrix} \Leftarrow \begin{pmatrix} 1.000 \\ 0.000 \\ 0.000 \\ 0.000 \\ 0.000 \\ 0.000 \end{pmatrix} \quad \begin{pmatrix} 0.400 \\ 0.200 \\ 0.200 \\ 0.100 \\ 0.100 \\ 0.000 \end{pmatrix}$$

(1) Conditions for calculating the degradation prediction formula of each member of each bridge

In calculating the degradation prediction formula, the following conditions are established in order to simplify the calculation process.

1) Assuming that the level of degradation in each damage evaluation classification falls by one stage per year or it stays the same, falls of two stages or recovery of the damage evaluation classification shall not be considered.

Specifically, assuming that damage that is evaluated to be damage classification 2 in a certain year moves to damage classification 3 or remains at damage classification 2 in the next year, this approach stipulates that there can be no transition to damage classification 4 or recovery to damage classification 1. Moreover, because damage in the final stage of damage classification U cannot deteriorate any more than that, the probability of remaining as the U classification shall be 1.0.

		From					
		1	2	3	4	5	U
To	1	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
	2	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	X_{26}
	3	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	X_{36}
	4	X_{41}	X_{42}	X_{43}	X_{44}	X_{45}	X_{46}
	5	X_{51}	X_{52}	X_{53}	X_{54}	X_{55}	X_{56}
	U	X_{61}	X_{62}	X_{63}	X_{64}	X_{65}	X_{66}

		From					
		1	2	3	4	5	U
To	1	X_{11}	0.000	0.000	0.000	0.000	0.000
	2	X_{21}	X_{22}	0.000	0.000	0.000	0.000
	3	0.000	X_{32}	X_{33}	0.000	0.000	0.000
	4	0.000	0.000	X_{43}	X_{44}	0.000	0.000
	5	0.000	0.000	0.000	X_{54}	X_{55}	0.000
	U	0.000	0.000	0.000	0.000	X_{65}	1.000

Through applying this regulation, the transition probability matrix becomes as follows.

2) The significant figure of the transition probability shall be down to the third decimal point.

3) Set so that the total of the row of determinants always becomes 1.0.

4) The probability that a certain damage evaluation classification moves to a one-rank lower damage evaluation classification is calculated using the following formula:

$$X_{21}=1\text{-}X_{11} \qquad X_{32}=1\text{-}X_{22} \qquad X_{43}=1\text{-}X_{33} \qquad X_{54}=1\text{-}X_{44} \qquad X_{65}=1\text{-}X_{5}$$

Based on this formula, the transition probability matrix becomes as follows.

		From					
		1	2	3	4	5	U
To	1	X_{11}	0.000	0.000	0.000	0.000	0.000
	2	X_{21}	X_{22}	0.000	0.000	0.000	0.000
	3	0.000	X_{32}	X_{33}	0.000	0.000	0.000
	4	0.000	0.000	X_{43}	X_{44}	0.000	0.000
	5	0.000	0.000	0.000	X_{54}	X_{55}	0.000
	U	0.000	0.000	0.000	0.000	X_{65}	1.000

⇨

		From					
		1	2	3	4	5	U
To	1	X_{11}	0.000	0.000	0.000	0.000	0.000
	2	$1\text{-}X_{11}$	X_{22}	0.000	0.000	0.000	0.000
	3	0.000	$1\text{-}X_{22}$	X_{33}	0.000	0.000	0.000
	4	0.000	0.000	$1\text{-}X_{33}$	X_{44}	0.000	0.000
	5	0.000	0.000	0.000	$1\text{-}X_{44}$	X_{55}	0.000
	U	0.000	0.000	0.000	0.000	$1\text{-}X_{55}$	1.000

5) The probability (X11) that damage classification 1 remains at damage classification 1 is calculated as follows.

$$\begin{array}{ccccc} \text{One-year transition probability matrix} & & \text{Damage distribution at present} & & \text{Inspection result after t years} \\ \begin{pmatrix} X_{11} & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\ 1\text{-}X_{11} & X_{22} & 0.000 & 0.000 & 0.000 & 0.000 \\ 0.000 & 1\text{-}X_{22} & X_{33} & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.000 & 1\text{-}X_{33} & X_{44} & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.000 & 1\text{-}X_{44} & X_{55} & 0.000 \\ 0.000 & 0.000 & 0.000 & 0.000 & 1\text{-}X_{55} & 1.000 \end{pmatrix}^{t} & \times & \begin{pmatrix} 1_1 \\ 2_1 \\ 3_1 \\ 4_1 \\ 5_1 \\ U_1 \end{pmatrix} & = & \begin{pmatrix} 1_2 \\ 2_2 \\ 3_2 \\ 4_2 \\ 5_2 \\ U_2 \end{pmatrix} \end{array}$$

$$X_{11}=(1_2/1_1)^{1/t}$$

Considering that the damage distribution at the time of completion is all contained in the “a” classification, it becomes as follows:

$$X_{11}=1_2^{\,1/t}$$

6) Concerning the probability that damage classification 2 remains at damage classification 2, the value where the disparity between the actually measured value (= inspection result) and predicted value is smallest will be calculated by means of trial calculation. The probability at this time will be expressed in units of 0.001.

The ratio of member numbers with damage classification 2 after t years represents the total of the ratio of members that drop from damage classification 1 to damage classification 2 in t years and the ratio of members that remain at damage classification 2 over t years. Therefore, it is difficult to calculate the ratio of damage classification 2 after t years using a certain formula. Accordingly, upon setting an optional probability, it was decided to conduct trial calculation of the value where the disparity between a predicted value after t years calculated using the optional probability and the actually measured value (= inspection results) becomes the smallest. The calculation image is indicated below.

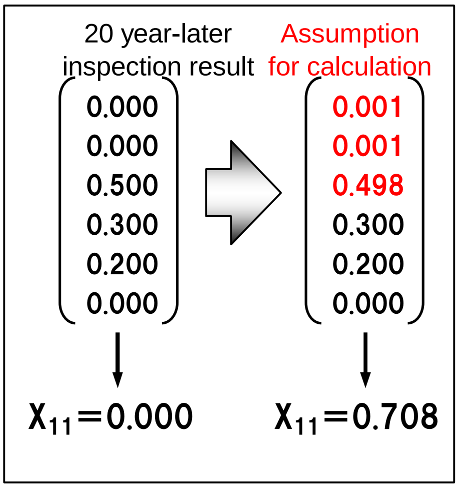
Random probability	Prediction	Actual	Difference
0.957	0.521	0.500	0.021
0.956	0.515	0.500	0.015
0.955	0.509	0.500	0.009
0.954	0.503	0.500	0.003 MIN
0.953	0.496	0.500	0.004
0.952	0.490	0.500	0.010
0.951	0.484	0.500	0.016

Incidentally, the precondition here is that the transition probability of a one-rank higher damage evaluation classification (= damage classification 1) is calculated based on 5) and 4) above.

7) The probability that damage classification 3 remains at damage classification 3 and that damage classification 4 remains at damage classification 4 is calculated according to the same method that was described in paragraph 6) above.

8) In the inspection results after t years, even if there are no member numbers that indicate a certain damage evaluation classification, calculation will be conducted assuming that 0.1% exists (however, not in the case of the U classification).

For example, considering the case where X11 stated in 5) is sought, assuming that the ratio of damage classification 1 after t years is 0%, the calculation will show X11＝0.000. This indicates that all elements of damage classification 1 will become damage classification 2 in the next year, and this isn't realistic. Therefore, in calculation of the degradation prediction formula, even if a damage level doesn't exist in the inspection results, it will be assumed to exist as 0.1% in the calculation.



9) Concerning the probability that damage classification 5 remains at damage classification 5, because the aforementioned calculation method cannot be adopted, an optional value will be set.

The damage evaluation classification U, which is the next rank below damage classification 5, is a hypothetical damage evaluation classification used to express the adverse impacts that are experienced when damage classification 5 is left unattended. Therefore, since U is not a damage evaluation classification that can be obtained in inspections, the aforementioned calculation method cannot be adopted. Therefore, it has been decided to adopt an optional value as the probability for transition to the U classification. Moreover, because the transition probability to the U classification is an extremely important value in compiling the long-term maintenance plan, it is desirable to set it carefully.

10) The maximum probability and minimum probability that a certain damage classification remains at the same damage classification shall be 0.990 and 0.600 respectively. This shall be applicable for when seeking the transition probability for damage classifications of 2 and under, but it shall not be applied to calculating the transition probability of damage classification 1.

If there is a reasonable variance in damage classifications 1~5 in the damage distribution obtained from the inspection results, the degradation prediction formula can be calculated relatively accurately from the aforementioned methods 1)~9). However, in the case where a certain damage classification occupies a large proportion of the damage distribution, there is a risk that an unrealistic degradation prediction formula will be computed if using only methods 1)~9). Accordingly, even if a certain damage classification occupies a large proportion of the damage distribution in the inspection, it has been decided to establish a maximum value and a minimum value for the transition probability in order to express that degradation has moved in stages.

Damage distribution at construction completion	20 year-later inspection result	Assumption for calculation
$\begin{pmatrix} 1.000 \\ 0.000 \\ 0.000 \\ 0.000 \\ 0.000 \\ 0.000 \end{pmatrix}$	$\begin{pmatrix} 0.000 \\ 0.000 \\ 1.000 \\ 0.000 \\ 0.000 \\ 0.000 \end{pmatrix}$	$\begin{pmatrix} 0.001 \\ 0.001 \\ 0.996 \\ 0.001 \\ 0.001 \\ 0.000 \end{pmatrix}$

Calculation at ①～⑨

		From					
		1	2	3	4	5	U
	1	0.708	0.000	0.000	0.000	0.000	0.000
	2	0.292	0.124	0.000	0.000	0.000	0.000
To	3	0.000	0.876	0.999	0.000	0.000	0.000
	4	0.000	0.000	0.001	0.999	0.000	0.000
	5	0.000	0.000	0.000	0.001	0.990	0.000
	U	0.000	0.000	0.000	0.000	0.010	1.000

Apply ⑩

		From					
		1	2	3	4	5	U
	1	0.708	0.000	0.000	0.000	0.000	0.000
	2	0.292	0.600	0.000	0.000	0.000	0.000
To	3	0.000	0.400	0.990	0.000	0.000	0.000
	4	0.000	0.000	0.010	0.990	0.000	0.000
	5	0.000	0.000	0.000	0.010	0.990	0.000
	U	0.000	0.000	0.000	0.000	0.010	1.000

Figure 1.4.2: Example of application of damage classification with little scatter

(2) Example of calculation results

The following paragraphs show an example of the degradation prediction formula calculated using this method.

1) Case 1-1

Damage distribution: Damage is moderately dispersed

Case 1 Years of service : 10 years

Damage distribution at completion	10 year-later damage distribution
1.000	0.300
0.000	0.300
0.000	0.200
0.000	0.100
0.000	0.100
0.000	0.000

Degradation prediction formula calculated (To / From)

	1	2	3	4	5	U
1	0.887	0.000	0.000	0.000	0.000	0.000
2	0.113	0.837	0.000	0.000	0.000	0.000
3	0.000	0.163	0.781	0.000	0.000	0.000
4	0.000	0.000	0.219	0.667	0.000	0.000
5	0.000	0.000	0.000	0.333	0.990	0.000
R	0.000	0.000	0.000	0.000	0.010	1.000

10 year-later calculation result from degradation prediction formula
0.301
0.300
0.200
0.100
0.098
0.002

Soundness degree 68.0 67.9

Difference between inspection result and prediction 0.147%

2) Case 1-2

Damage distribution: Damage is moderately dispersed

Case 2 Years of service : 20 years

Damage distribution at completion	20 year-later damage distribution
1.000	0.300
0.000	0.300
0.000	0.200
0.000	0.100
0.000	0.100
0.000	0.000

Degradation prediction formula calculated (To / From)

	1	2	3	4	5	U
1	0.942	0.000	0.000	0.000	0.000	0.000
2	0.058	0.920	0.000	0.000	0.000	0.000
3	0.000	0.080	0.898	0.000	0.000	0.000
4	0.000	0.000	0.102	0.855	0.000	0.000
5	0.000	0.000	0.000	0.145	0.990	0.000
U	0.000	0.000	0.000	0.000	0.010	1.000

20 year-later calculation result from degradation prediction formula
0.303
0.301
0.199
0.100
0.093
0.004

Soundness degree 68.0 67.8

Difference between inspection result and prediction 0.294%

3) Case 1-3

Damage distribution: Damage is moderately dispersed

Case 3 Years of service : 30 years

Damage distribution at completion	30 year-later damage distribution
1.000	0.300
0.000	0.300
0.000	0.200
0.000	0.100
0.000	0.100
0.000	0.000

Degradation prediction formula calculated (To / From)

	1	2	3	4	5	U
1	0.961	0.000	0.000	0.000	0.000	0.000
2	0.039	0.947	0.000	0.000	0.000	0.000
3	0.000	0.053	0.934	0.000	0.000	0.000
4	0.000	0.000	0.066	0.908	0.000	0.000
5	0.000	0.000	0.000	0.092	0.990	0.000
U	0.000	0.000	0.000	0.000	0.010	1.000

30 year-later calculation result from degradation prediction formula
0.303
0.301
0.200
0.100
0.090
0.006

Soundness degree 68.0 67.7

Difference between inspection result and prediction 0.441%

4) Case 2-1

Damage distribution: Damage is concentrated in the lower judgment range

Case 4 Years of service : 10 years

	Damage distribution at completion	10 year-later damage distribution
	1.000	0.000
	0.000	0.000
	0.000	0.500
	0.000	0.300
	0.000	0.200
	0.000	0.000
Soundness degree		36.0

Degradation prediction formula calculated

To \ From	1	2	3	4	5	U
1	0.501	0.000	0.000	0.000	0.000	0.000
2	0.499	0.600	0.000	0.000	0.000	0.000
3	0.000	0.400	0.884	0.000	0.000	0.000
4	0.000	0.000	0.116	0.843	0.000	0.000
5	0.000	0.000	0.000	0.157	0.990	0.000
U	0.000	0.000	0.000	0.000	0.010	1.000

10 year-later calculation result from degradation prediction formula
0.001
0.025
0.497
0.300
0.173
0.003
37.4

Difference between inspection result and prediction 3.743%

5) Case 2-2

Damage distribution: Damage is concentrated in the lower judgment range

Case 5 Years of service : 20 years

	Damage distribution at completion	20 year-later damage distribution
	1.000	0.000
	0.000	0.000
	0.000	0.500
	0.000	0.300
	0.000	0.200
	0.000	0.000
Soundness degree		36.0

Degradation prediction formula calculated

To \ From	1	2	3	4	5	U
1	0.708	0.000	0.000	0.000	0.000	0.000
2	0.292	0.600	0.000	0.000	0.000	0.000
3	0.000	0.400	0.951	0.000	0.000	0.000
4	0.000	0.000	0.049	0.930	0.000	0.000
5	0.000	0.000	0.000	0.070	0.990	0.000
U	0.000	0.000	0.000	0.000	0.010	1.000

20 year-later calculation result from degradation prediction formula
0.001
0.003
0.497
0.299
0.190
0.010
35.0

Difference between inspection result and prediction 2.854%

6) Case 2-3

Damage distribution: Damage is concentrated in the lower judgment range

Case 6 Years of service : 30 years

	Damage distribution at completion	30 year-later damage distribution
	1.000	0.000
	0.000	0.000
	0.000	0.500
	0.000	0.300
	0.000	0.200
	0.000	0.000
Soundness degree		36.0

Degradation prediction formula calculated

To \ From	1	2	3	4	5	U
1	0.794	0.000	0.000	0.000	0.000	0.000
2	0.206	0.600	0.000	0.000	0.000	0.000
3	0.000	0.400	0.969	0.000	0.000	0.000
4	0.000	0.000	0.031	0.956	0.000	0.000
5	0.000	0.000	0.000	0.044	0.990	0.000
U	0.000	0.000	0.000	0.000	0.010	1.000

30 year-later calculation result from degradation prediction formula
0.001
0.001
0.494
0.300
0.188
0.017
34.1

Difference between inspection result and prediction 5.572%

1.5. Setting of Maintenance and Repair Measures according to Soundness

1.5.1. Relation between the Definition of Measures and Control level

Table 1.4.1 shows the relationship between the definition of measures, control level and soundness setting during countermeasures.

Table 1.5.1: Term definition and control level concept

Control level	Definition in repair		Before-repair soundness
A	Preventive action	Preventive action to slight defect	80
B	Repair 1 (soft)	Repair for soft damage at low cost	60
C	Repair 2 (medium)	Repair for medium damage at high cost	40
D	Repair 3 (hard)	Repair for hard damage at high cost through replacement	20
Other	Replacement	Bridge replacement	0

1.5.2. Setting of Maintenance and Repair Measures according to Members

(1) Floor slabs (floor slab bridge, plank girder bridge, box girder bridge)

Table 1.5.2: maintenance and repair of floor slab (floor slab bridge, plank girder bridge, box girder bridge)

Control level	Measures	Repair item	Before-repair soundness	After-repair soundness	Unit price per square meter
A	Preventive action	Protection painting, Scaffolding	80	95	3,000 THB/m^2
B	Repair 1 (soft)	Protection painting, Anti-crack injection, Section recovery, Scaffolding	60	95	4,000 THB/m^2
C	Repair 2 (medium)	Protection painting, Anti-crack injection, Section recovery, Scaffolding	40	95	4,000 THB/m^2
D	Repair 3 (hard)	Protection painting, Anti-crack injection, Section recovery, CFRP sheet attachment, Scaffolding	20	100	14,000 THB/m^2
Other	Replacement	Bridge replacement	0	100	118,800 THB/m^2

- The outline works costs are calculated according to the following formula:
  Outline works cost = Span length x Width x Rough works unit cost

- In cases where there is extreme damage to main girders (soundness is 0 or below), it is envisaged that the entire bridge will be rebuilt.

(2) PCI girder bridges

Table 1.5.3: maintenance and repair of PCI girder bridge

Control level	Measures	Repair item	Before-repair soundness	After-repair soundness	Unit price per square meter
A	Preventive action	Waterproofing, Asphalt pavement, Protection painting, Scaffolding	80	95	5,000 THB/m^2
B	Repair 1 (soft)	Waterproofing, Asphalt pavement, Protection painting, Anti-crack injection, Section recovery, Scaffolding	60	95	7,000 THB/m^2
C	Repair 2 (medium)	Waterproofing, Asphalt pavement, Protection painting, Anti-crack injection, Section recovery, Scaffolding	40	95	8,000 THB/m^2
D	Repair 3 (hard)	Waterproofing, Asphalt pavement, Protection painting, Anti-crack injection, Section recovery, CFRP sheet attachment, Scaffolding	20	100	33,000 THB/m^2
Other	Replacement	Bridge replacement	0	100	118,800 THB/m^2

- The outline works costs are calculated according to the following formula:

  Outline works cost = Span length x Width x Rough works unit cost

- In cases where there is extreme damage to main girders (soundness is 0 or below), it is envisaged that the entire bridge will be rebuilt.

(3) Filled floor slab bridges (plank girder bridges, box girder bridges)

Table 1.5.4: maintenance and repair of filled floor slab bridge (plank girder bridge, box girder bridge)

Control level	Measures	Repair	Before-repair soundness	After-repair soundness	Unit price per square meter
A	Preventive action	Waterproofing, Asphalt pavement	80	95	600 THB/m^2
B	Repair 1 (soft)	Waterproofing, Asphalt pavement	60	95	600 THB/m^2
C	Repair 2 (medium)	Waterproofing, Asphalt pavement	40	95	600 THB/m^2
D	Repair 3 (hard)	Waterproofing, Asphalt pavement, Slab deck section recovery	20	100	2,000 THB/m^2
Other	Replacement	Bridge replacement	0	100	118,800 THB/m^2

- The outline works costs are calculated according to the following formula:

  Outline works cost = Span length x Width x Rough works unit cost

- In cases where there is extreme damage to floor slabs (soundness is 0 or below), it is envisaged that the entire bridge will be rebuilt.

(4) Slab deck girder bridge

Table 1.5.5: maintenance and repair of slab deck girder (PCT girder bridge)

Control level	Measures	Repair item	Before-repair soundness	After-repair soundness	Unit price per square meter
A	Preventive action	Waterproofing, Asphalt pavement, Protection painting, Scaffolding	80	95	3,000 THB/m^2
B	Repair 1 (soft)	Waterproofing, Asphalt pavement, Protection painting, Anti-crack injection, Section recovery, Scaffolding	60	95	3,000 THB/m^2
C	Repair 2 (medium)	Waterproofing, Asphalt pavement, Protection painting, Anti-crack injection, Section recovery, Scaffolding	40	95	9,000 THB/m^2
D	Repair 3 (hard)	Waterproofing, Asphalt pavement, Protection painting, Anti-crack injection, Section recovery, CFRP sheet attachment, Scaffolding	20	100	60,000 THB/m^2
Other	Replacement	Bridge replacement	0	100	118,800 THB/m^2

- The outline works costs (excluding the case of bridge rebuilding) are calculated according to the following formula:

  Outline works cost = Span length x Width x Rough works unit cost

- In cases where there is extreme damage to floor slabs (soundness is 0 or below), it is envisaged that the entire bridge will be rebuilt.

(5) Bearings

Table 1.5.6: maintenance and repair of bearings

Control level	Measures	Repair	Before-repair soundness	After-repair soundness	Unit price per square meter
A	Preventive action	-	80	-	- THB/each
B	Repair 1 (soft)	Repainting	60	95	12,000 THB/each
C	Repair 2 (medium)	Renewal	40	95	29,000 THB/each
D	Repair 3 (hard)	Replacement	20	100	297,000 THB/each
Other	Replacement	Bridge replacement	0	100	118,800 THB/m^2

- The outline works costs are calculated according to the following formula:
  Outline works cost = Number of bearings x Rough works unit cost
- In cases where there is extreme damage to bearings (soundness is 0 or below), it is envisaged that the entire bridge will be rebuilt.

(6) Bridge piers

Table 1.5.7: maintenance and repair of bridge piers

Control level	Measures	Repair	Before-repair soundness	After-repair soundness	Unit price per square meter
A	Preventive action	Protection painting, Scaffolding	80	95	388,750 THB/each
B	Repair 1 (soft)	Protection painting, Anti-crack injection, Section recovery, Scaffolding	60	95	463,000 THB/each
C	Repair 2 (medium)	Protection painting, Anti-crack injection, Section recovery, Scaffolding	40	95	537,000 THB/each
D	Repair 3 (hard)	Anticrack injection, Section recovery, RC reinforcement, Scaffolding	20	100	795,000 THB/each
Other	Replacement	Bridge replacement	0	100	118,800 THB/m^2

- The outline works costs (excluding the case of bridge rebuilding) are calculated according to the following formula:
  Outline works cost = Number of bridge piers x Rough works unit cost
- In cases where there is extreme damage to bridge piers (soundness is 0 or below), it is envisaged that the entire bridge will be rebuilt.

(7) Abutments

Table 1.5.8: maintenance and repair of abutments

Control level	Measures	Repair	Before-repair soundness	After-repair soundness	Unit price per square meter
A	Preventive action	Protection painting, Scaffolding	80	95	90,000 THB/each
B	Repair 1 (soft)	Protection painting, Anti-crack injection, Section recovery, Scaffolding	60	95	110,000 THB/each
C	Repair 2 (medium)	Protection painting, Anti-crack injection, Section recovery, Scaffolding	40	95	130,000 THB/each
D	Repair 3 (hard)	Anticrack injection, Section recovery, RC reinforcement, Scaffolding	20	100	234,000 THB/each
Other	Replacement	Bridge replacement	0	100	118,800 THB/m^2

- The outline works costs are calculated according to the following formula:

  Outline works cost = Number of bridge abutments x Rough works unit cost
- In cases where there is extreme damage to bridge abutments (soundness is 0 or below), it is envisaged that the entire bridge will be rebuilt.

1.6. Policy for Deciding the Order of Priority of Countermeasures

In order to compile the long-term maintenance plan, it is necessary to calculate the feasible single year budget for DRR while sustaining the future soundness of bridges (i.e. equalize the budget), and in order to consider budget equalization it is necessary to decide the order of priority of maintenance. Figure 1.6.1 sums up the previously mentioned approaches used when deciding the order of priority of maintenance.

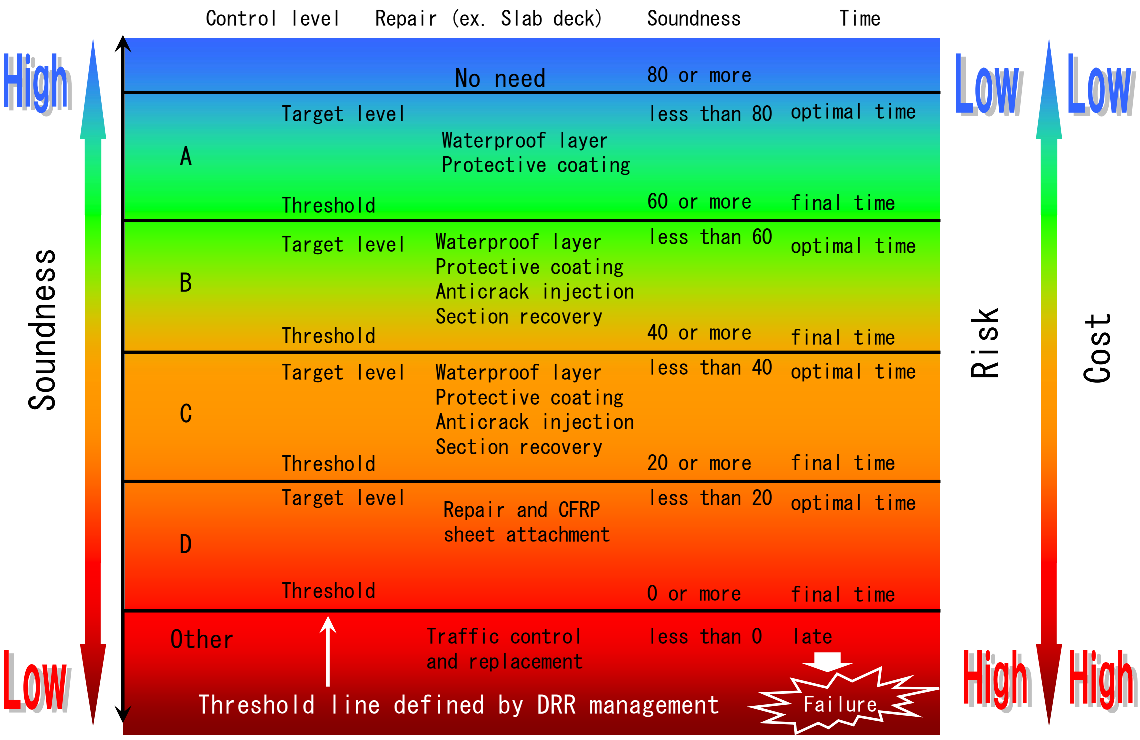


Figure 1.6.1: Control level, repair, soundness, and time in long-term maintenance and management plan

- The vertical axis expresses soundness so that high soundness is shown at the top and low soundness at the bottom.
- Control Level A, Control Level B, Control Level C and Control Level D are arranged moving from the top towards the bottom.
- Concerning the countermeasures that correspond to each control level, taking the example of slab deck in girder bridges, the following measures are applied: insertion of waterproof layer and protective coating in Control Level A; insertion of waterproof layer, protective coating and anti-crack injection in Control Level B; maintenance and repair works + CFRP sheet

attachment in Control Level C; and slab deck replacement in Control Level D.

- Expressing the timing for implementation of countermeasures at each control level in terms of the soundness value, Control Level A is 60~79, Control Level B is 40~59, Control Level C is 20~39, and Control Level D is 0~19.
- According to the above, assuming the timing of countermeasures in each control level has a range of 20 in terms of soundness value, the maximum level in the range indicates the optimum (ideal) time for implementing measures, and the minimum level indicates the final stage for implementing measures (if measures cannot be implemented at this last stage, the countermeasure level increases by one rank and the envisaged maintenance and repair cost increases massively).
- Upon arranging the control level that needs to be sustained in each bridge as the target level and threshold level, the aforementioned countermeasure timing can be applied as it is, and the "target level" can be expressed as the "optimum timing of countermeasures" while the "threshold level" can be expressed as the "final time for countermeasures."
- Judging from the viewpoint of risk management by the road manager, risk increases as soundness goes down, and decreases as soundness goes up.

Figure 1.6.2 shows the conceptual view of budget equalization.

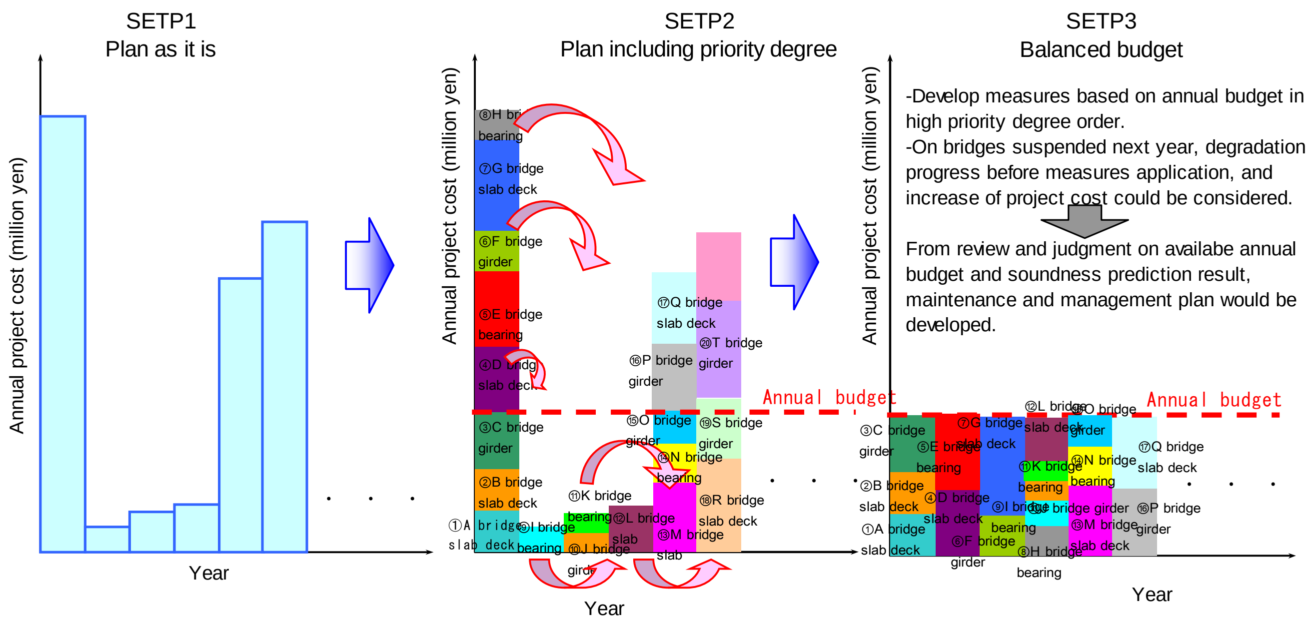


Figure 1.6.2: Budget balancing scheme

Taking the above points into consideration, the method for determining the order of priority of countermeasures in DRR is indicated below.
This policy expresses the desire to switch to a policy of preventive repairs aimed at securing future bridge soundness and reducing the maintenance budget while giving top priority to securing safety.

1st: Bridges with soundness of less than 10

Top priority shall be given to bridges with soundness of less than 10 because there is a risk of bridge collapse or impairment of traffic safety. (It is essential to give top priority to risk management and ensure that there are no bridges that end up needing rebuilding).

2nd: Bridges with a major drop in the soundness of optimum measures

As the next order of priority, measures will be conducted on those bridges that have a large drop in soundness judging from the optimum timing of countermeasures (in order to limit increase in the cost of countermeasures).

Optimum countermeasure timing: Control Level A: soundness 80
Control Level B: soundness 60
Control Level C: soundness 40
Control Level D: soundness 20

Soundness drop = Optimum measures timing – Current (future) soundness

3rd: Bridges with a low control level

In cases where the drop in soundness is the same value, maintenance work will first be conducted from bridges with a low control level. (Giving priority to risk management)

4th: If the control level is the same, bridges that have a higher importance evaluation score

In cases where the drop in soundness and the control level are the same, priority shall be given to bridges that have a higher importance evaluation score. (Improvement of service, and accountability)

The following figure shows an example of calculating the order of priority of countermeasures.

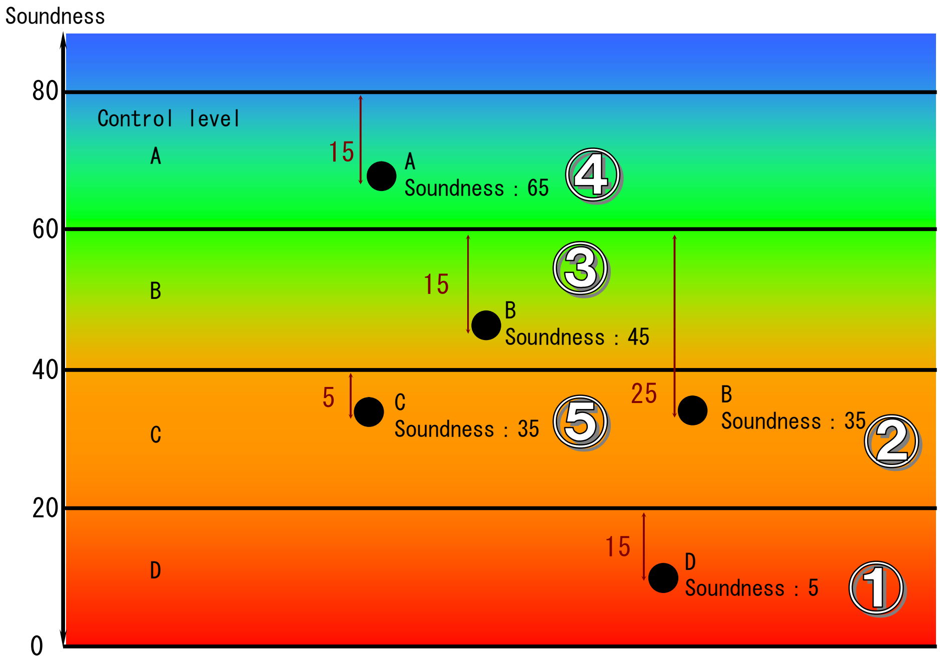
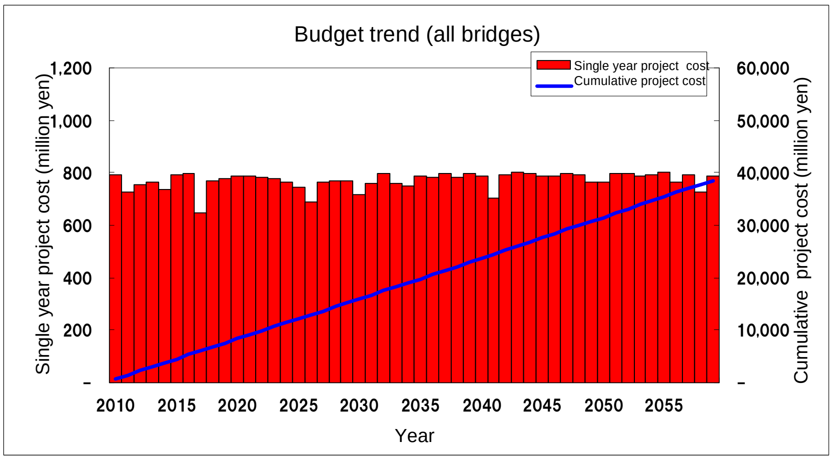


Figure 1.6.3: Priority order calculation example

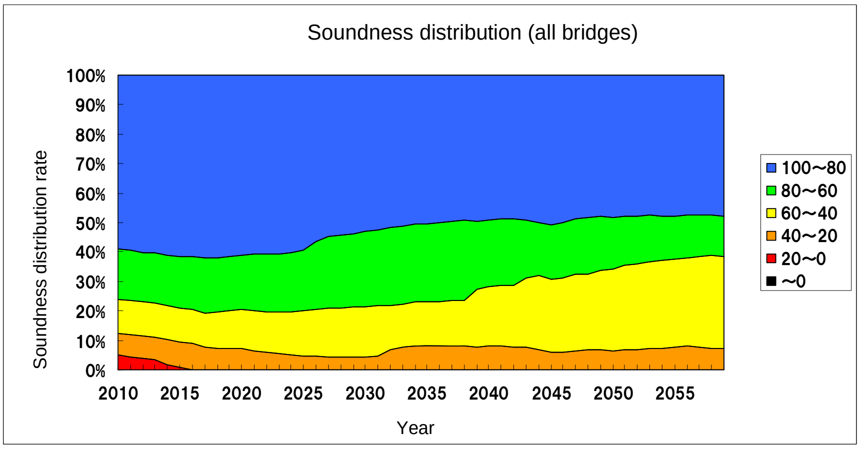
1.7. Commentary on the Results of Simulation

(1) Budget trend graph



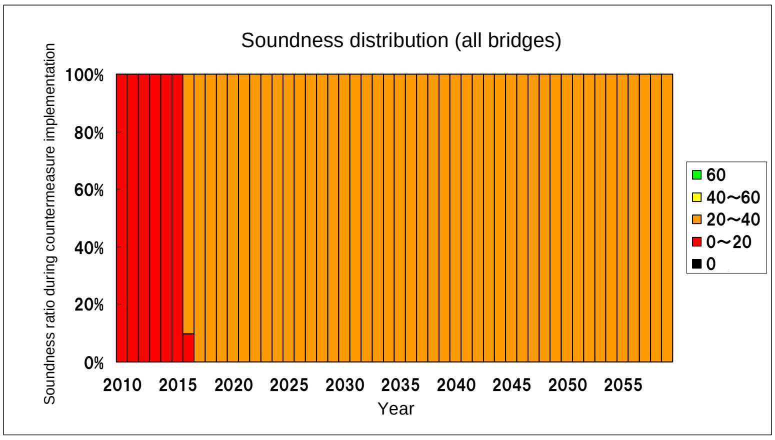
- This graph shows the budget trends during the period of future simulation.
- The bar graph shows movements in the single year project cost, while the line plot shows the cumulative project cost.
- In the case where the budget is equalized, assuming that the set budget amount is the maximum value, simulation is conducted so that the budget falls within that level. In other words, if the budget for a year is exceeded due to conducting maintenance and repair measures on the bridge with the next highest priority, all subsequent measures will be deferred to the next fiscal year.
- If the budget (measures budget) for the year is not appropriated, it is either because there are no bridges that need countermeasures, or the cost of countermeasures for top priority bridges exceeds that year's budget.

(2) Soundness Distribution Transition Graph



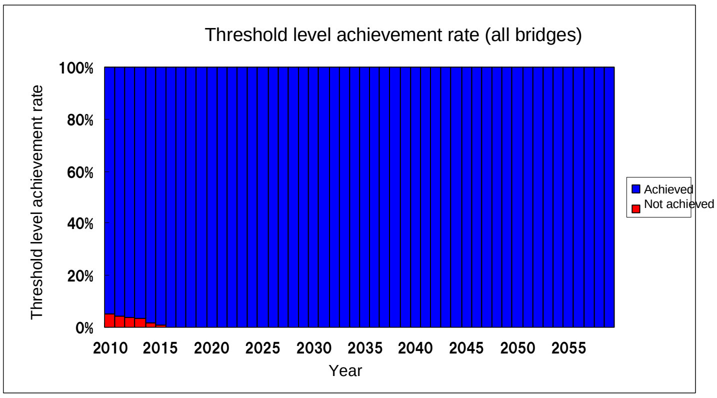
- This graph shows movements in the distribution when the overall soundness of members during the future simulation period is aggregated.
- Because the soundness is calculated in units of members and span size, this graph shows the aggregate soundness of each span and each member in all the target bridges.
- Black color appears when soundness drops to less than 0. Soundness of less than 0 indicates a situation where normal service is impaired (traffic is impaired).

(3) Soundness Ratio during Implementation of Countermeasures



- This graph represents overall soundness when implementing countermeasures and shows the ratio of each soundness range.
- Because the timing of countermeasure implementation is set according to each control level, the level of satisfaction in the set budget can be inferred from the timing of countermeasures. In other words, if the budget is satisfactory, the ratio of yellow (target timing for Control Level B or A countermeasures) and green (target timing for Control Level A countermeasures) increases, whereas if the budget is insufficient, the ratio of orange (target timing for Control Level C countermeasures) and red (target timing for Control Level D countermeasures) increases.
- If countermeasures are conducted at timing represented by soundness of less than 0, the countermeasures comprise either replacement of members or rebuilding of bridge and are expressed as black on the graph. This indicates that regular service is difficult and that either replacement of members or rebuilding of bridge is implemented as the countermeasure.

(4) Threshold Level Achievement Rate



- The threshold level achievement rate indicates the ratio of bridges that satisfy the threshold level that is set for each control level (for example, soundness 40 in the case of Control Level B).
- The existence of bridges that don't satisfy the threshold level indicates that there is insufficient budget and the target maintenance control level cannot be met. In other words, the target maintenance scenario isn't fulfilled, for example, even though it is intended to conduct repeated maintenance and repair, bridges are actually left unattended until major reinforcements become necessary.

2. Examination Geared to Long-term Maintenance Planning

2.1. Simulation Flow

The overall flow of long-term maintenance planning is indicated in Figure 1.1.1, but here the concrete flow of the long-term planning simulation is shown in Figure 2.1.1.

① Setting of the control level

Configure the control goals through setting the allocation of control levels A~D.

② Equalization based on budget restriction

Set the upper limit for the annual budget and execute the simulation.

③ Evaluation of simulation results

Based on the soundness trends in each control level and the results of total budget, etc., verify if the control target is being attained and if the scale of budget is feasible and so on.

④ In cases where the control target cannot be achieved due to lack of budget, reset the annual budget and execute the simulation again.

⑤ In the case where the annual budget for achieving the control target is an unfeasible amount, reset the control target and repeat activities ② and ③.

⑥ Based on activities ①~⑤, decide the optimum long-term maintenance plan.

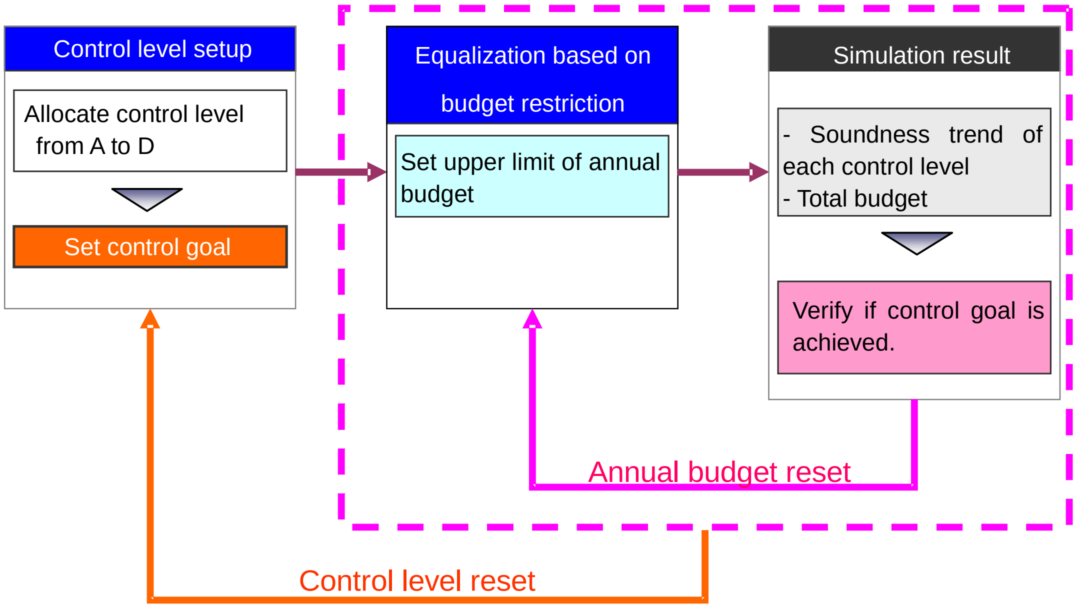


Figure 2.1.1: simulation flow

2.2. Setting of the Control Level

Through setting the lower limit of the importance evaluation for each control level A~D, set the ratio of each control level with respect to the target bridge. A setting example is shown below.

Table 2.2.1 shows an image of setting the ratio of each control level assuming Case 1 to be the high control level, Case 2 to be the medium control level and Case 3 to be the low control level upon considering the importance evaluation score for bridges A~Z.

Table 2.2.1: Example of control level allocation setup

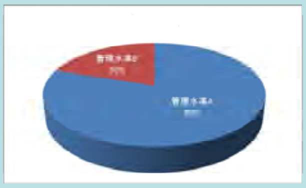
Bridge	Evaluation score	Allocation of control level setup		
		Case 1 control level: high	Case 2 control level: medium	Case 3 control level: low
A	30	control level A＞80 control level B＞20 control level C＞ 0 control level D＞ 0 	control level A＞50 control level B＞30 control level C＞20 control level D＞ 0 	control level A＞10 control level B＞30 control level C＞40 control level D＞20 
B	40			
C	50			
D	20			
E	10			
F	60			
G	70			
.	.			
.	.			
Z	90			

Table 2.2.2 shows the general point of view of the four items of maintenance level, the number of bridges that require countermeasures, the safety and peace of mind level, and the cost of countermeasures, as the effects obtained from setting the control levels.

Table 2.2.2:Control level setup and its effect

Maintenance level target	Control level setup (example)	Effect by target setup			
		Maintenance level	No. of bridge	Safety	Cost
Case 1	Control level A:80% Control level B:20% Control level C: 0% Control level D: 0%	High	Many	High	High
Case 2	Control level A:50% Control level B:30% Control level C:20% Control level D: 0%	Medium	Average	Medium	Medium
Case 3	Control level A:10% Control level B:30% Control level C:40% Control level D:20%	Low	Few	Low	Low

2.3. Setting of the Simulation Period and Single Year Budget

In cases where restriction of the single year budget is necessary, simulation is executed upon inputting the upper limit of the budget.

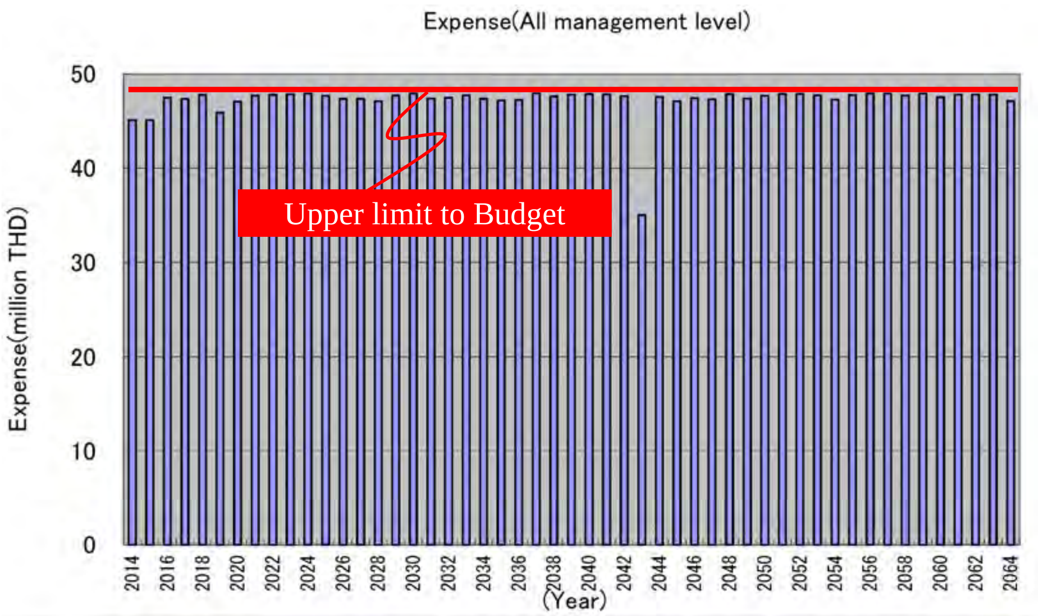


Figure 2.3.1: Upper limit to budget

2.4. Method for Evaluating the Examination Results based on the Simulation Example

The simulation implementation example based on sample data is used to indicate the method for evaluating examination results.

2.4.1. Outline of the Simulation Implementation Example

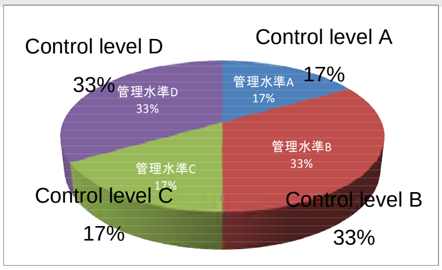
- No. of bridge in simulation = 90
- No. of case = 3

Case1 Set control level A on all bridges

Case2 Set control level A∼D considering priority degree

Case3 Corrective action

By ignoring damage state from inspection, defer maintenance and let bridges deteriorate until renewal and replacement of bridges at the needed time.



2.4.2. Results of the Simulation Implementation Example

(1) Case 1: Set Control Level A for all bridges

- The examination period is 50 years.
- The budget upper limit is 48 million Baht.
- The control level is satisfied in 10 years.

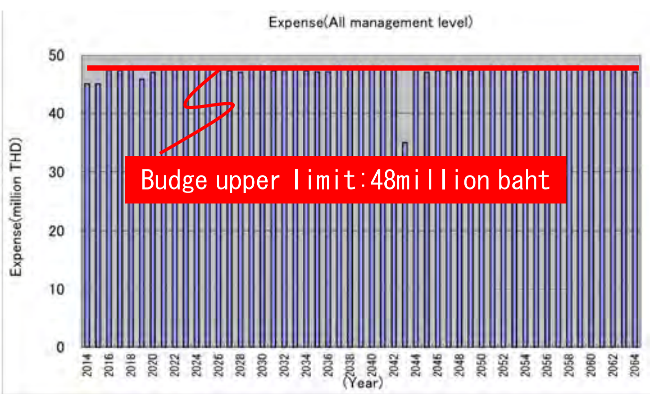


Figure 2.4.1: Budget upper limit

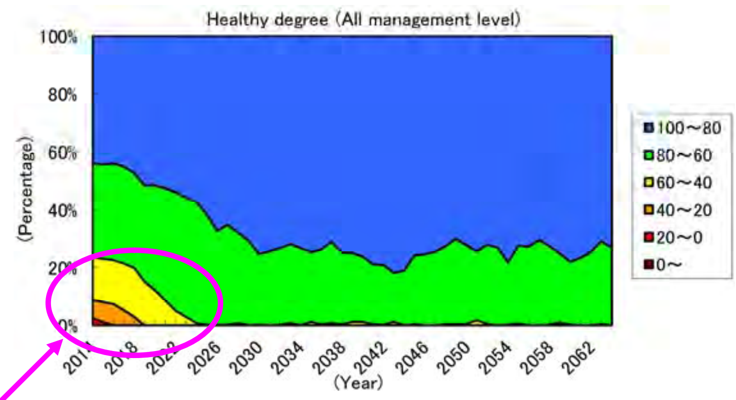


Figure 2.4.2: Soundness trend (Control level A)

Satisfy control level after a decade

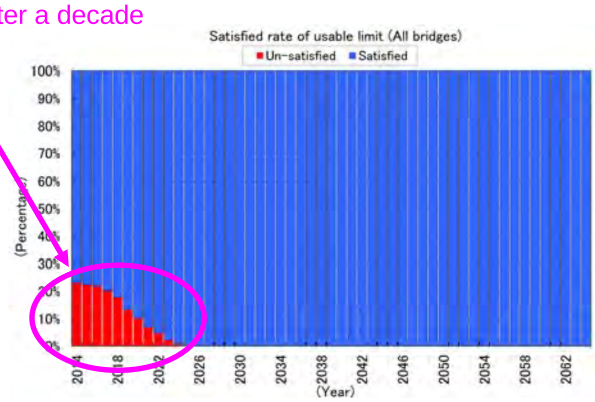


Figure 2.4.3: Limit level satisfaction rate trend (Control level A)

(2) Case 1: Set Control Level A for all bridges (target not achieved)

- The examination period is 50 years.
- The budget upper limit is 30 million Baht.

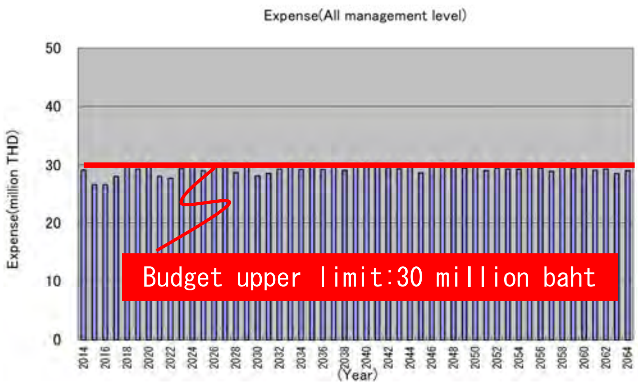


Figure 2.4.4: Budget upper limit

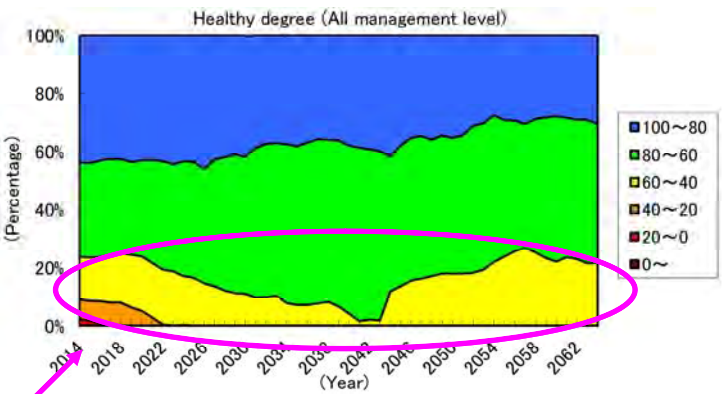


Figure 2.4.5: Soundness trend (Control level A)

Fail to achieve a target during study

Lack of budget

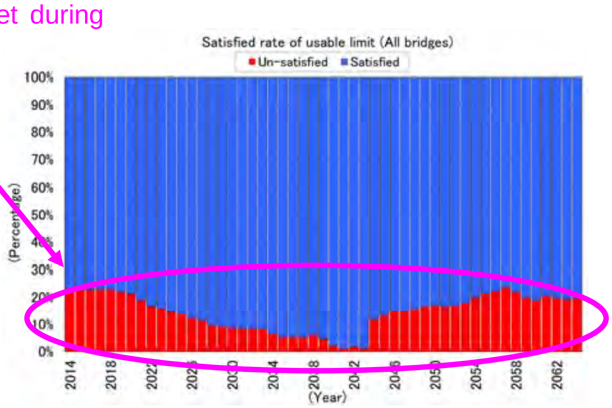


Figure 2.4.6: Limit level satisfaction rate trend (Control level A)

(3) Case 2: Set Control Levels A~D according to the importance of bridges

- The examination period is 50 years.
- The budget upper limit is 22 million Baht.
- The control level is satisfied in 12 years.

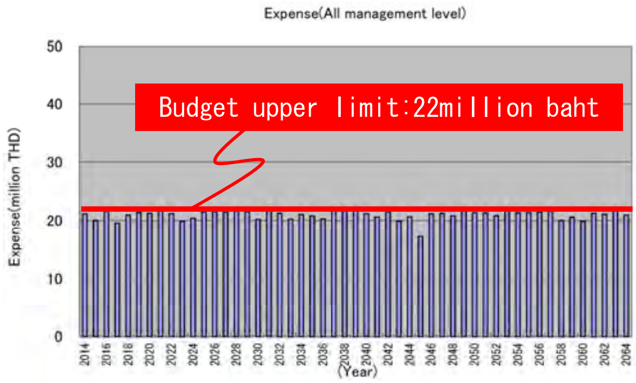


Figure 2.4.7: Budget upper limit

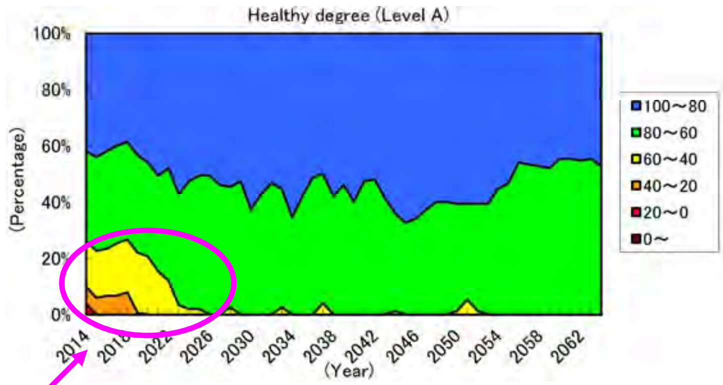


Figure 2.4.8: Soundness trend (Control level A)

Satisfy control level 12 years

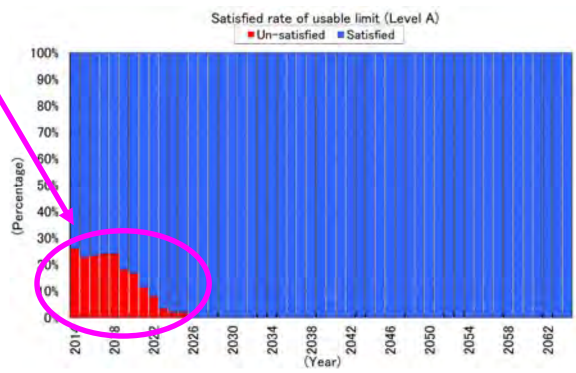


Figure 2.4.9: Limit level satisfaction rate trend (Control level A)

(4) Case 2: Set Control Levels A~D according to the importance of bridges (target not achieved)

- The examination period is 50 years.
- The budget upper limit is 15 million Baht.

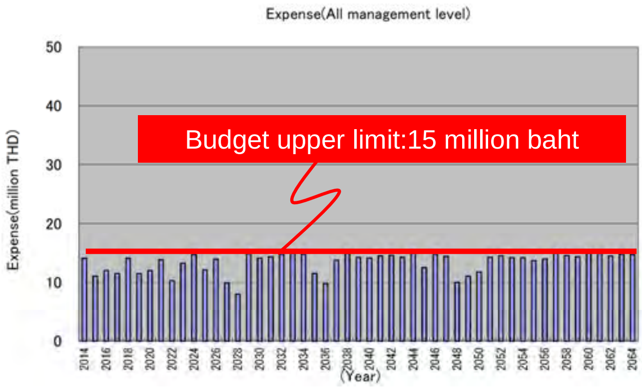


Figure 2.4.10: Budget upper limit

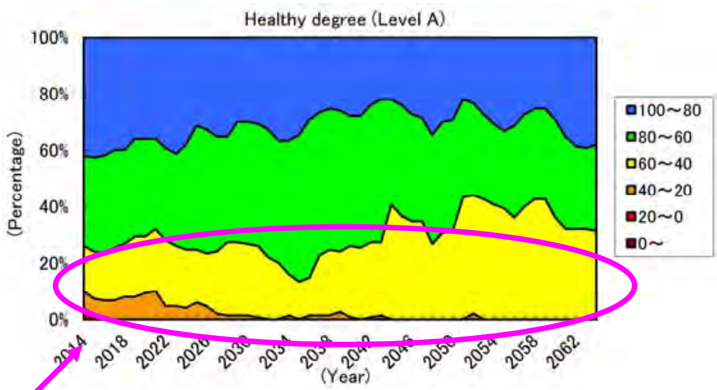


Figure 2.4.11: Soundness trend (Control level A)

Fail to achieve a target during study

Lack of budget

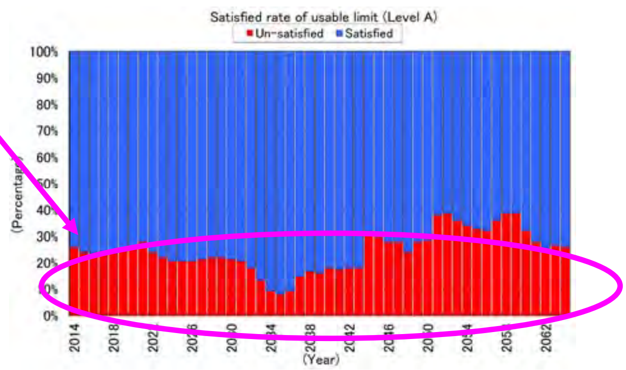


Figure 2.4.12: Limit level satisfaction rate trend (Control level A)

(5) Case 3: Breakdown maintenance

- The examination period is 50 years.
- There is no budget upper limit.

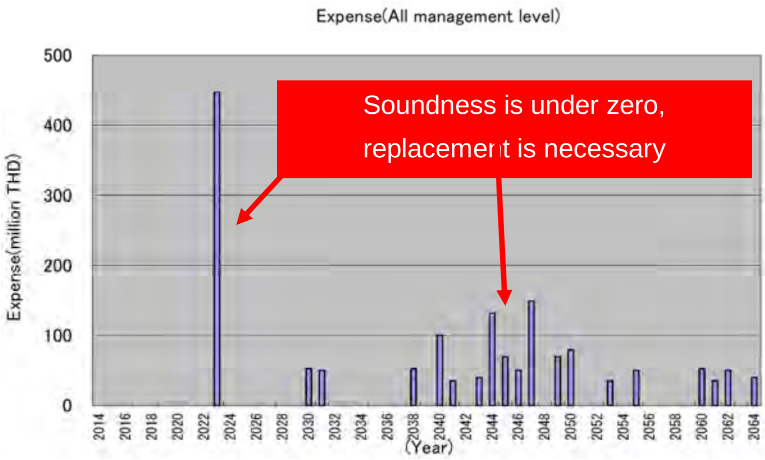


Figure 2.4.10: Total budget

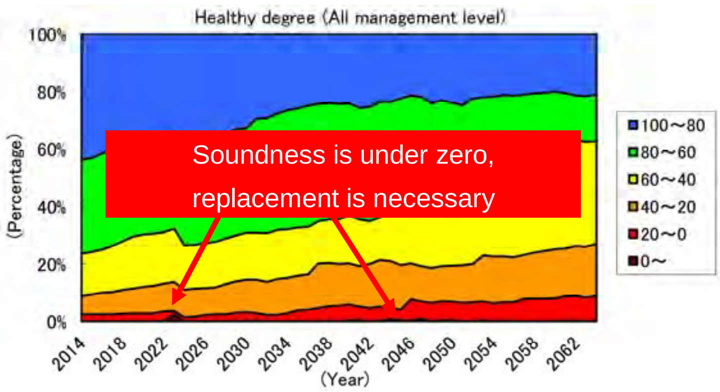


Figure 2.4.11: Soundness trend

Fail to have safety

2.4.3. Results of the Simulation Implementation Example

The method for evaluating the simulation examination results is described below.

• Any difference of relationship between control level and current state of bridge.

→See if the bridge necessary for a high priority is under low control level.

• Budget estimate

→See if single year budget and total budget are accountable or not.

• Target soundness achievement after X years and safety assurance

→See if soundness trend and limit level satisfaction rate satisfy a certain target level in the planned period.

• Compare with total budget necessary for corrective action

• Based on description above, develop the most appropriate long-term maintenance and management plan.

Table 2.4.1: Study result

Case	Control level	Effect by target setup			Evaluation
		Maintenance level	Cost (million Baht)	Safety	
Case 1	Control level A : 100% Control level B : 0% Control level C : 0% Control level D : 0%	High	2,410	High	
Case 2	Control level A : 17% Control level B : 33% Control level C : 17% Control level D : 33%	Medium	1,070	Medium	
Case 3	Corrective action	Much low	1,590	Much low	×

Reference 1 Cost estimation on repair work

Cost estimation for repair construction considered first the actual cost of each work performed in Thailand. For the work type not identified in Thailand, the cost estimation was referring to standard quantity per unit work defined in Japan, and unit price or labor cost was set based on it.

Table 1.1.1 – 1.1.8 presents cost estimate of repair works, Figure 1.1.1 shows cost estimate for bridge replacement, and Table1.1.9 – 1.1.17 summarizes the result of interview done to learn about the actual cost in Thailand.

【Cost estimation of repair relating work type】

Table 1.1.1: Cost estimate of repair work of slab deck (slab deck bridge, Plank Girder Bridge, Box Girder Bridge)

Member	Measure Level	Construction method	Unit price(THB)	Notes (Basis of unit price)
Slab girder bridge Plank girder bridge Box girder bridge	Preventive measure	Bridge surface water proofing	70 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Asphalt paving	500 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Surface protection	1,850 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10)
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding+Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**3,000** THB/m^2	1,000THBround
	Measure 1 (Slight)	Pavement and surface repair	2,450 THB/m^2	- Sum of Bridge surface water proofing+Asphalt paving+Surface protection - Unit price=70THB/m2+500THB/m2+1,850THB/m2=2,420THB/m2→2,450THB/m2
		Injection to cracks	650 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 1m/m2 - Unit price=630THB/m2×1m/m2=630THB/m2→650THB/m2
		Section restration	150 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 10%/m2 - Unit price=120THB/m2×0.1=120THB/m2→150THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding+Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**4,000** THB/m^2	1,000THBround
	Measure 2 (Middle)	Pavement and surface repair	2,450 THB/m^2	- Sum of Bridge surface water proofing+Asphalt paving+Surface protection - Unit price=70THB/m2+500THB/m2+1,850THB/m2=2,420THB/m2→2,450THB/m2
		Injection to cracks	950 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 1.5m/m2 - Unit price=630THB/m2×1.5m/m2=945THB/m2→950THB/m2
		Section restration	250 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 20%/m2 - Unit price=1,200THB/m2×0.2=240THB/m2→250THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding+Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**4,000** THB/m^2	1,000THBround
	Measure 3 (Severe)	Pavement and surface repair	2,450 THB/m^2	- Sum of Bridge surface water proofing+Asphalt paving+Surface protection - Unit price=70THB/m2+500THB/m2+1,850THB/m2=2,420THB/m2→2,450THB/m2
		Injection to cracks	1,300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 2m/m2 - Unit price=630THB/m2×2m/m2=1,260THB/m2→1,300THB/m2
		Section restration	400 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 30%/m2 - Unit price=1,200THB/m2×0.3=360THB/m2→400THB/m2
		Carbon fiber gluing	9,450 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.13) - Sum of Carbon fiber gluing+Ground treatment
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding+Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**14,000** THB/m^2	1,000THBround

Table1.1.2: Cost estimate of repair work of PCI Girder Bridge

Member	Measure Level	Construction method	Unit price(THB)	Notes (Basis of unit price)
PCI girder bridge	Preventive measure	Surface protection	4,650 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Girder all surface/Bridge area=2.5 - Unit price=1,850THB/m2×2.5=4,625THB/m2→4,650THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding＋Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**5,000** THB/m^2	1,000THBround
	Measure 1 (Slight)	Surface protection	4,650 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Girder all surface/Bridge area=2.5 - Unit price=1,850THB/m2×2.5=4,625THB/m2→4,650THB/m2
		Injection to cracks	1,600 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 1m/m2 - Girder all surface/Bridge area=2.5 - Unit price=630THB/m2×1m/m2×2.5=1,575THB/m2→1,600THB/m2
		Section restration	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 10%/m2 - Girder all surface/Bridge area=2.5 - Unit price=120THB/m2×0.1×2.5=300THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding＋Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**7,000** THB/m^2	1,000THBround
	Measure 2 (Middle)	Surface protection	4,650 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Girder all surface/Bridge area=2.5 - Unit price=1,850THB/m2×2.5=4,625THB/m2→4,650THB/m2
		Injection to cracks	2,400 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 1.5m/m2 - Girder all surface/Bridge area=2.5 - Unit price=630THB/m2×1.5m/m2×2.5=2,362THB/m2→2,400THB/m2
		Section restration	600 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 20%/m2 - Girder all surface/Bridge area=2.5 - Unit price=1,200THB/m2×0.2×2.5=600THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding＋Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**8,000** THB/m^2	1,000THBround
	Measure 3 (Severe)	Surface protection	4,650 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Girder all surface/Bridge area=2.5 - Unit price=1,850THB/m2×2.5=4,625THB/m2→4,650THB/m2
		Injection to cracks	3,150 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 2m/m2 - Girder all surface/Bridge area=2.5 - Unit price=630THB/m2×2m/m2×2.5=3,150THB/m2
		Section restration	900 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 30%/m2 - Girder all surface/Bridge area=2.5 - Unit price=1,200THB/m2×0.3×2.5=900THB/m2
		Carbon fiber gluing	23,650 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.13) - Sum of Carbon fiber gluing+Ground treatment - Girder all surface/Bridge area=2.5 - Unit price=9,450THB/m2×2.5=23,625THB/m2→23,650THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding＋Safety fence - ,Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**33,000** THB/m^2	1,000THBround

Table 1.1.3: Cost estimate of repair work of filled floor slab bridges (Plank Girder Bridge, Box Girder Bridge)

Member	Measure Level	Construction method	Unit price(THB)	Notes (Basis of unit price)
Slab (Plank girder Box girder)	Preventive measure	Bridge surface water proofing	70 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Asphalt paving	500 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Total	**600** THB/m^2	500THBround
	Measure 1 (Slight)	Bridge surface water proofing	70 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Asphalt paving	500 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Total	**600** THB/m^2	500THBround
	Measure 2 (Middle)	Bridge surface water proofing	70 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Asphalt paving	500 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Total	**600** THB/m^2	500THBround
	Measure 3 (Severe)	Bridge surface water proofing	70 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Asphalt paving	500 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Repair of slab surface works	900 THB/m^2	- Injection to cracks,Section restration are considered as Repair of slab surface work - Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of (Injection to cracks+Ground treatment)+(Clipping works+Section restration) - Density of crack is asummed as 1m/m2 - Repair area is asummed as 20%/m2 - Unit price=630THB/m2×1m/m2+1,200THB/m2×0.2=870THB/m2→900THB/m2
		Total	**2,000** THB/m^2	1,000THBround

Table 1.1.4: Cost estimate of repair work of slab deck (PCT Girder Bridge)

Member	Measure Level	Construction method	Unit price(THB)	Notes (Basis of unit price)
Slab (PCI girder)	Preventive measure	Bridge surface water proofing	70 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Asphalt paving	500 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.9)
		Surface protection	1,150 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Slab area/Bridge area=0.6 - Unit price=1,850THB/m2×0.6=1,110THB/m2→1,150THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding＋Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**3,000** THB/m^2	1,000THBround
	Measure 1 (Slight)	Pavement and surface repair	1,750 THB/m^2	- Sum of Bridge surface water proofing+Asphalt paving+Surface protection - Unit price=70THB/m2+500THB/m2+1,150THB/m2=1,720THB/m2→1,750THB/m2
		Injection to cracks	400 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 1m/m2 - Slab area/Bridge area=0.6 - Unit price=630THB/m2×1m/m2×0.6=378THB/m2→400THB/m2
		Section restration	150 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 20%/m2 - Slab area/Bridge area=0.6 - Unit price=1,200THB/m2×0.2×0.6=144THB/m2→150THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding＋Safety fence - ,Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**3,000** THB/m^2	1,000THBround
	Measure 2 (Middle)	Pavement and surface repair	1,750 THB/m^2	- Sum of Bridge surface water proofing+Asphalt paving+Surface protection - Unit price=70THB/m2+500THB/m2+1,150THB/m2=1,720THB/m2→1,750THB/m2
		Injection to cracks	800 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 2m/m2 - Slab area/Bridge area=0.6 - Unit price=630THB/m2×2m/m2×0.6=756THB/m2→800THB/m2
		Section restration	250 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 30%/m2 - Slab area/Bridge area=0.6 - Unit price=1,200THB/m2×0.3×0.6=216THB/m2→250THB/m2
		Carbon fiber gluing	5,670 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.13) - Sum of Carbon fiber gluing+Ground treatment - Slab area/Bridge area=0.6 - Unit price=9,450THB/m2×2.5=23,625THB/m2→23,650THB/m2
		Scaffolding (Suspended scaffolding)	300 THB/m^2	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.16) - Sum of Suspended scaffolding＋Safety fence - Scaffolding area/Bridge area=1.2 - Unit price=230THB/m2×1.2=276THB/m2→300THB/m2
		Total	**9,000** THB/m^2	1,000THBround
	Measure 3 (Severe)	Slab replacement	59,400 THB/m^2	- Ratio of Japanese price and Thai price is assumed from sample work (referring to metallization works). Then the ratio multiplies to unit price of Japan. Price of metallization of Japan 150,000Yen/unit×0.33=49,500THB/unit-① Price of metallization of Thailand 28,680THB/unit-② Ratio=①/②=0.58→0.60-③ - Unit price of Slab replacement of Japan300,000円/m2×0.33=99,000THB/m2-④ - Unit price of Slab replacement =④×③=59,400THB/m2
		Total	**60,000** THB/m^2	1,000THBround

Table 1.1.5: Cost estimate of repair work of bearing

Member	Measure Level	Construction method	Unit price(THB)	Notes (Basis of unit price)
Bearing	Preventive measure	-	- THB/Pier	
		Total	**-** THB/Pier	1,000THBround
	Measure 1 (Slight)	再塗装工	11,400 THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.14) - 10 bearing is in a bearing line - Scaffolding 20m2 - Unit price=735THB/Bearing×10Bearing+202THB/m2×20m2=11,390THB/m2→11,400THB/m2
		Total	**12,000** THB/Pier	1,000THBround
	Measure 2 (Middle)	溶射工	28,700 THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.15) - 10 bearing is in a bearing line - Scaffolding 20m2 - Unit price=2,464THB/Bearing×10Bearing+202THB/m2×20m2=28,680THB/m2→28,700THB/m2
		Total	**29,000** THB/Pier	1,000THBround
	Measure 3 (Severe)	Bearing replacement	297,000 THB/Pier	- Ratio of Japanese price and Thai price is assumed from sample work (referring to metallization works). Then the ratio multiplies to unit price of Japan. Price of metallization of Japan 150,000Yen/unit×0.33=49,500THB/unit-① Price of metallization of Thailand 28,680THB/unit-② Ratio=①/②=0.58→0.60-③ - Unit price of Bearing replacement of Japan 1,500,000Yen/Pier×0.33=495,000THB/Pier-④ - Unit price of Bearing replacement=④×③=297,000THB/Pier
		Total	**297,000** THB/Pier	1,000THBround

Table 1.1.6: Cost estimate of repair work of pier

Member	Measure Level	Construction method	Unit price(THB)		Notes (Basis of unit price)
Pier	Preventive measure	Surface protection	314,500	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Standard surface area is assumed 170m2 in 1 pier - Unit price=1,850THB/m2×170=314,500THB/m2
		Scaffolding	74,250	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.17) - Standard scaffolding volume is assumed 550m3 in 1 pier - Unit price=135THB/m2×550=74,250THB/m2
		Total	**388,750**	THB/Pier	1,000THBround
	Measure 1 (Slight)	Surface protection	314,500	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Standard surface area is assumed 170m2 in 1 pier - Unit price=1,850THB/m2×170=314,500THB/m2
		Injection to cracks	53,550	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 0.5m/m2 - Standard surface area is assumed 170m2 in 1 pier - Unit price=630THB/m2×0.5m/m2×170m2=53,550THB/m2
		Section restration	20,400	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 10%/m2 - Standard surface area is assumed 170m2 in 1 pier - Unit price=1,200THB/m2×0.1×170m2=20,400THB/m2
		Scaffolding	74,250	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.17) - Standard scaffolding volume is assumed 550m3 in 1 pier - Unit price=135THB/m2×550=74,250THB/m2
		Total	**463,000**	THB/Pier	1,000THBround
	Measure 2 (Middle)	Surface protection	314,500	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Standard surface area is assumed 170m2 in 1 pier - Unit price=1,850THB/m2×170=314,500THB/m2
		Injection to cracks	107,100	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 1m/m2 - Standard surface area is assumed 170m2 in 1 pier - Unit price=630THB/m2×1m/m2×170m2=107,100THB/m2
		Section restration	40,800	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 20%/m2 - Standard surface area is assumed 170m2 in 1 pier - Unit price=1,200THB/m2×0.2×170m2=40,800THB/m2
		Scaffolding	74,250	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.17) - Standard scaffolding volume is assumed 550m3 in 1 pier - Unit price=135THB/m2×550=74,250THB/m2
		Total	**537,000**	THB/Pier	1,000THBround
	Measure 3 (Severe)	Surface protection	314,500	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Standard surface area is assumed 170m2 in 1 pier - Unit price=1,850THB/m2×170=314,500THB/m2
		Injection to cracks	107,100	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.11) - Sum of Injection to cracks+Ground treatment - Density of crack is asummed as 1m/m2 - Standard surface area is assumed 170m2 in 1 pier - Unit price=630THB/m2×1m/m2×170m2=107,100THB/m2
		Section restration	61,200	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.12) - Sum of Clipping works+Section restration - Repair area is asummed as 30%/m2 - Standard surface area is assumed 170m2 in 1 pier - Unit price=1,200THB/m2×0.3×170m2=61,200THB/m2
		RC jacketing method	237,600	THB/Pier	- Ratio of Japanese price and Thai price is assumed from sample work (referring to metallization works). Then the ratio multiplies to unit price of Japan. Price of metallization of Japan 150,000Yen/unit×0.33=49,500THB/unit-① Price of metallization of Thailand 28,680THB/unit-② Ratio=①/②=0.58→0.60-③ - Unit price of RC jacketing method of Japan 1,200,000Yen/Pier×0.33=396,000THB/Pier-④ - Unit price of RC jacketing method=④×③=237,600THB/Pier
		Scaffolding	74,250	THB/Pier	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.17) - Standard scaffolding volume is assumed 550m3 in 1 pier - Unit price=135THB/m2×550=74,250THB/m2
		Total	**795,000**	THB/Pier	1,000THBround

Table 1.1.7: Cost estimate of repair work of abutment

Member	Measure Level	Construction method	Unit price(THB)		Notes (Basis of unit price)
Abutment	Preventive measure	Surface protection	83,250	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.10) - Standard surface area is assumed 45m2 in 1 abutment - Unit price=1,850THB/m2×45=83,250THB/m2
		Scaffolding	6,750	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference(Table 1.1.17) - Standard scaffolding volume is assumed 50m3 in 1 abutment - Unit price=135THB/m2×50=6,750THB/m2
		Total	**90,000**	THB/Abutment	1,000THBround
	Measure 1 (Slight)	Surface protection	83,250	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.10) - Standard surface area is assumed 45m2 in 1 abutment - Unit price=1,850THB/m2×45=83,250THB/m2
		Injection to cracks	14,200	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.11) - Sum of Injection to cracks + Ground treatment - Density of crack is assumed as 0.5m/m2 - Standard surface area is assumed 45m2 in 1 abutment - Unit price=630THB/m2×0.5m/m2×45m2=14,175THB/m2→14,200THB/m2
		Section restoration	5,400	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.12) - Sum of Clipping works + Section restoration - Repair area is assumed as 10%/m2 - Standard surface area is assumed 45m2 in 1 abutment - Unit price=1,200THB/m2×0.1×45m2=5,400THB/m2
		Scaffolding	6,750	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.17) - Standard scaffolding volume is assumed 50m3 in 1 abutment - Unit price=135THB/m2×50=6,750THB/m2
		Total	**110,000**	THB/Abutment	1,000THBround
	Measure 2 (Middle)	Surface protection	83,250	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.10) - Standard surface area is assumed 45m2 in 1 abutment - Unit price=1,850THB/m2×45=83,250THB/m2
		Injection to cracks	28,350	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.11) - Sum of Injection to cracks + Ground treatment - Density of crack is assumed as 1m/m2 - Standard surface area is assumed 45m2 in 1 abutment - Unit price=630THB/m2×1m/m2×45m2=28,350THB/m2
		Section restoration	10,800	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.12) - Sum of Clipping works + Section restoration - Repair area is assumed as 20%/m2 - Standard surface area is assumed 45m2 in 1 abutment - Unit price=1,200THB/m2×0.2×45m2=10,800THB/m2
		Scaffolding	6,750	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.17) - Standard scaffolding volume is assumed 50m3 in 1 abutment - Unit price=135THB/m2×50=6,750THB/m2
		Total	**130,000**	THB/Abutment	1,000THBround
	Measure 3 (Severe)	Surface protection	83,250	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.10) - Standard surface area is assumed 45m2 in 1 abutment - Unit price=1,850THB/m2×45=83,250THB/m2
		Injection to cracks	28,350	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.11) - Sum of Injection to cracks + Ground treatment - Density of crack is assumed as 1m/m2 - Standard surface area is assumed 45m2 in 1 abutment - Unit price=630THB/m2×1m/m2×45m2=28,350THB/m2
		Section restoration	16,200	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.12) - Sum of Clipping works + Section restoration - Repair area is assumed as 30%/m2 - Standard surface area is assumed 45m2 in 1 abutment - Unit price=1,200THB/m2×0.3×45m2=16,200THB/m2
		RC jacketing method	99,000	THB/Abutment	- Ratio of Japanese price and Thai price is assumed from sample work (referring to metallization works). Then the ratio multiplies to unit price of Japan. Price of metallization of Japan 150,000Yen/unit×0.33=49,500THB/unit-① Price of metallization of Thailand 28,680THB/unit-② Ratio=①/②=0.58→0.60-③ - Unit price of RC jacketing method of Japan 500,000円/Abutment×0.33=165,000THB/Abutment-④ - Unit price of RC jacketing method=④×③=99,000THB/Abutment
		Scaffolding	6,750	THB/Abutment	- Unit price and labor cost of Thailand is inputted to standard quantity per unit work of Japan for reference (Table 1.1.17) - Standard scaffolding volume is assumed 50m3 in 1 abutment - Unit price=135THB/m2×50=6,750THB/m2
		Total	**234,000**	THB/Abutment	1,000THBround

Table 1.1.8: Cost estimate of replacement work

Member	Measure Level	Construction method	Unit price(THB)		Notes (Basis of unit price)
All members	Replacement of whole bridge	Replacement of whole bridge	118,800	THB/m^2	- Ratio of Japanese price and Thai price is assumed from sample work (referring to metallization works). Then the ratio multiplies to unit price of Japan. Price of metallization of Japan 150,000Yen/unit×0.33=49,500THB/unit-① Price of metallization of Thailand 28,680THB/unit-② Ratio=①/②=0.58→0.60-③ - Unit price of Whole bridge replacement of Japan 600,000Yen/m2×0.33=198,000THB/m2-④ - Unit price of Whole bridge replacement=④×③=118,800THB/m2
		Total	**118,800**	THB/m^2	1,000THBround

【Cost Estimate for replacement】

Cost estimate for bridge replacement refers to the result of statistics obtained from investigation on road bridge service life in Japan.

Replacement

Excerpted from Study for Bridge Replacement (III), No. 3512, Public Works Research Institute, Oct 1997

Figure shows cost for replacement of steel and concrete bridge in length less than 500m, plotted as cost per 1m^2. Total replacement cost includes dismantling the old bridge and making the temporary bridge setup, except building approach road.

Bridge replacement cost varies widely depending on many conditions of bridge. Relatively long bridge replacement may take approximately 300~600 thousand yen / m^2 as plotted in the figure, only if ignoring data extremely scattered on it. The cost looks higher than that for a new bridge construction because when replacing the bridge in service, it may take more to get rid of the old bridge and also lift other restraints lying on various construction processes.

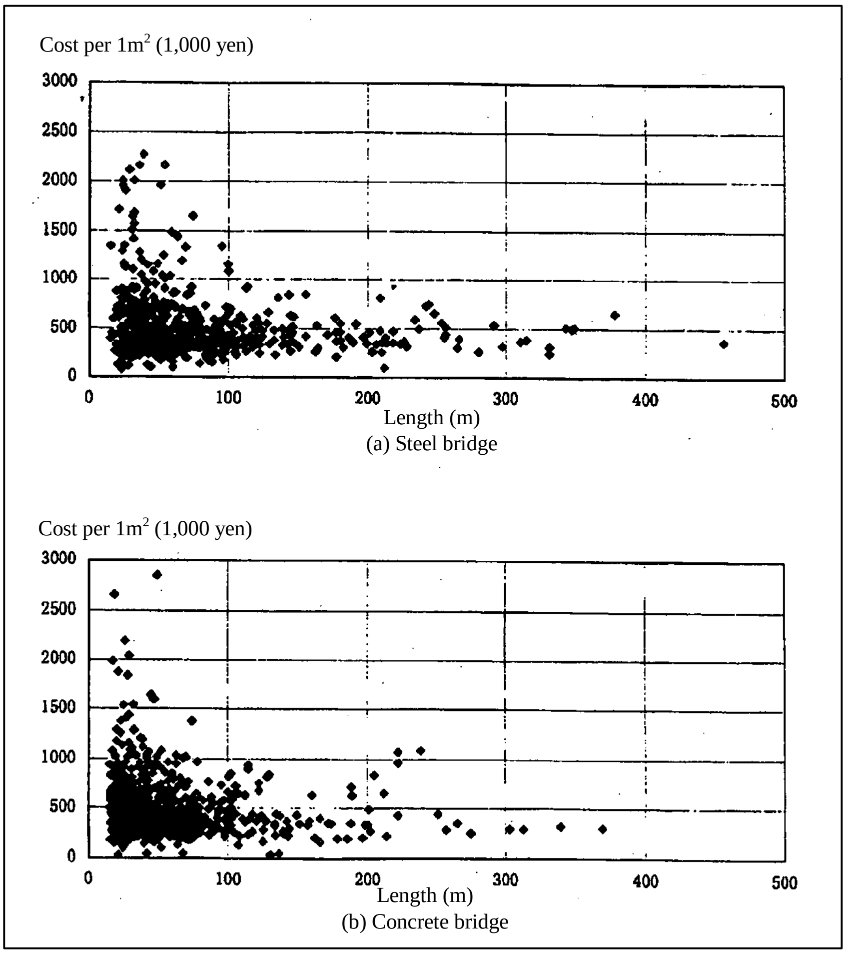


Figure 1.1.1: Excerpts from Investigation and study for service life of road bridges, Dec, 2004, National Institute for Land and Infrastructure Management

【Actual cost in Thailand】

Table 1.1.9: Actual cost of waterproofing layer and asphalt pavement

Waterproofing layer (/ 100.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Material		m2	100.0	34.22	3,422	
Labor		m2	100.0	35.00	3,500	
			Total		6,922	
	/ 1.0 m2				69	

Asphalt pavement (/ 100.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Asphalt pavement		m2	100.0	500.00	50,000	
			Total		50,000	
	/ 1.0 m2				500	

NOTICE

＊ Labor is based on labor cost data, Feb 2012

＊ Asphalt is based on data from Bureau of Trade and Economic indices Ministry of Commerce, April 2013. (Asphalt type AC-60/70 BLUK)

＊ Paint (Gross type) 3.785 ℓ Captain Brand 1 can：18㎡/can＝616 Baht

＊ Asphalt pavement thickness = 5cm,
Cost relys on work scope (repair quantity, distance from plant)

Table 1.1.10: Actual cost of protective coating

Protective coating (/ 140.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			1.0	2,250.00	2,250	
Skilled worker			2.0	600.00	1,200	
Worker			2.0	450.00	900	
Paint	ไซเลน	kg	61.6	2,970.00	182,952	JPY 9000
Adjunt material			1.0	1,155.00	1,155	JPY 3500
Generator	5KVA	ea	1.0	15,000.00	15,000	+
Air compressor	0.4kw	ea	1.0	6,000.00	6,000	
Machine expense		day	8.2	3,000.00	24,600	
	Oil		1.0	73	73	JPY 221
	Roller		4.0	330	1,320	JPY 1000
			Total		235,450	
	/ 1.0 m2				1,682	

NOTICE

+ 2KVA changed to 5KVA (2KVA price not found)

Surface treatment (/ 10.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			0.21	2,250.00	473	
Skilled worker			0.83	600.00	498	
Worker			0.42	450.00	189	
Overhead		%	5.00		58	
			Total		1,218	
	/ 1.0 m2				122	

NOTICE

* Labor is based on labor cost data, 2007 from Budget Bureau,

Table 1.1.11: Actual cost of anti-crack injection

Anticrack injection （Avg w = 0.3 mm 、Avg d = 60 mm） (/ 100.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			4.70	2,250.00	10,575	
Skilled worker			12.90	600.00	7,740	
Worker			4.20	450.00	1,890	
Sealant		kg	29.33	250.00	7,333	+
Injection mat.	Epoxy resin	kg	2.38	480.00	1,142	++
Injector		M.	334.00	60.00	20,040	+++
Overhead		%	4.00		1,949	
			Total		50,669	
	/ 1.0 m2				507	

NOTICE

	W		T		Unit weight		loss rate		Length			
Sealing mat.	0.030	×	0.005	×	1700 kg/m^3	×	1.15	×	100.0	=	29.33	kg
	W		T		Unit weight		loss rate		L			
Inject mat.	0.0003	×	0.060	×	1150 kg/m^3	×	1.15	×	100.0	=	2.38	kg

※ Assume injection depth 60mm

* Labor is based on labor cost data, 2007 from Budget Bureau,
But cost up by 1.5 times.
\+ From Sika
++ From repair cost in DRR
+++ From Internet

Surface treatment (/ 10.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			0.21	2,250.00	473	
Skilled worker			0.83	600.00	498	
Worker			0.42	450.00	189	
Overhead		%	5.00		58	
			Total		1,218	
	/ 1.0 m2				122	

NOTICE

* Labor is based on labor cost data, 2007 from Budget Bureau,

Table 1.1.12: Actual cost of section recovery

Chipping (t = 10 ～ 20 mm) (/ 10.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Diesel		liter	21.21	29.99	636	+
Foreman			0.38	2,250.00	855	
Skilled worker			1.52	600.00	912	
Worker			0.38	450.00	171	
Machine expense	Compressor 5m^3/min	day	0.51	907.50	463	JPY 2750
Equip. expense	Hammer 7.5kg	day	1.52	24.75	38	JPY 75
			Total		3,075	
	/ 1.0 m2				308	

NOTICE

+ Diesel is based on data from Bureau of Trade and Economic indices Ministry of Commerce, April 2013.
* Labor is based on labor cost data, 2007 from Budget Bureau, But cost up by 1.5 times.

Section recovery (t = 30 mm) (/ 1.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			5.30	2,250.00	11,925	
Skilled worker			15.00	600.00	9,000	
Worker			11.00	450.00	4,950	
Polymer cement mortar		m^3	1.00	1,762.40	1,762	
Overhead		%	3.00		829	
			Total		28,466	
	/ 1.0 m2				854	

NOTICE

* Labor is based on labor cost data, 2007 from Budget Bureau, But cost up by 1.5 times.

Table 1.1.13: Actual cost of CFRP attachment

CFRP attachment (/ 10.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			2.00	2,250.00	4,500	
Skilled worker			5.00	600.00	3,000	
Worker			2.00	450.00	900	
Primer		kg	1.50	450.00	675	+
CFRP		m2	20.00	3,900.00	78,000	++
Overhead		%			4,354	
			Total		91,429	
	/ 1.0 m2				9,143	

NOTICE

+ From Sika
++ From Sika
* Labor is based on labor cost data, 2007 from Budget Bureau,
But cost up by 1.5 times.

Surface treatment (/ 10.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			0.21	2,250.00	473	
Skilled worker			0.83	600.00	498	
Worker			0.42	450.00	189	
Polymer cement mortar			1.00	1,762.40	1,762	+++
Overhead		%	5.00		146	
			Total		3,068	
	/ 1.0 m2				307	

NOTICE

+++ From repair cost in DRR
* Labor is based on labor cost data, 2007 from Budget Bureau,
But cost up by 1.5 times.

Table 1.1.14: Actual cost of repainting

Repainting (/ 10.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Cleaning		m^2	10.00	35.00	350	+
Surface prepara		m^2	10.00	55.00	550	++
Base coating	epoxy resin	m^2	10.00	129.00	1,290	+++
Base coating	epoxy resin	m^2	10.00	129.00	1,290	
Base coating	epoxy resin	m^2	10.00	129.00	1,290	
Second coating	fluorine	m^2	10.00	129.00	1,290	++++
Top coating	fluorine	m^2	10.00	129.00	1,290	+++++
			Total		7,350	
	/ 1.0 m2				735	

NOTICE

+ Calculated from painting
++ Surface preparation is based on cost data, 2007 from Budget Bureau,
+++ From Sika
++++ , +++++ Same with epoxy resin price

Table 1.1.15: Actual cost of thermal spraying

Thermal spraying (/ 1 project)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman			0.50	2,250.00	1,125	
Skilled worker			1.00	600.00	600	
Worker			1.00	450.00	450	
Thermal spraying	epoxy resin	m2	0.50	129.00	65	++
Overhead		%	10.00		224	
			รวม		2,464	
	ต่อ 1 ตร.ม.				2,464	

NOTICE

++ From Sika

Scaffolding (suspension type) (/ 1.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Skilled worker			0.13	400.00	52	
Scaffold expense		Month	1.00	150.00	150	
Overhead		%	-		0	
			รวม		202	
	ต่อ 1 ตร.ม.				202	

Table 1.1.16: Actual cost of scaffolding (suspension type)

Scaffolding (suspension type) (/ 1.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Skilled worker		day	0.13	400.00	52	
Scaffold expense		month	1.00	150.00	150	
Overhead		%	-		0	
			รวม		202	
	ต่อ 1 ตร.ม.				202	

Scaffolding (fall prevention) (/ 1.0 m2)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Skilled worker			0.02	400.00	9	
Scaffold expense		month	1.00	17.00	17	
Overhead		%	-		0	
			รวม		26	
	ต่อ 1 ตร.ม.				26	

Total 228 Baht/m2

Table 1.1.17: Actual cost of formwork

Formwork (pipe support) (/ 100.0 m3)

Item	Spec	Unit	Qnty	Unit price	Cost	Remark
Foreman		day	2.60	2,250.00	5,850	
Form worker		day	4.70	510.00	2,397	
Scaffolding worker		day	2.20	540.00	1,188	
Worker		day	5.10	450.00	2,295	
Overhead		%	15.00		1,760	
			Total		13,490	
	/1.0m3				135	Baht