3.5 Review of deterioration factors

This section describes present situations, estimation of deterioration factors, required actions, etc., focusing on problems unique to each of PC bridges (7 bridges), steel truss bridges (4 bridges) and cable stayed bridges (2 bridges).

3.5.1 Superstructures and piers

(1) PC bridges

This item describes cracks found in PC bridges. The results of non-destructive test are described at the end.

1) V-shape cracks generated at the lower end of bridge footings in the river

V-shape cracks were observed in bridge footings of Rama 4, Rama 5 and other bridges. These cracks are assumed to be occurred under construction. Since the location of crack propagation is subjected to compression forces, these cracks would not propagate. Filling cracks with seal is considered to be acceptable.

2) Main beam

Cracks and free lime were found in main girder of Taksin (on the Thon Buri side, span 3). Similar deformation was also found on web of both sides which is approximately 23 m from the Bangkok side.

This deformation is considered to be cold joint because sand appears on the surface along cracks, and is assumed to have occurred at the construction stage. Since the possibility of development of these cracks is considered low, measures to prevent penetration of external water must be taken by filling with sealing material.

3) Results of non-destructive test

Since so many cracks were not found in concrete structures, they are healthy in whole. For example, main reinforcement, which was found inside handrails in Japan, was not observed at all. This section confirmed the concrete strength with a Schmidt hammer and inspected the thickness of concrete covering and about the position of steel reinforcement bars with an electromagnetic wave radar. However, since design drawings were not procured, values after construction could not be compared with those on design drawings.

As the result, the concrete strength is considered to be equivalent to that usually used in Japan. In addition, appropriate construction is considered to have been implemented for the thickness of concrete covering and about the position of steel reinforcement bars.

However, since design drawings were not procured to review detailed results, values after construction could not be compared with those on design drawings.

Table 3.5.1: Results of non-destructive test

Inspection name / Name of bridge	Scleroscope hardness (N/mm^2) Confirmation of concrete strength	Electromagnetic wave radar (mm) Confirmation of intervals of arranged bars and the thickness of concrete covering
Rama 4 (Completed in 2006)	29 N/mm^2 on average (pier) (26.7 to 30.8 N/mm^2)	• Arrangement of bars at equal intervals (Main reinforcement of 100 mm, distributing bar of 150 mm) • the thickness of concrete covering of 50 mm
Rama 5 (Completed in 2002)	32 N/mm^2 on average (pier) (31.4 to 33.3 N/mm^2)	• Arrangement of bars at equal intervals (Main reinforcement of 300 mm, distributing bar of 150 mm) • the thickness of concrete covering of 58 mm
Phra Po Klao (Completed in 1984)	24 N/mm^2 (Handrail)	• With slight dispersion in arrangement of bars (Main reinforcement of 150 to 300 mm) • the thickness of concrete covering of 44.8 mm

(2) Steel truss bridge

This item describes major damages of steel structures, including corrosion, fatigue and member deformation.

1) Corrosion

Adherent salt volume on coated film surface was measured to estimate deterioration of steel structures due to corrosion. Plate thickness was measured to confirm current corrosion quantity. The Krung Thron bridge, Memorial bridge and Krung Thep bridge are located 26 km, 22 km, and 18 km from the coast line, respectively.

a) Measurement of adherent salt volume

Judging from the results of measurements, the salt volume on the top surface or side surface is smaller than that on the bottom surface, which is not disposed to rain, and incoming salt is found to have impact. The adherent salt volume is clearly different depending on the time of repainting. In the Memorial Bridge repainted in 2001, the adherent salt volume was 56.6 mg/m^2 at end post and on the bottom surface of diagonal.

b) Measurement of plate thickness

Plate thickness of the main body structure was measured by using a device that can measure plate thickness without the thickness of coated film.

In targeted bridges built 50 to 80 years ago, it was found from the result of this measurement that the thickness of major members in some area was decreased by approximately 2 mm.

c) Estimation of deterioration and countermeasures

On the other hand, since design calculation documents and structure diagrams were not procured with respect to reduction of plate thickness, the safety cannot be stated conclusively.

Theoretically, the truss structures have no redundancy. However, actually the nodes which are connected more than two members can be carried the moment and shear forces to other members. So the real truss structures have higher load carrying capacity than that of design.

As the results, those structures should be enforced as soon as possible, however, it is unlikely to require emergency measures because of the lack of structural safety. In addition, since load restriction (including restriction on the number of wheels) on vehicles passing through these bridges has been implemented on a step-by-step basis, it is considered to be a realistic measure to continue the current repainting policy for preventing reducing cross-section of the steel.

In many cases, the allowable value of adherent salt volume on a painted surface with it repainted is set to 50 mg/m^2 or less with NaCl. However, the painting system considers that the allowable limit is 100 mg/m^2 maximum.

For this reason, it is desirable to manage adherent salt during repainting and remove salt by washing with water, if necessary.

The non-destructive test is detailed in Appendix-5.

Table 3.5.2: Summary of non-destructive test results (steel truss bridge)

Inspection name / Name of bridge	Measurement of adherent salt volume (mg/m^2) (Average value)	Measurement of plate thickness (mm) Confirmation of reduction of plate thickness of steel material
Krung Thon (Completed in 1958) (Repainted in 2010)	• Diagonal, vertical and end post (side face) 6.7mg/m^2 • Diagonal and end post (bottom surface) 29.5 mg/m^2	• Reduction of plate thickness can be catched
Memorial (Completed in 1932) (Repainted in 2001)	• End post and diagonal (top surface) 30.7 mg/m^2 • End post and diagonal (side surface) 11.7mg/m^2 • End post and diagonal (bottom surface) 56.6 mg/m^2	• End post and diagonal (upper flange) Reduction of plate thickness by approx. 2 mm (19 mm around, 17 mm at places of thickness reduction) • Corrosion place in splice plate of end post and diagonal Reduction of plate thickness by 1 to 3 mm (10 mm around, 7 to 9mm at places of thickness reduction)
Krung Thep (Completed in 1959) (Repainted in 2005)	• End post, vertical, and web of drawspan (side surface) 11.1 mg/m^2 • End post and web of drawspan (bottom surface) 38.3 mg/m^2	• Corrosion plate at the bottom of vertical stiffener of drawspan Reduction of plate thickness by 3 to 7 mm (13 mm around, 7 to 10 mm at the relevant place)

2) Fatigue

2-1) Fatigue endurance of steel truss bridges

Of 12 Chao Phraya bridges, three steel truss bridges (Krung Thon, Memorial, and Krung Thep) are also currently in-service. Each bridge has endured the long-time use since the construction. For these bridges, the DRR, a road administrator, has changed restrictions on vehicles passing through them with the times. As mentioned in the traffic survey at Krung Thon, vehicles that are not permitted to pass through the bridge for the reason of not observing the load restriction amount to approximately 1 %. as the actual condition.

Considering fatigue endurance of steel structures, if load on a steel structure is twice larger than the reference load, the impact on it is assumed to be larger by 8 times. This section therefore describes fatigue endurance, focusing on large vehicles (truck, semi-trailer, and trailer).

The Krung Thon is assumed to be the target bridge. This is because many vehicles are found to be operated beyond load restriction, the truss structure of the Krung Thon bridge is similar to that of the Krung Thep bridge, and the results of strain measurements carried out by a local consultant in a past fiscal year by using vehicles run actually is available. For the Memorial bridge whose in-service period is the longest, suggestion for the fatigue problem is refrained because of the available sources of information about the bridge, such as "As-built"bridge plans.

a) Overview of static load carrying test at Krung Thon

The outline of the test executed by the local consultant is as follows,

- The road of the Krung Thon bridge was closed to perform the test.
- For the traveling position when two vehicles with load of 25 t (3 axes with 10 tires) travel side by side (at a speed of 5 km/h), the test was carried out in the two cases: wheel passes through a position 1.2 m from the side track and 1.2 m from a divided lane.
- Strain measurement positions are vertical material, diagonal, lower chord, upper chord, floor beam, and stringer. This measurement focuses on the stress (max. 92μ) of floor beam under the divided lane near the center of effective span.
- As the result of coupon test, the quality of steel material was equivalent to SS400.
- As the result of test, the elastic modulus of steel material was 210,000 MPa.

The strain of 92μ generates the stress of 19.3 N/mm^2. (193kgf/cm^2)

Advanced inspection for the Krung Thon takes several months. As the result of the inspection, cracks, detected in the upper chord, were assumed to be flaws generated at a temporary stage, because the members are usually subjected to compression forces.

b) Arrangement of traffic volume

In a vehicle used in the above load test, rear wheels are dominant for fatigue. A truck has the rear wheels (2 axes, 8 wheels, 10 t per axis). The number of this rear wheel was investigated for trailers and semi-trailers. As a result both trailer and semi-trailer are equipped with two rear wheels (2 axes, 8 wheels, 10 t per axis) respectively. The number of large vehicles on a public holiday and on a week day, as mentioned above, is converted into the number of rear wheels in each truck, as follows.

Public holiday (24h)		Weekday (24h)	
Toward Bangkok	Toward Thon Buri	Toward Bangkok	Toward Thon Buri
453 vehicles (0.31)	513 vehicles (0.36)	449 vehicles (0.31)	478 vehicles (0.33)

Note: The number of vehicles passing through for a minute is put in parentheses

Table 3.5.3 Number of violator vehicles equivalent to truck

If a large vehicle passes through the bridge at a speed of 60 kmph, it stays on a 58m simple truss for approx. 3.5 sec. Therefore, the possibility that more than 2 vehicles passing through the bridge in the direction perpendicular to bridge axis is low within the bridge. So, only one vehicle is assumed to travel on the bridge. In this case, the stress is 9.65 N/mm^2 (96.5 kgf/mm^2) if the degree of the generated stress mentioned above is assumed to be reduced by half.

In this study, every vehicle is assumed obeyed the traffic load regulation. Therefore, excessive stress would be measured when some drivers run a vehicle which was overweight compared to the regulation. According the hearing form DRR, the overweight trucks were detected in other area, not on this bridge. The fatigue problem is more serious when effect of the overweight trucks on the bridge is considered.

c) Summary

Since the rivet joint currently being used are expected to be replaced sooner or later with high-strength bolted friction connection, relationships of the base material with fatigue strength was investigated when high-strength bolted friction connection was used for a joint receiving direct stress. As the result, the value obtained is approximately 45 N/mm^2 for variable stress when the fatigue limit is class D. If passage of vehicles continues beyond the current situation or load restriction, a problem on fatigue will occur in future.

Consideration in this section covers not overload vehicles but vehicles exceeding the load restriction. If vehicles exceeding the load restriction include a certain number of overload vehicles, a problem on fatigue will occur at an early date.

Early detection of cracks will be required by using not only periodic inspection but also every opportunity, e.g., repainting work, where workers can be close to structures.

2-2) Crack damage in a composite deck

On the Thon Buri side of the drawbridge portion (center span) of the Krung Thep Bridge, crack of approximately 3.5 m in length was visually checked in the bridge axis direction on the steel plate of a composite deck.

The crack passes through two angles and an edge of a rectangle portion cut out, and is found to develop when viewed from a different angle. Since rust from the crack is observed, it is considered that the crack extends throughout RC slab and rain penetrates from road surface.

In the relevant area, the crossbeam interval is 6.1 m, and the stringer interval is 1.25 m. A composite deck is made up of steel plate of 8 mm, concrete slab of 90 mm, and pavement of 10 mm. Stud is considered to have been welded onto the steel plate

The place where the crack occurs is located on a division line on the road surface. Although damages were not found by observing the road surface, marks of repair made in the past were detected on the pavement of the running line located near the place of the damage.

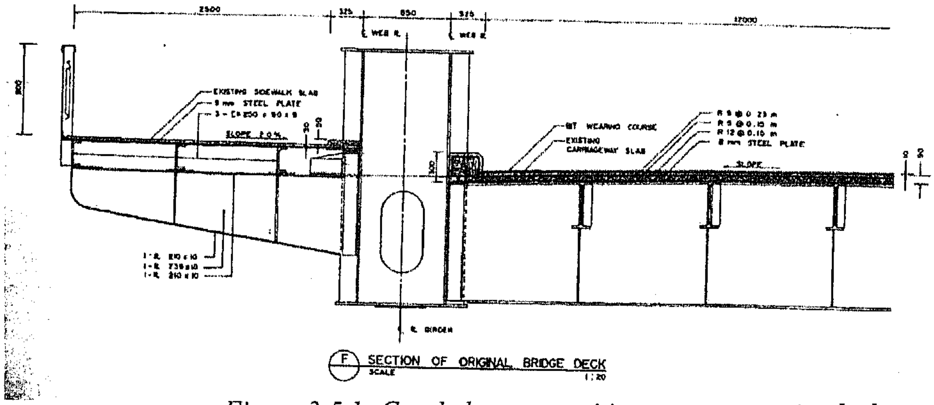


Figure 3.5.1: Crack damage position on a composite deck

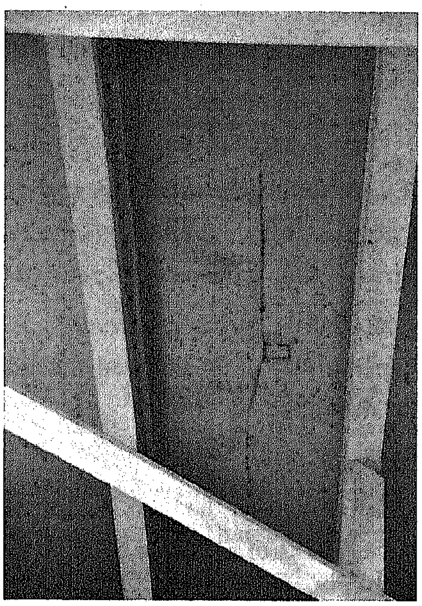


Figure 3.5.2: Crack damage 1 on a composite deck

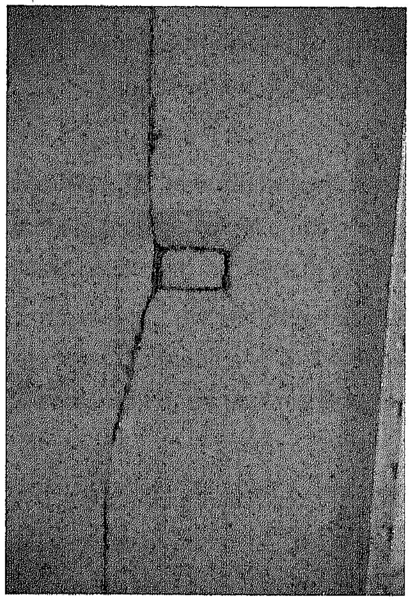


Figure 3.5.3: Crack damage 2 on a composite deck

- Estimation of damage cause and countermeasure

Judging from intervals of crossbeams and stringers, bending moment on a composite deck by the passage of vehicles is dominant in the deck span direction (direction perpendicular to bridge axis).The direct stress generated from this contributes to propagate the cracks. It is therefore assumed that cracks were generated by stress concentration at four corners of the rectangular.

Since cracks at the relevant place are located on a division line, and deck span is 1.25 m in length which is wider than wheels, the crack propagation must also be observed in future continuously for the traffic safety.

In addition to the relevant place, some areas of steel plate were cut out and then welded at a later day. However, they were circular or elliptic shaped, and cracks were not visually checked. That the shape of holes should be circular for preventing stress concentration on the plate was proposed.

2-3) Deformation of members

In each steel truss bridge, deformations of members to lower chord and diaphragm due to collision with ships and vehicles passing through it were found. How these deformations will transition cannot be predicted, because they are accidents and different from aged deterioration. This section describes notes for correcting or replacing deformed members according to the request from DRR.

As a method of correcting members, correction by heating is assumable. However, lower chord is considered as a member that is difficult to correct by heating for structural reasons. On the other hand, a lower lateral bracing is considered to be appropriately treated by replacing the member itself instead of correcting it by heating. Actual replacement requires preparation of design documents and design calculation documents at the time of design for the present structure. If structures were altered until now after their new construction stages, their design documents are to be prepared. However, if design documents cannot be procured, it is necessary to grasp shapes of relevant structures and understand properties of materials by coupon test, etc. In addition, a loading test is carried out to grasp relationships between load and deformation.

Such information is used to select appropriate models for structural calculation and grasp behaviors of structures. After that, it is necessary to confirm the safety at each stage. Calculation must be needed to grasp the movement of the structure according to the process including member removal, installation, etc.

As notes on replacement of members in the construction, safety measures must be taken considering rebound of members with stress released, because deformed members are acted on by unexpected force. In addition, introduction of predetermined stress for installing new members may require jacks to adjust the stress in some cases.

Anyway, the execution of work must start after confirming the safety in steps from the start stage of construction to the completion.

2-4) Missing bolt

During the bridge inspection, some holes which might be considered the cause of brittle fracture of high tension bolt were observed. This phenomenon is not appeared significant plastic deformation before braking, under tension force acting on the material for some time. In Japan, this phenomenon was recorded on F13T high-tension bolt (Tension strength: 1300 N/mm^2), and then F11T high-tension bolt (Tension strength: 1100 N/mm^2) was also observed the same phenomenon. The result of checking bolts which was replaced from rivets was F10T. This bolt has not been reported the phenomenon up to now.

For this reason, the cause of missing bolt is not the brittle facture.

Figure 3.5.4: Repainting on HTB(F10T)

(3) Cable-Stayed Bridges

IRR (south) and IRR (north) have the same structure type, and similar damages were found in them.

1) Cracks in the vertical direction in the main tower base.

A crack in the vertical direction was observed in the main tower. This is considered to be a temperature crack. Concrete tends to expand right after it is placed and then shrink as time goes by. In this series of movement, horizontal placement surface restrains the movement of concrete from expansion to shrinkage. As the result, crack is considered to have occurred in the perpendicular direction to placed cement.

Since this crack occurred at the construction stage, development of the crack assumed to be unlikely. As a measure to be taken, it is considered appropriate to prevent entry of water from outside by filling the crack with seal to avoid corrosion of internal reinforcing iron.

2) Cracks on the column cap

Actual stress status at this place is unknown for structural reasons. In this place, a crack has propagated more than two directions . This example is unlikely to have occurred due to transmission of force in a constant direction but is considered to have occurred due to action of alternate stress. Although typical examples of alternate stress are wind and earthquake, the crack is assumed to have occurred due to earthquake, judging from the location.

Since the stress status at the place is complicated, it is necessary to monitor over time whether or not the crack has propagated.

3) Cracks on projected area of a deck

Multiple cracks in a constant direction were observed in concrete slab surrounded with main beams, stringers and crossbeams. Similar damages have been observed in multiple slabs. In some of them, precipitation of free lime is found. These cracks are assumed to be caused by shear deformation of slab due to tensioning force of cable. As the result, multiple cracks are caused with resultant diagonal tension (brusting).

It is considered this is caused by the design. In the future, it is necessary to monitor, over time in the field, as to whether these cracks have developed and to fill material into cracks on the upper surface of the projected deck to prevent entry of rain. Review for investigation of the cause is considered necessary by returning to the design stage.

4) Cracks in a cable fixing area

In a cable fixing area, cracks have developed from the center of cable toward the periphery. It is unknown whether these cracks occurred at the construction stage and whether they are also developing currently. If the cracks are assumed to have developed at the construction stage, it is estimated that tensioning force was introduced at a stage where concrete strength had not been developed or inappropriate tensioning force was introduced. After the construction, if cracks have developed with concrete strength developed as expected initially, the introduction of tensioning force is assumed to have been inappropriate.

At any rate, it is considered necessary to continuously check whether cracks have developed, conduct a review at the design stage, and confirm the strength of concrete in the field.

5) Cracks in bridge columns

Horizontal streaks were found at equal intervals in the bridge columns axis direction around the bridge columns and in the direction perpendicular to the axis direction. In addition, reticulated cracks were found to spread to the relevant area. These streaks are not cracks but are assumed to be caused by formwork, because lattice streaks are found, through reconfirmation, not only in specific bridge footings but also in circumferential bridge columns, and slipform was used for formwork during construction.

For reticulated cracks, It seems highly possibility that those have occurred due to drying shrinkage.

If the width of those cracks becomes wider, water proofing on the cracks is highly recommended.

3.5.2 Substructures

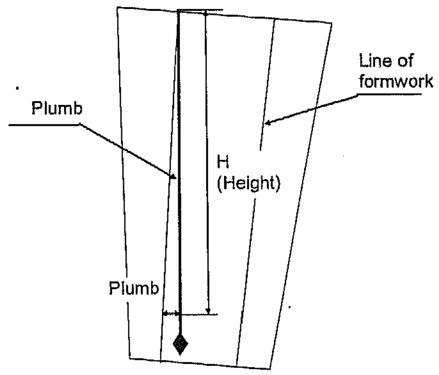
Since visual inspection found bridge columns on the Thon Buri side of Rama 5 to incline toward Bangkok side, actual measurement of inclination amount, inspection of surrounding environment and estimation of the cause were carried out.

(1) Measurement of inclination of bridge columns (slant amount)

Measurement with a plumb was made to confirm the slant amount of bridge footings.

A "plumb" so called here is a tool made of an iron weight (cone) to which thread is attached and is used to check for perpendicularity by dropping it. Since a formwork is generally installed vertically, the streaks of formwork were assumed to be vertical. (See the lower left drawing.) The "Plumb" used this case was: 43 (mm) in diameter X 84.5 (mm) in length, 300g in weight.

Thread was fixed at the top of the column. H (height) and W (width) were then measured at a place where the mark was relatively clear. With accuracy of mm in the measurement, those values were obtained by rounding off to the closest whole number.



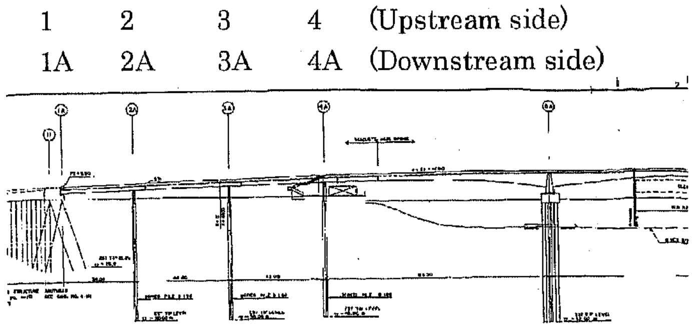


Table 3.5.4: Summary of inclination amount

Inspection name / Name of bridge	Measurement by "Plumb" (rad) Confirmation of inclination of bridge columns (slant amount)
Rama 5 (Completed in 2002)	#4 (upstream side) Bridge axis direction H = 4280 (mm), W = 20 (mm) Inclination amount: 0.0046 (toward the Chao Phraya River)
	#3 (upstream side) Bridge axis direction H = 3220 (mm), W = 20 (mm) Inclination amount: 0.0062 (rad) (toward the Chao Phraya River)
	#3 (upstream side) Bridge perpendicular direction H = 3300 (mm), W = 2 (mm) Inclination amount: 0.0006 (rad) (toward the inner)

(2) Investigation of surrounding environment

Damages were not found in houses, electric lamps, retaining walls, etc., around places where inclination had been detected.

Inspection was carried out in a 500m, between intersection of Soi Wat Sangkratan and the river. The results were as follows:

- Settlement was observed in one of the interlocking blocks of bridge columns closer to the Chao Phraya River than to the intersection.
- Two pedestrian crossover bridges are constructed in the section to this intersection. Although level difference was found between each base of those bridge columns and footpath, bridge footings were not felt inclined.

The status before construction can be observed from the plan view of a design drawing. In the plan view, houses are close together on the Bangkok side, but on the Thon Buri side, houses are lined up in a line along a river and waterways appear to be formed.

According to these situations, it is estimated that earth to be refilled was used to prepare the land to some degree of depth when this bridge and the road attached to it were constructed.

(3) Evaluation of earth to be refilled

According to the specifications for highway bridges V (seismic design for bridges) of Japan Road Association, the following four points as sandy soil layer where judgment of liquefaction is required to construct a new bridge.

a) Sandy soil layer of alluvial formation

b) Saturation soil layer whose groundwater level is within 10 m from the ground surface and that is located at the depth of 20 m or less from ground surface.

c) Soil layer whose fine-grained fraction content FC (passage mass percentage of soil fraction of 75μm or less in particle size) is 35% or less or whose plasticity index is 15 or less when FC is more than 35%

d) Soil layer whose average particle size D50 is 10 mm or less with 10% particle diameter D10 of 1 mm or less

If the location and results of indoor test of collected soil are applied,

a) Since clay of alluvial formation is covered with the layer, it is assumed to be sandy soil layer of alluvial formation or earth to be refilled.

b) Judging from the water level of the Chao Phraya River, the underground water level is estimated to be within 10 m from the ground surface.

c) Satisfied because fine-grained fraction content was 10.2%.

d) Satisfied because average particle size D50 is 0.25 mm, and 10% grain D10 was 0.071 mm.

The type of collected soil is classified as sand.

From the points above, sand at least observed on the surface has the possibility of liquefaction.

3.6 Maintenance status

This bridge inspection (visual inspection) has revealed the actual repair status of bridges maintained by the DRR. Details are shown with photos in Appendix-4.

Steel bridges have been regularly repainted and their rivets have been replaced with HTB (F10T). In concrete bridges, crack repair, and cross-section repair at places without concrete have been observed. In addition, touch-up against graffiti, regular cleaning, and deck replacement have been confirmed.

3.7 Summary (Review of deterioration factors)

(1) Superstructures

1) Concrete bridge

Obvious cracks are assumed to have occurred at the construction stage.

2) Steel bridge

If the present traffic situation remains unchanged, fatigue problem may occur depending on the number of in-service years in future.

3) Cable stayed bridge

Obvious cracks occurred in the construction stage. However, it is unknown whether some other cracks are caused by design or construction stages. In addition, some cracks are assumed to have occurred due to alternate forces, e.g. impact of earthquakes.

(2) Substructures

Judging from the ground situation, the possibility of impact of earthquakes cannot be denied. As mentioned in 3.2.5, the influenced the long-period earthquake wave for high-building were recorded in the Bangkok. In the future, the impact on the foundations with the inclination of columns should be reviewed in addition to the measurement of range and degrees of inclination of those columns.

Chapter 4 Formulation of long-term maintenance planning for the Chao Phraya river crossing bridges

4.1 Collection and analysis of existing management information

The 12 bridges over the Chao Phraya are individually maintained by the maintenance offices in vicinity of them. The current situation of those maintenance works is likely to be responsive that they take countermeasure to the serious damages detected by their daily inspection. This kind of responsive maintenance conducted for each bridge, however, is generally known to eventually increase LCC and reduce safety and reliability of the structure.

As summarized regarding the results of information collection on the maintenance status of the DRR bridges over the Chao Phraya in Section 2.2 and 2.3, basic data (bridge inventory data, inspection results, maintenance records, etc.) necessary to develop a long-term maintenance plan are not integrally managed. Given those circumstances, the long-term maintenance plans being formulated here will be such that is mainly based on the available information at this moment, the periodic inspection that is to be conducted according to "Inspection and evaluation manual", and the data obtained from the experiences in Japan. When more data are accumulated in the future from periodic inspections and repair countermeasures, the long-term maintenance plans should be reviewed so as to improve the precision of the plans.

4.2 Proposals concerning the formulation of long-term maintenance plan

The 12 bridges over the Chao Phraya river are all considerably important, which is why DRR conducts daily maintenance including road patrol. However, it is likely to be responsive maintenance and also the maintenance records are not integrally managed.

As the maintenance cost of those bridges is expected to increase in the future with the progress of bridge aging, it is important that the maintenance procedure be shifted to preventive one to reduce LCC of the bridges, elongate the service life and maintain a sufficient level of bridge safety and reliability.

The long-term maintenance plans to be formulated here are based on the preventive maintenance approach proposed as a solution for effective use of the limited budget.

The following are the points of proposals and these specific contents are described in Section 4.3:

- Target maintenance level should be clearly defined.
- Classification of countermeasure should be judged, such as whether repair or emergency response is necessary or not, using the results of periodic inspection according to "Inspection and evaluation manual".
- The repair cost should be calculated according to the classification of countermeasure in the inspection results or the progress of damage by deterioration over time identified after inspection, and LCC should be estimated.

4.3 Estimation of life cycle cost

4.3.1 Estimation of LCC for repair planning

(1) Concept of the maintenance level

The concept of maintenance level is introduced as an efficient and effective maintenance method for the 12 Chao Phraya bridges. Using the maintenance level allows management of a bridge by the level related to the importance of the bridge and the purpose. In other words, it will involve writing of a maintenance scenario for each bridge.

Considering the bridge characteristics (including importance and environmental characteristics), the status of maintenance, and inspection results for the 12 Chao Phraya bridges, it is decided that the "countermeasure classification 3 (CC 3)" or more as shown in Table 4.3.1 is the target for the maintenance level to be fulfilled (specific countermeasure should be taken as soon as the condition reached the "countermeasure classification 2 (CC 2)"). Compliance with this maintenance level will enable planned maintenance of safety and serviceability of bridges.

Table 4.3.1: Maintenance level for the 12 Chao Phraya bridges

Countermeasure Classification (CC) [Condition level]	Description	Reference	
		AASHTO	Japan
5	No damage	VERY GOOD	A
4	Almost no damage	GOOD	A
3	Repair is necessary depending on the situation	FAIR	B
2	Repair is swiftly necessary.	POOR	C
1	Repair is urgently necessary to ensure structural safety of bridge or to prevent damage to third parties.	CRITICAL	E

(2) Estimation method for LCC

A long-term maintenance plan for each bridge should be described using the total sum of LCC in 100 years hereafter.

In a long-term maintenance plan, countermeasure will be taken that corresponds to the countermeasure classification for the damage detected in the initial periodic inspection. After the appropriate countermeasure is taken to restore the sound condition of the bridge, periodic repair and member exchange appropriate for the service life of the bridge will be properly conducted from the viewpoint of preventive maintenance, thereby ensuring efficient maintenance of bridge soundness. The flow chart for LCC estimation is shown in Fig. 4.3.1. LCC occurring from maintenance work should be estimated for the following items:

LCC = total sum of the maintenance cost in 100 years hereafter

[STEP-1: Maintenance cost for the damage detected by periodic inspection]

= Repair cost for the damage detected in the periodic inspection (1)

[STEP 2: Estimation of the planned maintenance cost to occur after the repair]

+ Cost for periodically conducted inspection work ························ (2)
+ Cost of repair for damage due to deterioration over time ············ (3)
+ Cost for renewal of members whose periodic exchange is necessary ·· (4)

- Cost (1) is the repair cost of damaged members identified as "CC 2" in the initial inspection.

- Cost (2) is the reserve cost related to periodic inspection, daily maintenance work and unexpected countermeasure.

- Cost (3) is the repair cost for the members identified as "CC 2" due to the deterioration over time which was originally identified as "CC 5" to "CC 3" in the initial inspection. In addition, the repair cost after the service life of the member repaired by planned repair.

- Cost (4) is the repair cost after the service life of the common members to be planned renewal.

- The timing of posting the repair cost varies depending on the service life of members or the countermeasure classification. Figure 4.3.2 is the conceptual diagram showing the countermeasure classification changes due to deterioration over time.

- For the "CC 1", it triggers implementation of emergency response measures, and therefore it is ruled out of LCC.

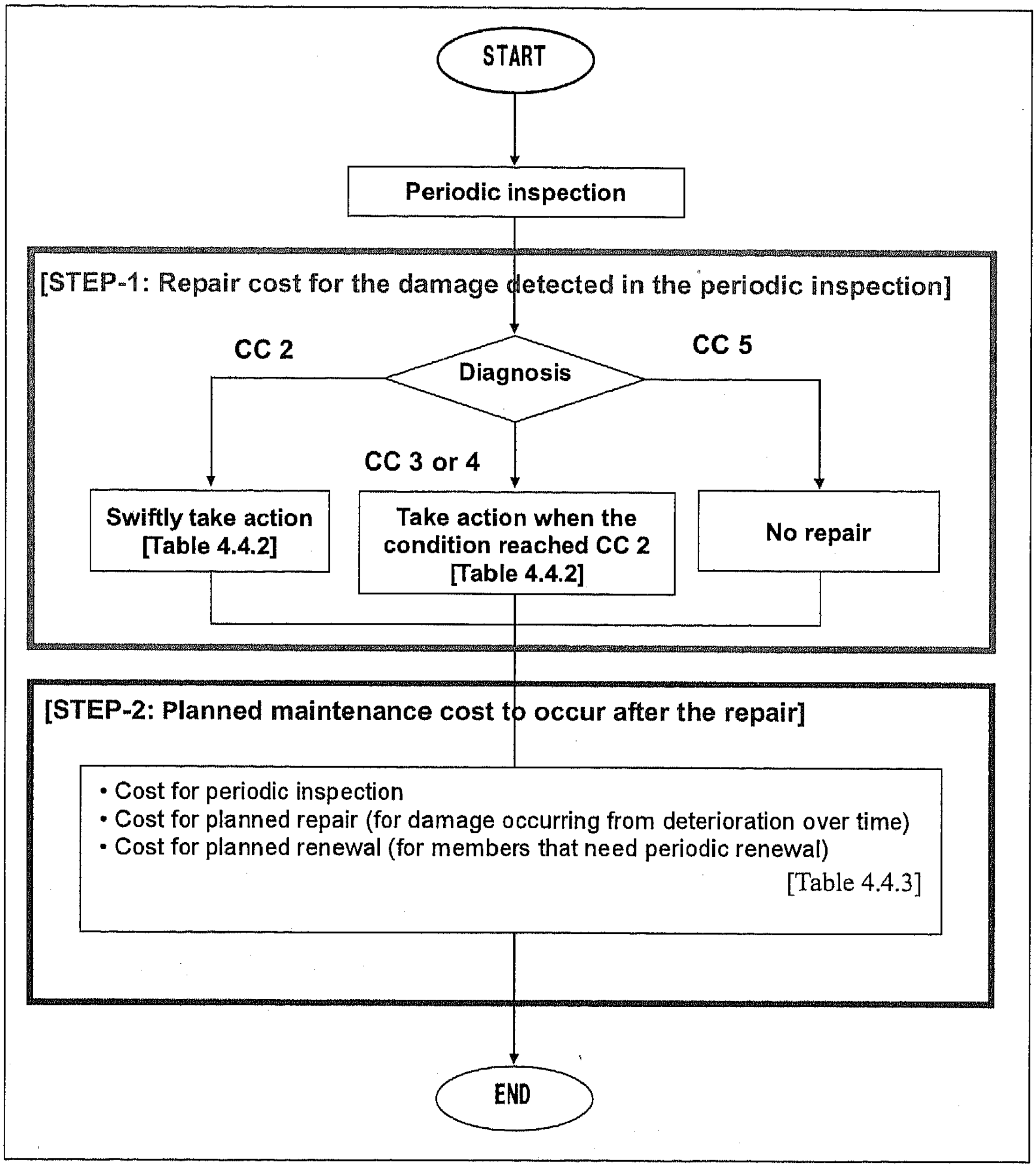


Figure 4.3.1: Flow chart for LCC estimation

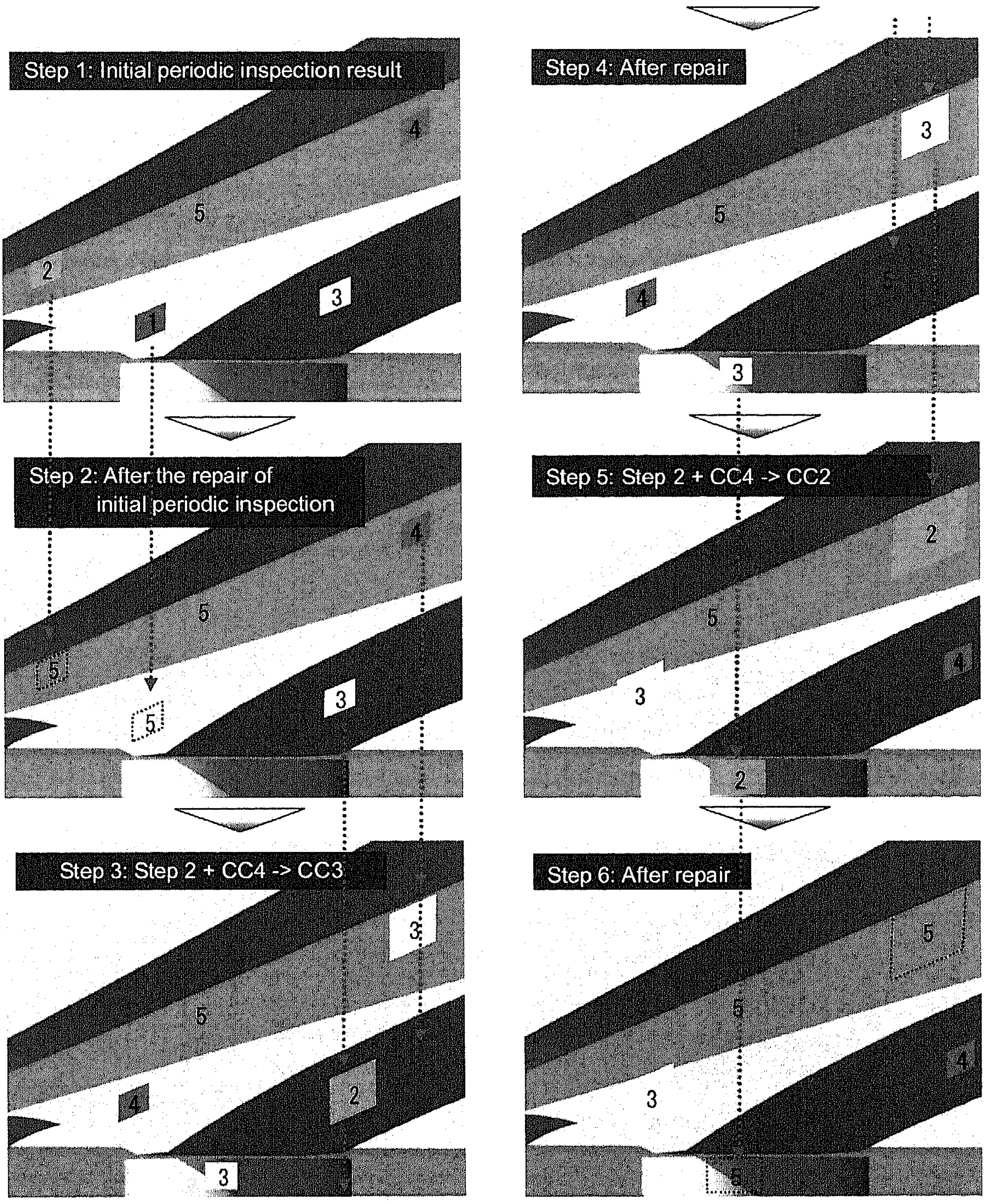


Figure 4.3.2: Schematic diagram of repair for damage occurring from deterioration over time

Table 4.3.2: Countermeasure classification (CC)

Countermeasure classification	Judgment
5	No damage is seen. Or repair has been completed.
4	Minor damage that does not need repair
3	Repair is necessary depending on the condition.
2	Swift repair is necessary
1	Urgent repair is necessary to ensure structural safety or prevent damage to third parties

The following is an estimation example of LCC.

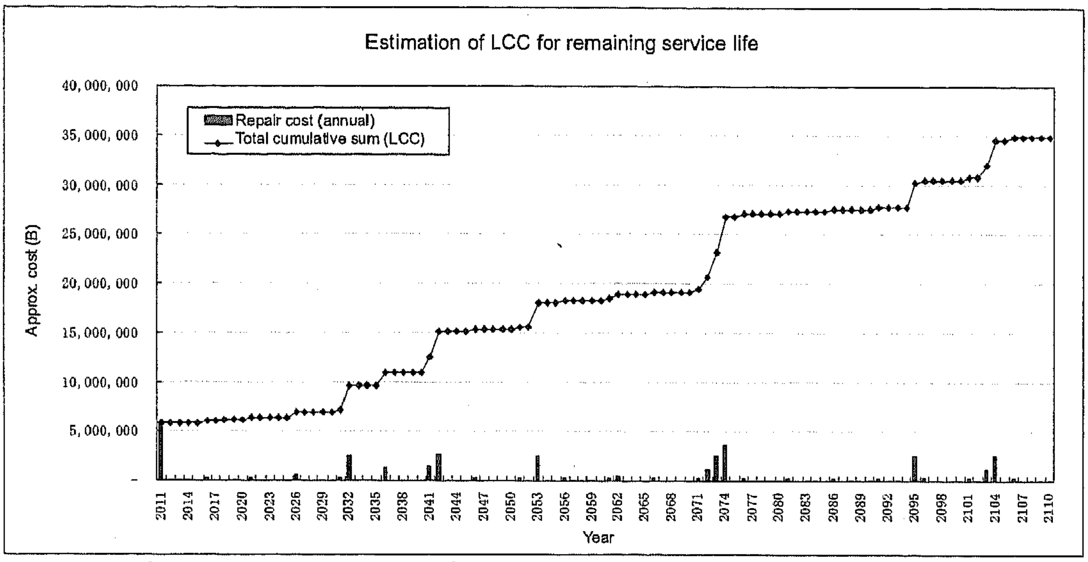


Figure 4.3.3: Estimation of example of LCC for remaining service life

Table 4.3.3 Planned maintenance repair and implementation year (example)

Member	No.	Type of damage	2011		2012		2013		2014		---	2109		2110	
			CC	Repair cost (B)	CC	Repair cost (B)	CC	Repair cost (B)	CC	Repair cost (B)		CC	Repair cost (B)	CC	Repair cost (B)
Girder	01	Crack, etc.	4		3.9	-	3.7	-	3.6	-		-	-		-
		Rebar exposure	5		4.9	-	4.8	-	4.7	-		4.5	-	4.4	-
		Damage at the anchorage of prestressing tendons	5		5.0	-	4.9	-	4.9	-		2.1	-	2.0	-
Deck	01	Rebar exposure	4		3.9	-	3.7	-	3.6	-		-	-	-	-
		Pop-outs	5		5.0	-	4.9	-	4.9	-		2.1	-	2.0	-
		Cracks in the deck	4		3.9	-	3.8	-	3.8	-		2.3	-	2.2	-
		Damage at the anchorage of prestressing tendons	5		5.0	-	4.9	-	4.9	-		2.1	-	2.0	-
	02	Rebar exposure	2	35,000	-	-	-	-	-	-		-	-	-	-
		Pop-outs	5	-	5.0	-	4.9	-	4.9	-		2.1	-	2.0	-
		Cracks in the deck	2	450,000	5.0	-	4.9	-	4.9	-		2.2	-	2.2	-
		Damage at the anchorage of prestressing tendons	5	-	5.0	-	4.9	-	4.9	-		2.1	-	2.0	-
Bearing	101	Functional damage at the bearings	2	120,000	5.0	-	4.9	-	4.8	-		4.6	-	4.5	-
	102	Functional damage at the bearings	2	120,000	5.0	-	4.9	-	4.8	-		4.6	-	4.5	-
	201	Functional damage at the bearings	5	-	5.0	-	4.8	-	4.7	-		4.5	-	4.4	-
	202	Functional damage at the bearings	5	-	4.9	-	4.8	-	4.7	-		4.5	-	4.4	-
Road surface	01	Unevenness of road surface	5	-	4.9	-	4.9	-	4.7	-		3.1	-	2.9	-
		Damage in pavement	2	2,500,000	5.0	-	4.9	-	4.7	-		3.1	-	2.9	-
Barrier	01	Damage in barriers	2	400,000	5.0	-	4.9	-	4.8	-		4.6	-	4.5	-
Expansion joint	01	Damage in expansion joints	2	1,467,400	5.0	-	4.9	-	4.8	-		4.6	-	4.5	-
Periodic inspection + reserve			2	233,400	5.0	-	2.0		5.0	-		-		5.0	-
Total				5,822,800		-				-		-			-

4.3.2 Prediction method of deterioration

In order to grasp post-inspection changes over time of the damage deterioration prediction by the damage is required. Although analysis of basic data such as inspection data is essential for deterioration prediction, it is difficult to establish a deterioration prediction method based on the inspection result, because no basic data are accumulated at the moment.

Instead of the above conventional approach, an alternative method is used instead, which sets countermeasure timing relating to its countermeasure classification determined from the periodic inspection while using the general deterioration trends as reference data.

The general deterioration tendency is shown below:

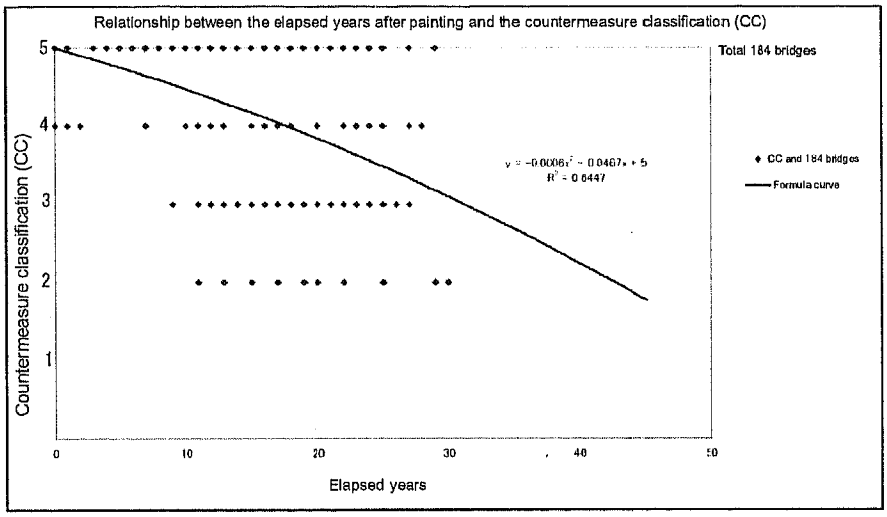


Figure 4.3.4 Example of deterioration curve

- A typical deterioration curve is plotted with the vertical axis for CC and the lateral axis for elapsed years.
- Fig. 4.3.4 is a plot of the " inspection result of painting: correlation between the elapsed years and the countermeasure" for various bridges (which differ in design, construction, service, environmental conditions, etc.).
- Performance tends to decrease at an accelerating pace with the increase in elapsed years.

Parabola approximation of the deterioration curve and then linear approximation for a line connecting the intersecting point of CC and elapsed years.

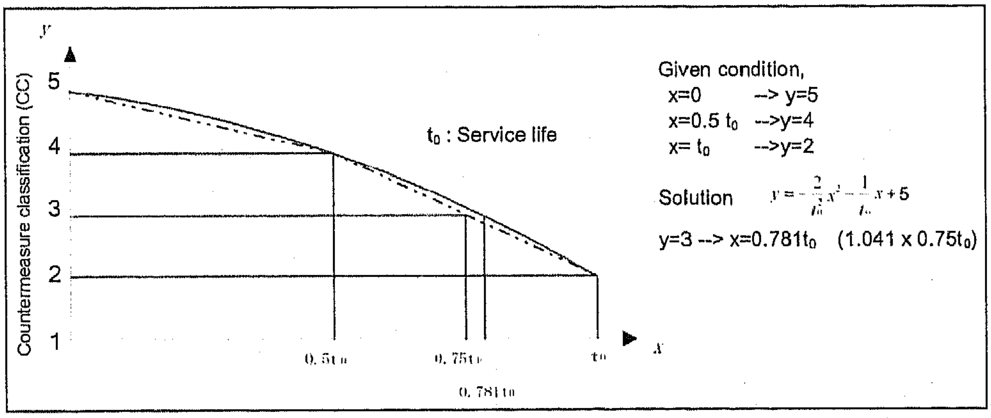


Figure 4.3.5 Parabola approximation of deterioration curve

Define the relationship between performance (CC) and timing for countermeasure.

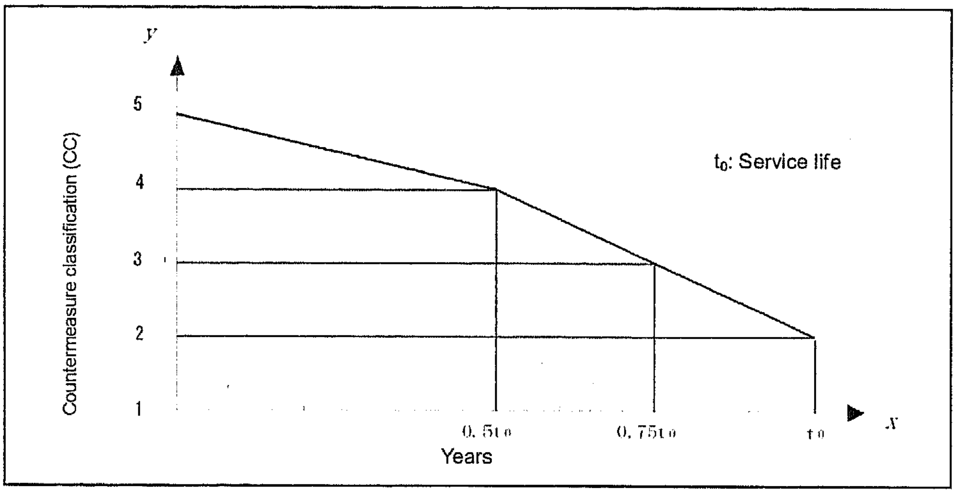


Figure 4.3.6: Approximation of deterioration curve with polygonal line

4.3.3 Estimation of LCC based on the repair method and repair timing

The timing for countermeasure will be determined based on CC identified by the inspection results based on the relationship shown in Figure 4.3.6, and the repair cost for each member will be estimated.

The unit price for the repair method depending on the type of damage is determined from the data of the typical method used in Japan. The quantity used for the estimation of the repair cost is determined based on "Area of bridge surface, etc. x coefficient" by reference to the estimation examples in Japan.

The calculation formula used is shown below:

Repair cost when the damage reaches "CC 2"
= unit price of the repair method corresponding to each damage type x [Area of bridge surface x coefficient (reference value in Japan)]

4.4 Formulation of long-term maintenance plan

4.4.1 Preparation of the manual for formulation of long-term maintenance plan

In the preparation of the manual for formulation of long-term maintenance plan, the basic idea of the manual was proposed and explained to DRR for their review. The final manual developed out of this repetitive process thus reflected the opinions and comments.

Figure 4.4.1 and 4.4.2 are the photos showing the progress of consultation involving the personnel of DRR and JICA study team.

While the intension was originally to develop a manual for formulation of long-term maintenance plan for the Chao Phraya bridges, DDR requested the manual be applicable to severely-deteriorated local bridges.

However, since the 12 Chao Phraya bridges are maintained with an advanced level and their structural types are known, which makes a stark contrast with locally managed bridges, said to total more than 7,000, with different structural types, construction conditions, service- and environmental-conditions, it was considered irrational to cover all of them under single long-term maintenance planning. Therefore, it was proposed that a separate reference document will be provided, as in Appendix 7, for preparation of separate long-term maintenance plans for local bridges, and this suggestion was accepted by the DRR personnel.

Figure 4.4.1 Discussion on the frame of the long-term maintenance plan, Jul. 30, 2010

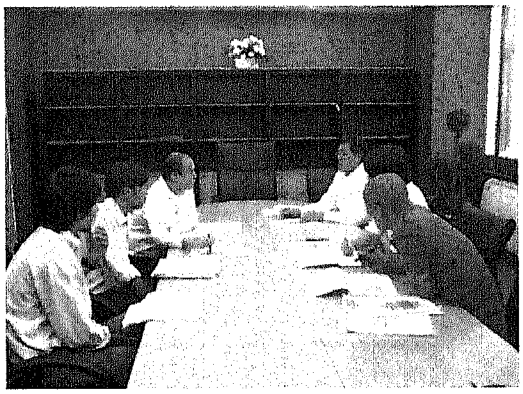


Figure 4.4.2 Discussion on the contents of the long-term maintenance plan, Nov. 29&30, 2010

4.4.2 Frame and scenario of the long-term maintenance plan

(1) Flow chart for long-term maintenance planning

In the bridge maintenance it is important to attempt more effective maintenance by circulating the cycle of Plan (long-term maintenance plan) - Do (repair countermeasure) - Check (bridge inspection) - Action (Plan, improvement and review) to ensure continuous improvement resulting from the accumulation of basic data, findings, knowledge and experience.

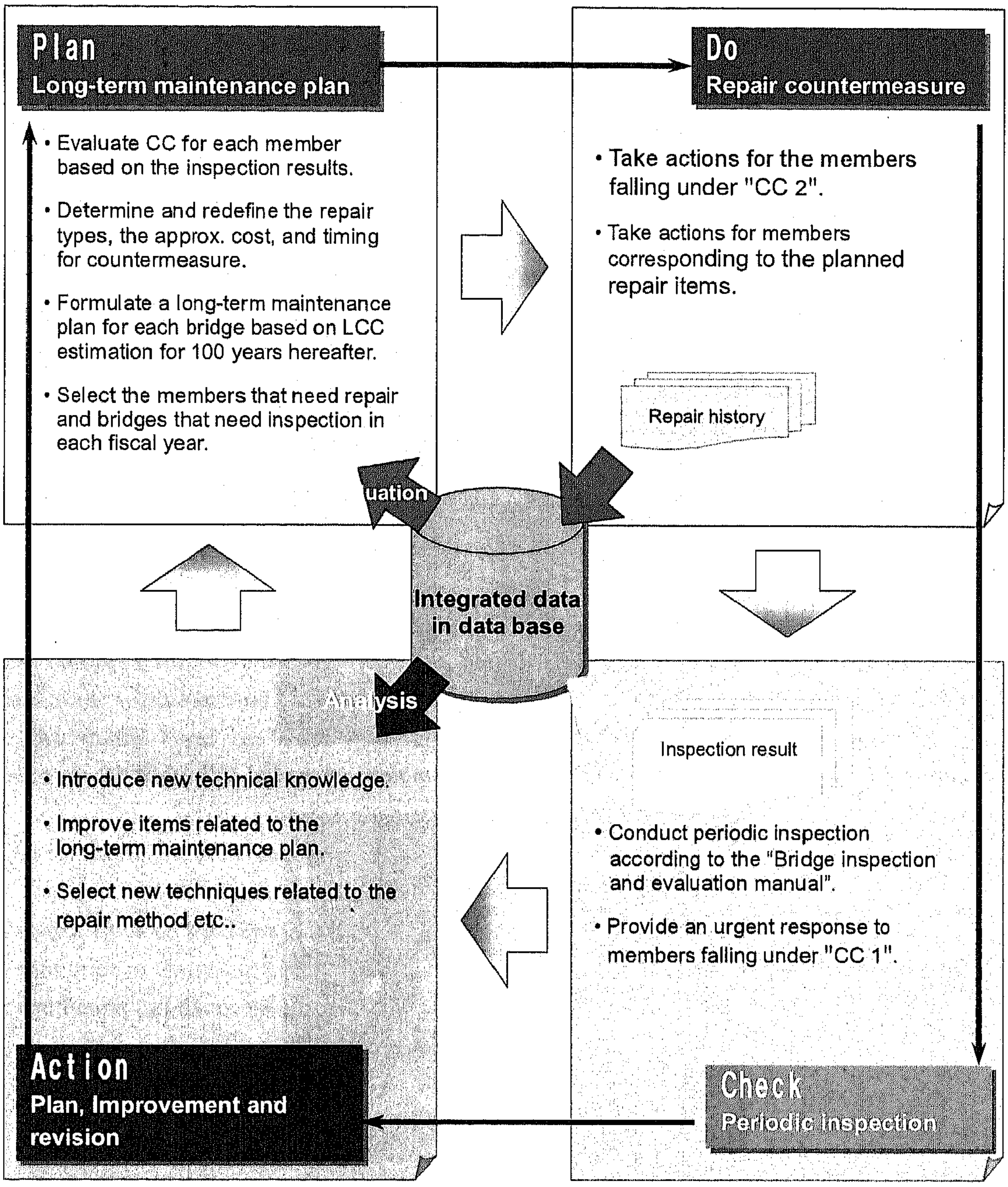


Figure 4.4.3: Procedural system of bridge maintenance

1) Plan (drafting a long-term maintenance plan)

The purpose is to formulate a long-term maintenance plan to ensure preventive maintenance for reduction of LCC and elongation of the service life of the structure by early detection of damage and early action, thereby realizing efficient and effective implementation of maintenance.

2) Do (implementation of repair and reinforcement countermeasure)

The purpose is to conduct advanced inspection (laboratory test, field non-destructive test, etc.) and review of repair method (estimation of damage factors, selection of best methods for the damage factors) and make repair designs based on the results of those and then conduct repair and reinforcement measures.

3) Check (periodic inspection of bridge)

The purpose is to conduct periodic inspection based on "Inspection and evaluation manual" to grasp the bridge condition and obtain the basic data necessary for developing a long-term maintenance plan. Accumulate the knowledge on the validity of the repair method and service life by monitoring the deterioration over time of the repaired and reinforced bridges thereby to improve the prediction accuracy of the long-term maintenance plan.

4) Action (sustainable plan, improvement and review)

The purpose is to ensure further improvement of the efficiency and quality of maintenance by implementing repair and reinforcement measures, analyzing periodic inspection results and introducing new knowledge, thereby revising the management level in the long-term maintenance plan or improving the accuracy of the deterioration prediction method.

(2) Judgment of countermeasure classification

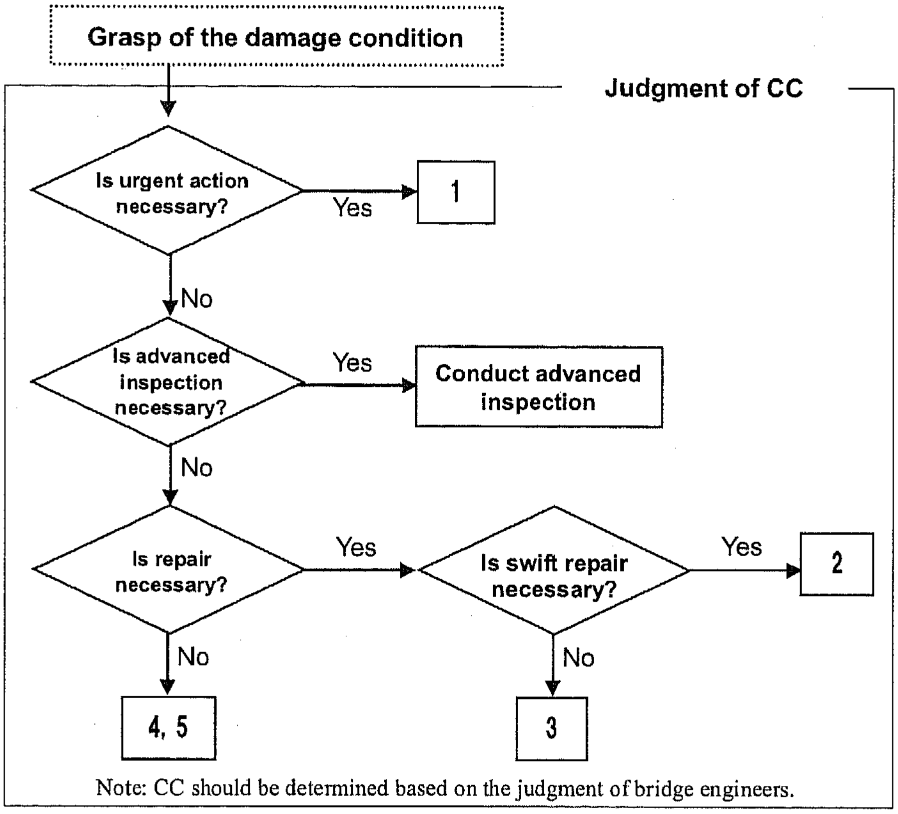


Figure 4.4.4: Flow chart for the determination of countermeasure classification

Judgment of countermeasure classification should be based on the synthetic evaluation of different damage factors including the importance of a members, the progress of damage, or environmental conditions according to the flow chart shown in Figure 4.4.4. In principle diagnosis should be made for each damage level by the member or the part.

The basic criteria of the determination of countermeasure based on the damage level obtained from inspection results are shown in Table 4.4.1.

Table 4.4.1: Countermeasure classification related to the damage level

Damage level	Classification for damage	Countermeasure	Judgement of countermeasure classification (CC)
S	a	5	5: No damage or after repair
	b	4	4: No need to be repaired due to slight damage
	c	3	3: Need to be repaired depending on the situation
	d	2	2: Need to be repaired immediately
L	e	1	1: Need to be countermeasured emergently from the view point of the structural safety and the injury of third person

Explanation of CC

[CC 5]
This level applies to the condition where no damage is detected by periodic inspection.

[CC 4]
This level applies to the condition where minor damage is detected by periodic inspection but it need not to be repaired.

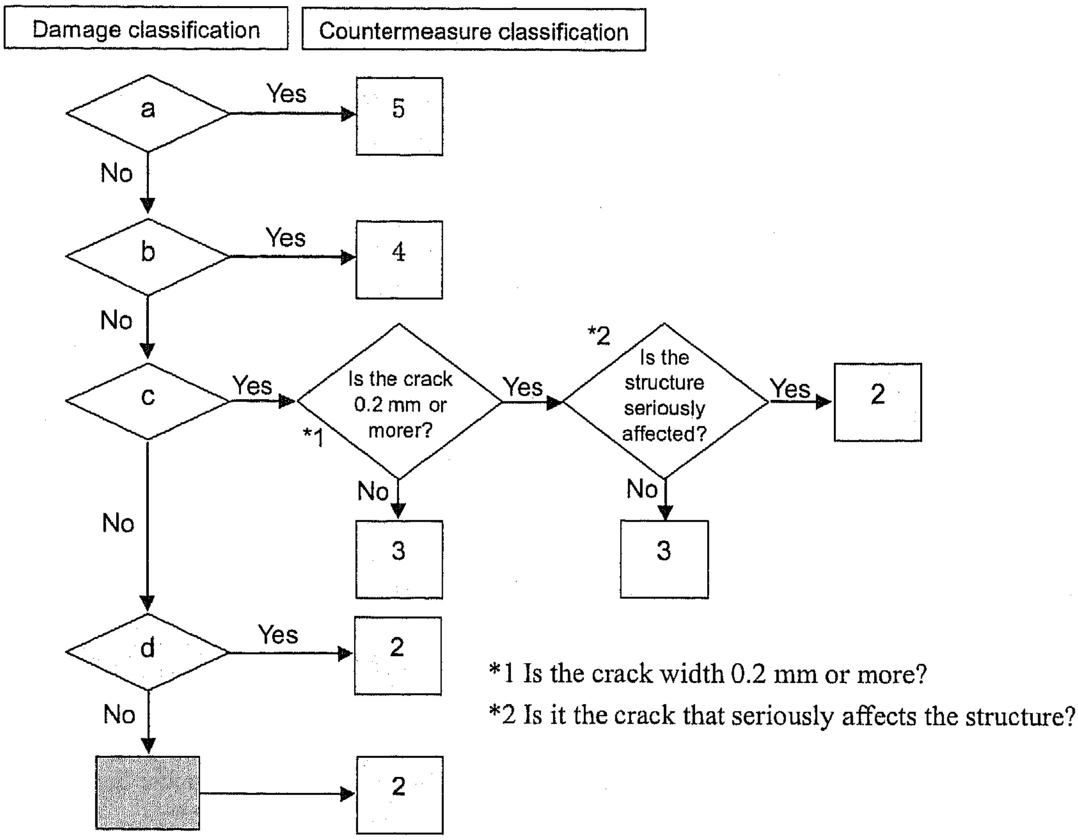
[CC 3]
This level applies to the condition where damage is detected by periodic inspection and it need to be repaired. It may also apply to the condition where the cause and extent of the damage is clear, there is no great urgency suggested, and it is judged no serious damage to the safety of the structure will occur until the next periodic inspection even if the identified damage is left unrepaired.

[CC 2]
This level applies to the condition where the damage detected by periodic inspection is a seriously advanced one, the functionality or safety of the damaged part or member is remarkably degraded, and it is judged some action such as repair is necessary until at least the next periodic inspection.

[CC 1]
This level applies to the condition where the structural safety of the bridge is seriously degraded and urgent action is judged necessary.

"Manual for the long-term maintenance plan" provides for the flow chart for CC judgment for 17 types of damage listed by "Bridge inspection and evaluation manual" to estimate LCC.

An example case on "cracking, water leakage and free lime (superstructure)" is shown in the next page.



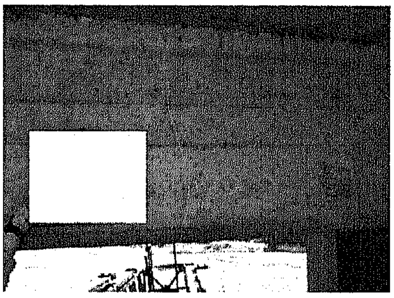
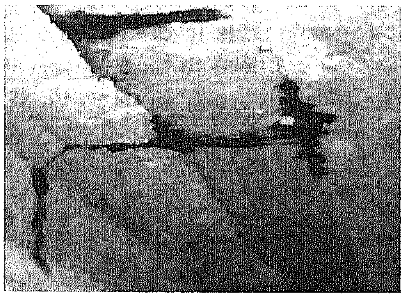
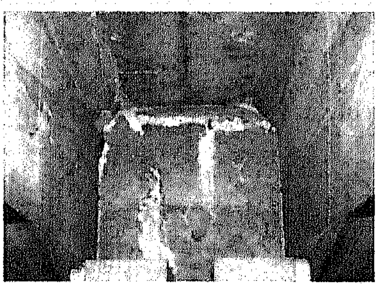
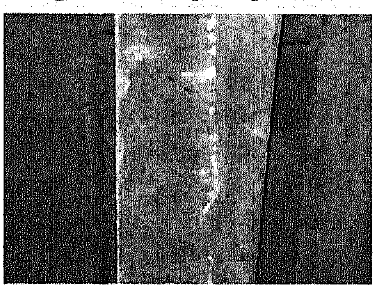
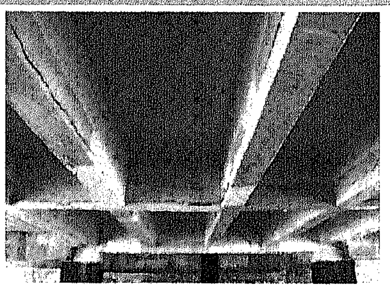
Damage level b -> [CC 4]  Cracks of small influence (marked with chalk)	**Damage level c -> [CC 2]**  Cracks of large influence (marked with chalk) **Crack pattern No.1**	**Damage level c -> [CC 3]**  Cracks of small influence with water leakage
Damage level d -> [CC 2]  Cracks of small influence with water leak age and free lime	**Damage level d -> [CC 2]**  Cracks of large influence with slight water leakage and free lime **Crack pattern No.2**	**Damage level e -> [CC 2]**  Cracks of large influence with rust stain **Crack pattern No.8**

Figure 4.4.5: Case example of the determination of CC (cracking, water leakage, free lime [superstructure]

(3) Repair measures against the damage detected by periodic inspection

[Basic policy for repair measures]

(a) Timing for repair measures

To cope with the damage identified by periodic inspection result, it is necessary to take appropriate measures in the stage where the corresponding maintenance level can be maintained. The Manual specifies, as the basic policy, implementation of appropriate repair measures depending on the member type when a member is evaluated to be in "CC 2" upon inspection or has reached the stage of "CC 2" after inspection as a result of deterioration over time so as to maintain the maintenance level of the 12 Chao Phraya bridges.

(b) Prediction method of deterioration

In order to follow post-inspection changes over time of damage, it is necessary to conduct deterioration prediction by the damage. Because of the following reasons, however, the manual specifies estimation of LCC by setting the action timing based on the consideration of the service life of members and the general modes of deterioration, therefore it is decided that deterioration prediction using theoretical methods or methods based on data analysis will not be applied.

[Reasons why the service life of the member is used for setting of the action timing for countermeasure]

- The 12 bridges over the Chao Phraya are daily maintained with a relatively advanced level by the maintenance offices in vicinity of them. Considering the ongoing periodic repair service including re-painting and replacement of members, as a first stage, it is judged that the setting of action timing based on the service life of member types, not the deterioration prediction based on inspection results or test results, well agrees with the actual maintenance condition.
- If the action timing were determined based on deterioration prediction, the inspection results in the past years should be available as the basic data that allow such deterioration prediction. However, since no such data are available in the first place, it is difficult to attain a sufficient level of prediction accuracy.
- The method of deterioration prediction using a theoretical methods based on the past facts requires implementation of various tests such as laboratory test with field samples or non-destructive test, and such prediction is highly likely to suffer degradation of prediction accuracy depending on the quality of construction or the environmental conditions. Considering these facts, this method is considered inappropriate for the 12 bridges.
- It is a general trend that the soundness of a member decreases at an accelerated pace as the years of use increase and the member nears to the limit of service life. This notion is illustrated based on the relationship between service life and CC as in Figure 4.4.6.