Journal of Civil Engineering and Architecture 9 (2015) 213-224
doi: 10.17265/1934-7359/2015.02.010

Introduction of a Japan Concrete Institute Guideline: Practical Guideline for Investigation, Repair and Strengthening of Cracked Concrete Structures

Nobuaki Otsuki[1], Akiyuki Shimizu[2] and Toshiro Kamada[3]

1. Department of International Development Engineering, Tokyo Institute of Technology, Tokyo 152-8550, Japan

2. Department of Architecture, Tokyo University of Science, Tokyo 125-8585, Japan

3. Division of Global Architecture, Osaka University, Osaka 565-0871, Japan

Abstract: There are many cracked concrete structures worldwide. Although there have been numerous efforts to eliminate cracks, some cracks are very harmful and should be repaired as soon as possible. On the other hand, some cracks are almost harmless. So, a good guideline regarding how to deal with cracks in concrete structures is needed. In this guideline, the practical investigation, repair and strengthening method of cracked concrete structures is discussed. And the detecting subjects are cracks generated immediately after casting and during the service time. This guideline targets on the owners (including managers) of concrete structure and the engineers working for the maintenance of concrete structure. JCI (Japan Concrete Institute) published first version of "Practical Guideline for Investigation and Repair of Cracked Concrete Structures" in 1980, and then the fourth version titled "Practical Guideline for Investigation, Repair and Strengthening of Cracked Concrete Structures—2009" was published. This guideline is very practical when cracks are observed in existing concrete structures, in any other countries as well as in Japan. These three authors led the establishment of this guideline.

Key words: Crack, concrete structure, investigation, repair, strengthening.

1. Introduction

The scope and object of this guideline are as follows:

(1) This guideline covers the practicable investigation of cracked concrete members (structures), causes of cracking, evaluation, judgment of the necessity of strengthening, selection of the most effective repair and strengthening method. This guideline mainly applies to in-situ cast concrete structures;

(2) This guideline covers the cracks generated in a structure immediately after casting and during the service period;

(3) The main targets of this guideline are the owners (including managers) of the concerned structures. Also, the engineers who are working for investigation, cause estimation, evaluation, judgment, repairing and strengthening of cracked concrete structures are included.

The most significant feature of this guideline is that the main users of this guideline are from a beginner to a middle career engineer who is in charge of a structure for maintenance and takes actions if there are cracks in the concrete structures or members. Therefore, this guideline is prepared in a simple way for easy learning and application of the learned knowledge in concerned structures. This guideline systematically describes the process of investigation (Section 2), cause estimation (Section 3), evaluation (Section 4), judgment (Section 5) and repair and strengthening (Section 6).

A flow diagram of the general procedure of this guideline from investigation to repair and strengthening [1] is shown in Fig. 1. Strictly speaking,

Corresponding author: Nobuaki Otsuki, Dr. Eng., professor, research field: concrete engineering. E-mail: otsuki@ide.titech.ac.jp.

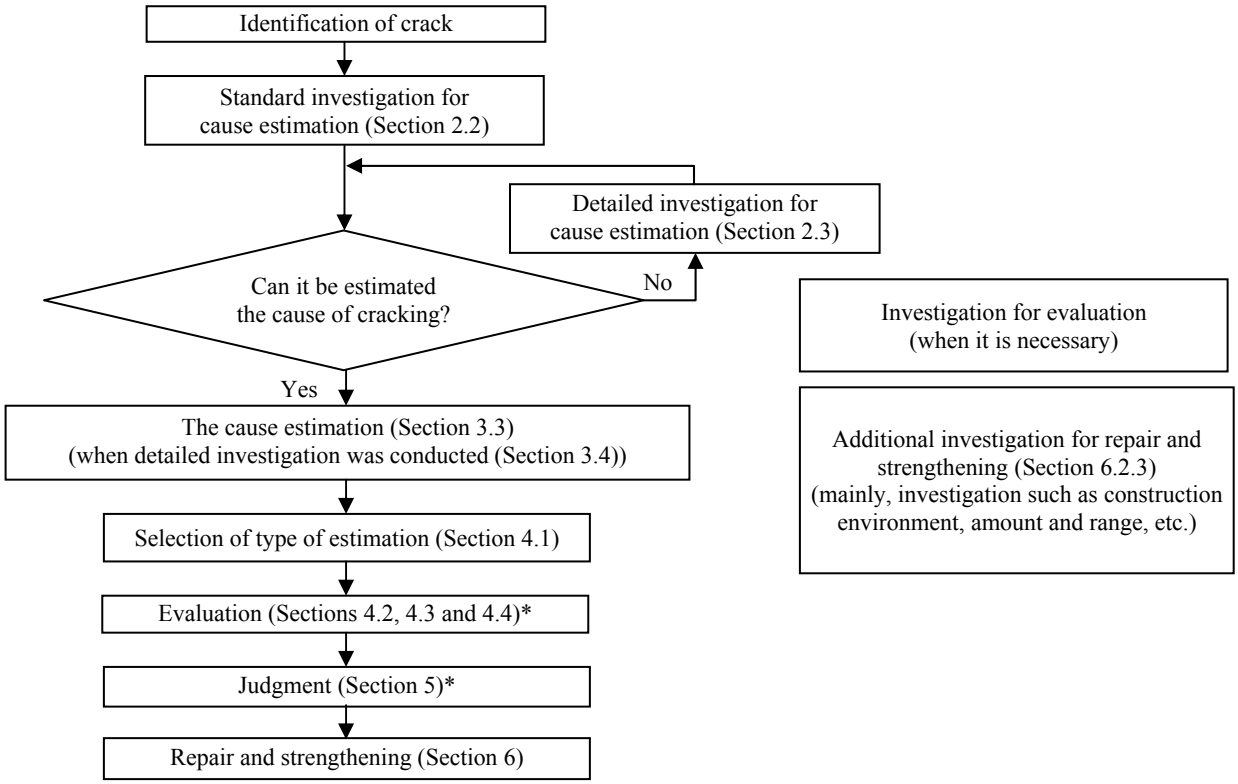

Fig. 1 Procedure from the investigation of cracks to the application of repair and strengthening.

* in the flow means that the evaluation and judgment method are different by the selection of Evaluation-I, Evaluation-II and Evaluation-III.

this procedure could not correspond to some situations while this flow diagram shows a standard procedure that can correspond to most of the cracks.

2. Investigation

2.1 General

The objective and the types of investigation are as follows:

(1) The main objective of investigation is to collect data for the estimation of the causes of cracking of a structure or its members. These data are also necessary for subsequent evaluation of cracks, judgment of the necessity of repair and strengthening;

(2) There are two types of investigation, such as standard investigation and detailed investigation.

Investigation described in this guideline is the beginning step for cause estimation, evaluation of cracks and a selection of repair and strengthening. Information based on the appropriate investigation enables not only to predict the cause of cracks but also to select suitable methods of repair and strengthening.

Also, "investigation" is divided into two steps, such as "standard investigation" and "detailed investigation". Standard investigation must be carried out as the preliminary investigation. The detailed investigation should be carried out in the case that cause estimation of cracks, repair and strengthening cannot be performed based on the standard investigation.

2.2 Standard Investigation

Standard investigation is carried out by investigating the documents and visual inspection of structures.

Standard investigation is carried out in the preliminary stage before estimating the causes of cracking followed by the repair and strengthening plan, as outlined in the flow diagram related to the approach to the investigation, repair and strengthening in Fig. 1. The standard investigation includes investigation of

documents and observation of the structures. The investigation of documents is carried out to estimate the cause of cracks of the member (structures) by collecting the information of the structures, geological condition and ground condition with naked eye and/or using simple tools. The standard investigation is limited to basic investigations that can be done very quickly without any experiments or long-term observation. In some cases, drying shrinkage cracks will be estimated by the standard investigation. In this case, drying shrinkage cracks can be evaluated as Evaluation-I defined in Section 4.1, which can be followed by an easy judgment of repair and strengthening.

The investigation of documents includes the investigation of engineering drawings, design report and specification, construction record, history of past investigation, repair and strengthening, service load condition, climate condition, geographical condition, ground condition, etc.. The observation of structures includes the investigation of the situation of cracks, inconvenience due to cracks, other phenomena such as peeling of concrete, unusual vibration, etc..

2.3 Detailed Investigation

Detailed investigation is carried out in cases when the estimation of the causes of cracking is not possible within the scope of standard investigation. The detailed investigation is divided into on-site investigation and laboratory test.

Detailed investigation should be carried out according to the flow chart shown in Fig. 1 in the case that the cause of crack is difficult to estimate based on the results of the standard investigation. The detailed investigation is performed with special equipment while the standard investigation is done by simple tools. The detailed investigation is more expensive and needs longer period than the standard investigation. Hence, the purpose of the detailed investigation must be fixed before planning the detailed investigation and also the number of the specimens to be tested must be fixed as per the budget and also time constraint. Detailed investigation is divided into on-site investigation and laboratory investigation. On-site investigation includes investigations of materials used in the structure, loadings on the structure, environmental conditions of the structure, foundation condition, structural performance, deformation and vibration of the structure. On the other hand, laboratory investigation is performed based on the symptoms of deterioration. The detailed investigation should be carried out on some selected items and hence will not be covered with all items described in this section. The results of laboratory investigation will contribute significantly to the judgment of an expert engineer. Hence, the items to be investigated in the laboratory should be discussed with an expert engineer prior to the laboratory investigation. Investigation will significantly contribute to the judgment of an expert engineer. Hence, the items to be investigated in the laboratory should be discussed with an expert engineer prior to the laboratory investigation.

3. Cause Estimation

3.1 General

As described in Section 1, this guideline evaluates the crack based on its cause, followed by judgment of necessity for repair and strengthening and their selection. The cause estimation of crack is a starting point of this flow. This section proposes a method to estimate the cause of crack and to obtain data for evaluation of crack, judgment of the necessity for repair and strengthening, and their selection.

The causes of cracks are determined based on the standard investigation as explained in Section 2.2. However, if the results of standard investigation are insufficient to judge the causes of cracking, detailed investigation is carried out according to the detailed investigation described in Section 3.4.

3.2 Causes of Cracking

There are many causes of the cracking. Those that

Table 1 Causes of cracking.

Major classification	Sub classification	Sub-sub	Number	Cause
A Materials	Used materials	Cement	A1	False setting of cement
			A2	Heat of hydration of cement
			A3	Abnormal expansion of cement
		Aggregate	A4	Clay inclusion in aggregate
			A5	Low quality aggregate
			A6	Reactive aggregate (alkali-aggregate reaction)
	Concrete	-	A7	Chloride in concrete
			A8	Settlement and bleeding of concrete
			A9	Drying shrinkage of concrete
			A10	Autogeneous shrinkage of concrete
B Construction	Concrete	Mixing	B1	Non-uniform dispersion of admixture
			B2	Long-time mixing
		Transport and placing	B3	Change of mix proportion at pumping
			B4	Inappropriate placing sequence
			B5	Rapid placing
		Compaction	B6	Inappropriate compaction
		Curing	B7	Loading or vibration before hardening
			B8	Rapid drying during initial curing
			B9	Early age frost damage
		Construction joint	B10	Inappropriate joint treatment
	Steel	Arrangement of steel	B11	Inappropriate placement of reinforcement
			B12	Lack of cover
	Formwork	Formwork	B13	Deformation of formwork
			B14	Water leakage (from formwork, into subgrade)
			B15	Early removal of formwork
		Support	B16	Settlement of support
	Others	Cold joint	B17	Inappropriate joint or discontinuity
		PC grout	B18	Insufficient grouting
C Environment	Physical	Temperature and humidity	C1	Change of environmental temperature and/or humidity
			C2	Difference of temperatures and humidity between two surfaces of member
			C3	Repeated cycles of freezing and thawing
			C4	Fire damage
			C5	Surface heating
	Chemical	Chemical reaction	C6	Chemical reaction of acid and/or salt
			C7	Corrosion of embedded steel due to carbonation
			C8	Corrosion of embedded steel due to chloride attack
D Structure and external force	Load	Long-term load	D1	Long-term load within design load
			D2	Long-term load over design load
		Short-term load	D3	Short-term load within design load
			D4	Short-term load over design load
	Structural design	-	D5	Insufficient cross sectional area or quantity of steel
			D6	Differential settlement of structure
	Support condition	-	D7	Freezing heave
E Others	-	-	-	Others

are generally observed in practice are listed in Table 1.

3.3 Cause Estimation Based on Standard Investigation

Cause estimation is performed by comparing the results of the standard investigation with Table 1.

Standard investigation described in Section 2 mainly consists of visual observation of cracks, and investigations of previous records and failures.

There are many cases for which the cause can be estimated by standard investigation.

For example, in many cases, the cause estimation will fall under the major classification materials described in Table 1. In some cases, it may not be possible to evaluate the exact cause from the results of the standard investigation, but some rough evaluations may be made from the standard investigations that can be useful during detailed investigation.

Procedure for cause estimation of crack—for beginners—shall be carried out according to the procedure Sections 3.3.1 to 3.3.3.

3.3.1 Classification of Cracks

The following four Categories (1) to (4) must be systematically followed to identify the probable causes of crack. In Category (1), the cause is roughly estimated based on the major Classifications A to D described in Table 1. Taking into consideration the crack patterns (generation period, regularity, extent), deformation associated with the structure, limit of structure affecting the deformation, mixture proportions and environmental conditions, the causes of cracking are further classified as A1 to A10, B1 to B18, C1 to C8 and D1 to D7 in each of Categories (2) to (4) (Tables 2 to 5) :

(1) major classifications of causes (Table1):

- materials (A);
- construction (B);
- service environment (C);
- structure and external force (D);

(2) classification based on generation period, regularity and extent of cracks (Table 2):

- generation period (several hours to one day, a few days, several 10 s of days);
- regularity (yes or no);

Table 2 Classifications based on the generation period, regularity and extent of cracks.

Pattern of cracks			Cause estimation
Generation period	Regularity	Extent	
Few hours to one day	Yes	Reticular	B2, B3
		Surface layer	A8, B2, B3, B5, B14, B16, B17
		Penetration	B2, B3, B4, B10, B16, B17
	No	Reticular	B8
		Surface layer	A1, B5, B7, B8, B13, B17
		Penetration	B4, B10, B17
Few days	Yes	Reticular	
		Surface layer	A2, A10, B15, D5
		Penetration	A2, A10, B16
	No	Reticular	A4, B9
		Surface layer	B7, B9
		Penetration	
More than several ten days[*1,*2]	Yes	Reticular	A6, A9, B2, B3, D2
		Surface layer	A6, A7, A9, A10, B2, B3, B11, B12, C1, C2, C7, C8, D1, D3, D5
		Penetration	A9, A10, B2, B3, B4, B10, B18, C1, D2, D4, D5, D6
	No	Reticular	A3, A4, A6, B1, B9, C3, C4, C5, C6
		Surface layer	A3, A4, A5, A6, B9, C3, C4, C5, C6, D7
		Penetration	B4, B10, B18, D6

[*1]Cracks form after development of required strength; [*2]if fatigue is the cause of cracking (D1 and D2), the generating period must be at least from few years to multiple of few 10-year.

Table 3 Classification based on the deformation and limits of consideration.

Deformation factors of concrete	Limit of consideration[*3]	Cause estimation
Shrinkage[*1]	Material	A1, A2, A4, A9, A10, B1, C1, C3, C4, C5
	Member	A2, A9, A10, B2, B3, B8, B14, B15, B17, B1, C2, C3, C4, C5
	Structure	A9, B2, B3, B8, B15, C1, C2, C3, C4, C5
Expansion[*2]	Material	A3, A5, A6, B1, C1, C3, C4, C5, C6
	Member	A7, B1, B12, B18, C1, C2, C3, C4, C5, C7, C8
	Structure	A7, C1, C4, C5
Settlement, bending and shearing	Material	A5, A5, C1
	Member	A8, B4, B5, B6, B7, B9, B10, B11, B12, B13, B16, B17, C1, C2, D1, D2, D3, D4, D5, D6, D7
	Structure	B6, C1, D1, D2, D3, D4, D6, D7

[*1]The cracked region shows the occurrence of shrinkage; [*2]the crack region shows the occurrence of expansion; [*3]material: it is required to investigate materials for cause estimation (mainly concrete); member: it is required to investigate members, such as beam, column, wall, slab, etc. for cause estimation; structure: it is required to investigate the whole structure (including roof and foundation) for cause estimation.

Table 4 Classifications based on mixture proportion.

Mixture proportion	Cause estimation	Standard
Rich	A2, A6, A9, A10	Cement content per unit volume of concrete is more than 350 kg/m^3
Poor	A8, C3, C6, C7, C8	Cement content per unit volume of concrete is less than 270 kg/m^3

Table 5 Classifications based on weather condition during placing concrete.

Weather condition at the placing of concrete	Cause estimation	Standard
High temperature	A2, B2, B8, B17	The daily men temperature during placing is higher than 25 °C, and the ambient temperature at placement is higher than 25 °C
Low temperature	A8, B7, B9, B13, B16, D7	The daily mean temperature at placing is lower than 4 °C
Low humidity	A4, A9, B8, B17	The humidity is lower than 60%

- extent (reticular, surface layer, and penetration).

The extent of cracks is defined as reticular for mesh type cracking, as surface layer if the depth of the cracks is limited to the surface region of the structure, and as penetration if the cracks continue through the section.

(3) classification based on deformation and limit of consideration (Table 3):

- deformation of concrete (drying shrinkage, expansion, settlement, bending, and shearing);
- limit of consideration (materials, member, and structure).

If the deformation is associated with the material of the structure, then the limit of consideration is defined as materials: if it is associated with a particular member of the structure, then the limit of consideration is defined as member, and if it is associated with the whole structure, then the limit of consideration is defined as structure.

(4) classifications based on mixture proportions and weather conditions (Tables 4 and 5):

- mixture proportion (rich and poor);
- weather conditions during placing of concrete (high or low temperature, and low humidity).

3.3.2 Detection of Common Causes

The common causes of cracking are identified by comparing the results of the investigations summarized in Categories (1) to (4). The non-matching causes of Categories (1) to (4) are excluded for simplicity.

3.3.3 Cause Estimation Based on Standard Investigation

Cause estimation should be performed based on the results of the detailed investigation explained in Section 3.4 if cause estimation cannot be performed based on the results of the standard investigation.

If it is difficult to evaluate the cause from the results of the standard investigation, which is performed as per

Section 3.4.

3.4 Cause Estimation Based on Detailed Investigation

If it is difficult to perform cause estimation from the results of standard investigation, cause estimation should be performed based on the results of detailed investigation, as explained in Fig. 1.

4. Evaluation of Cracks

4.1 General

In this guideline, "evaluation" is defined as an influence of cracking to concrete by using the data from investigation and cause estimation. Moreover in this guideline, evaluation type defined after considering the influence of the crack can be changed by the cause of cracking. In a word, cracking can be classified as three types as follows, after the cause estimation.

4.1.1 Evaluation-I (Applied for Dry Shrinkage Cracks, etc.)

The targeted cracks in this classification are cracks that will stop growing within several years after placing concrete. Also, these cracks themselves are not immediately responsible for corrosion. However, from cracks water, oxygen and/or chloride ions may penetrate and cracks indirectly cause corrosion of steel bars. So, the drying shrinkage and temperature cracks are classified in this group. At Evaluation-I, the durability of corrosion of steel bars and waterproof property are considered related to the kind of environment. It is evaluated with the width of the crack when at the time of the investigation or the repair is executed.

4.1.2 Evaluation-II (Applied for Cracks Due to Chloride Attack, Carbonation, etc.)

The targeted cracks in this classification are cracks that continue to grow once started. However, the progress or growing of the cracks can be somehow estimated. Chloride attack and carbonation cracks are classified in this group. This type of crack occurs several years later from the completion time of construction.

4.1.3 Evaluation-III (Applied for Cracks Due to Combined Deterioration, etc.)

The targeted cracks in this classification are cracks that could not be classified into Evaluation-I and Evaluation-II, and/or could decrease the structural performance. This evaluation should be done by the experts and may be used at the cases in which owners would like to use the structures for a very long time (more than 20 years), or when the crack causes serious damage at the condition of supports and load carrying capacity of the member (or structure).

The type of evaluation of cracks should be chosen based on Table 6 in accordance with the results of investigation and estimation of causes of cracks, and evaluation is carried out by the methods shown in Sections 4.2 to 4.4. The procedure of evaluation is explained in Fig. 2.

4.2 Evaluation-I (Applied for Drying Shrinkage Cracks and So on)

In Evaluation-I, the grade of influence of crack on the performances of the member is expressed as large, medium and small, when the required performance is the resistance against steel corrosion and water leakage. In the case of the evaluation of durability resistance against steel corrosion, Evaluation-I uses Table 7. Crack width means the width at surface of the member. In the case of the evaluation of durability resistance against water leakage, Evaluation-I uses Table 8. Penetrate crack is applicable. The crack width means the width of the crack on the surface of the member.

4.3 Evaluation-II (Applied for Cracks Due to Chloride Attacks and Carbonation, etc.)

In Evaluation-II, the grade of influence of crack to the performances of the member is expressed as large, medium, and small, the same as in the case of Evaluation-I, resistance to steel corrosion or concrete degradation.

Table 6 Causes of cracks and types of evaluation.

No.	Predicted causes	Type of evaluation		
		I	II	III
A1	False setting of cement			○
A2	Heat of hydration of cement	○		○
A3	Abnormal expansion of cement			○
A4	Mud included in aggregate	○		○
A5	Low quality aggregate		○	○
A6	Reactive aggregate		○	○
A7	Chloride in concrete		○	○
A8	Settlement and bleeding of concrete	○		○
A9	Drying shrinkage of concrete	○		○
A10	Autogeneous shrinkage	○		○
B1	Non-uniform dispersion of admixture	○		○
B2	Long-time mixing	○		○
B3	Inappropriate change of proportion at pumping	○		○
B4	Inappropriate placing sequence	○		○
B5	Rapid placing	○		○
B6	Inappropriate compaction	○		○
B7	Loading or vibration before hardening			○
B8	Rapid drying during initial curing	○		○
B9	Early age frost damage		○	○
B10	Inappropriate joint treatment	○		○
B11	Bad placement of rebar	○		○
B12	Lack of cover	○		○
B13	Deformation of formwork	○		○
B14	Water leakage from formwork	○		○
B15	Early removal of formwork	○		○
B16	Settlement of support	○		○
B17	Inappropriate joint of discontinuity	○		○
B18	Insufficient grouting			○
C1	Change of environmental temperature and/or humidity	○		○
C2	Difference in temperature or humidity of both sides			○
C3	Repeated cycles of freezing and thawing		○	○
C4	Fire			○
C5	Surface heating			○
C6	Chemical reaction of acid and salt with chloride		○	○
C7	Corrosion of embedded rebar due to carbonation		○	○
C8	Corrosion of embedded rebar due to chloride attack		○	○
D1	Long-term load within design load	○		○
D2	Long-term load over design load			○
D3	Short-term load within design load	○		○
D4	Short-term load over design load			○
D5	Insufficient cross section or quantity of steel			○
D6	Differential settlement of structure			○
D7	Freezing heave			○

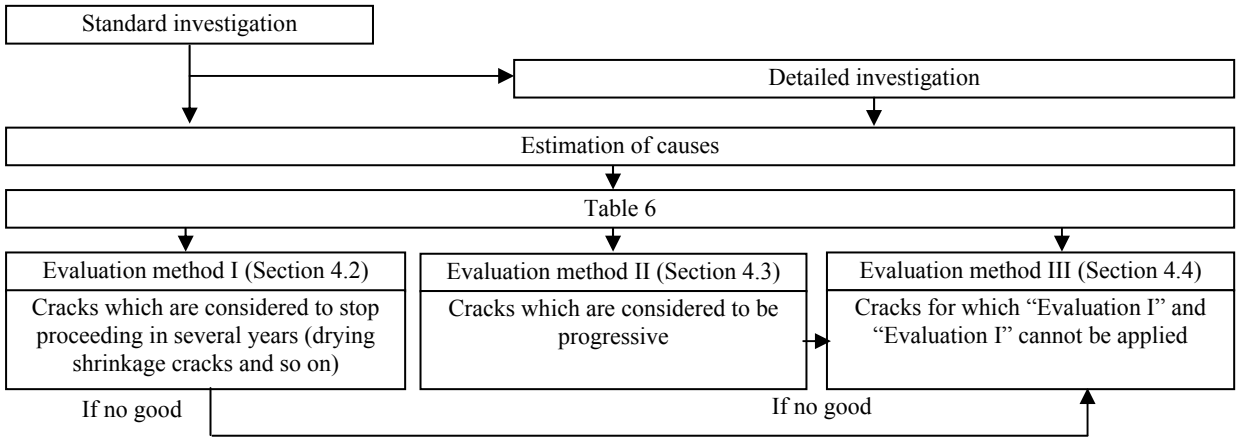

Fig. 2 Proceedings of evaluation.

Table 7 Influence of crack on the performance of member from the viewpoints of steel corrosion.

Environmental condition		Chloride and corrosion	Normal outdoor	Indoor or underground
Crack width: w (mm)	$w > 0.5$	Large (20-year durability)	Large (20-year durability)	Large (20-year durability)
	$0.4 < w \leq 0.5$	Large (20-year durability)	Large (20-year durability)	Medium (20-year durability)
	$0.3 < w \leq 0.4$	Large (20-year durability)	Medium (20-year durability)	Small (20-year durability)
	$0.2 < w \leq 0.3$	Medium (20-year durability)	Small (20-year durability)	Small (20-year durability)
	$w \leq 0.2$	Small (20-year durability)	Small (20-year durability)	Small (20-year durability)

Small: crack does not cause the degradation of performance and the required performance is satisfied; Medium: although crack is the cause of performance degradation, slight repairs are effective; Large: the performance degradation is remarkable and the member has not satisfied the required performance.

The value in the parentheses means the standard period that can guarantee the evaluation result of durability. "20-year durability" means that it is about 15~25 years to guarantee the result of evaluation after cracking. "20-year" is the average of 15 years and 25 years.

Table 8 Influence of crack on the performance of member from the viewpoints of water leakage.

Environmental condition and member thickness (mm)		Under water pressure		Others	
		Less than 180	More than 180	Less than 180	More than 180
Crack width: w (mm)	$w > 0.2$	Large	Large	Large	Large
	$0.15 < w \leq 0.20$	Large	Large	Large	Medium
	$0.05 < w \leq 0.15$	Medium	Medium	Medium	Small
	$w \leq 0.05$	Small	Small	Small	Small

Small: crack does not cause the degradation of performance and the required performance is satisfied; medium: although crack is the cause of performance degradation, slight repairs are effective; large: the performance degradation is remarkable and the member does not satisfy the required performance.

4.4 Evaluation-III (Applied for Cracks Due to Combined Deterioration, etc.)

Evaluation-III should be carried out based on advanced judgment by an expert engineer. Evaluation-III should be applied when the required performance is structural safety, durability or water tightness for a long period. Evaluation-III can be also applied to the crack due to combined deterioration or the crack which cannot be evaluated by Evaluation-I or Evaluation-II.

5. Judgment of Necessity of Repair and Strengthening

5.1 General

In order to ensure the performance of cracked concrete structures, necessity of repair and strengthening should be judged by owner of the structures in view of influence of cracks on

performance of members or structures and specific limitation such as importance of structures.

The necessity of repair and strengthening should be judged by the methods shown in Section 5.2 based on the results of evaluation of cracks in view of expected remaining service life, social importance of structures and economic efficiency. If results of the evaluation are not taken into consideration in the judgment of necessity of repair and strengthening, the repair and the strengthening for cracks do not connect with successful effect and the cost can become bigger. Thus, it is very important to take results of the evaluation of cracks into consideration in order to maximize the effect of the repair and the strengthening.

5.2 Methods of Judgment

In the case Evaluation-I which is carried out from the viewpoint of durability for steel corrosion, the judgment of necessity of repair can be performed based on Table 9.

In the case Evaluation-I which is carried out from the viewpoint of water resistance and water tightness, at this moment, the judgment of necessity of repair can be performed based on Table 10.

In the case, Evaluation-II is carried out, almost the same procedure to Evaluation-I can be adopted.

In the case that Evaluation-III is carried out, taking expected remaining service life into consideration, repair and strengthening should be performed by a professional engineer based on the results of evaluation of cracks.

6. Repair and Strengthening

6.1 General

The method most suitable for the purpose of repair or strengthening for cracks is to be adopted based on investigation, evaluation and judgment on necessity of repair or strengthening. The certified personnel, in principal, executes repair and strengthening.

6.2 Design of Repair and Strengthening

6.2.1 Basis of Repair and Strengthening Design

Repair and strengthening design are carried out to maintain the performance of the structure up to a certain level during the design service life of the structure expected by the owner when repair and strengthening works are executed.

6.2.2 Note of Repair and Strengthening Design

The following points are to be considered during repair and strengthening design:

Table 9 Table for judgment based on Evaluation Method I (in view of durability for steel corrosion).

Influence on performance of members	Expected remaining service life		
	Less than 10 years	From 10 to 20 years	Over 20 years
Small (20-year durability)	Repair is unnecessary	Repair is unnecessary	Repair is unnecessary (investigation of cracks should be done constantly)
Medium (20-year durability)	Repair is basically unnecessary (repair is necessary according to the circumstances)	Repair is basically unnecessary (repair is necessary according to the circumstances, and investigation of cracks should be done constantly)	Repair is necessary
Large (20-year durability)	Repair is basically necessary (repair is unnecessary according to the circumstances)	Repair is necessary	Repair is necessary (including strengthening, demolishment and removal)

Table 10 Table for judgment based on Evaluation Method I (Viewpoint of water resistance and water tightness).

Influence on performance of members	Judgment
Small	Repair is unnecessary
Medium	Repair is basically unnecessary (repair is unnecessary according to the circumstances, and investigation of cracks should be done constantly)
Large	Repair is necessary

(1) An effective repair is done based on the investigated causes of crack;

(2) The repair and strengthening method and the material are selected considering the expected service life;

(3) Even when strengthening is made, it is necessary to do an appropriate repair.

6.2.3 Additional Survey for Repair Design

Additional survey for the repair design is carried out to make up for the lack of necessary information.

6.2.4 Selection of Repair Method

The repair method of each structure should be selected based on major causes of crack, evaluation, judgment result, expected life period, and level of recovery target.

6.2.5 Selection of Strengthening Method

In the case of strengthening concrete structures whose structural strength is decreased due to the generation of crack, the appropriate method most suitable for the purpose of strengthening is adopted based on investigation, cause estimation, advance prediction of degradation, and judgment on the necessity of strengthening.

The target load carrying capacity after strengthening shall be determined taking into account the combination with repair methods and durability during the expected service life by the owner.

6.3 Repair Method

Suitable methods complying with the objectives should be applied for repair with understanding the cause of deterioration and damage and characteristics of methods themselves. The following categories of repair methods are applied:

(1) the crack repair methods:

- crack covering method (the method is used to cover only the crack);
- injection method;
- filling method (the method is used when the reinforcement is not corroded);

(2) section repair method:

- plaster method;
- mortar injection method;
- concrete filling method;
- spray method;

(3) surface coating method:

- surface coating method (which is used not only for cracks, but also for the entire concrete surfaces);

(4) spalling prevention method:

- anchor pinning method;
- fiber sheet covering method;
- renewal method for external wall by net over;

(5) electrochemical repair method:

- cathodic protection method;
- desalination method;
- re-alkalization method;
- the electro deposition method.

6.4 Strengthening Method

In the case of strengthening concrete structures, the method most suitable for the purpose of strengthening is to be adopted based on the appropriate understandings of the strengthening method and used materials. In this case, the load carrying capacity of the member (or the structure), the conditions for the strengthening works, and the environmental conditions should be considered.

In this section, the strengthening methods are classified into five categories and their characteristics and important points are introduced.

The five categories of strengthening methods are as follows:

(1) member replacement:

replacing method;

(2) addition of concrete sections:

- surface overlaying method;
- concrete jacketing method;

(3) bonding and jacketing:

- steel plate bonding method;
- continuous fiber sheet bonding method;
- steel plate jacketing method;
- continuous fiber sheet jacketing method;

- rebar addition method;

(4) introduction of pre-stress:

- external cable method;

(5) addition of members:

- member addition method.

6.5 Repair and Strengthening Materials

To select the repair and strengthening materials, it is necessary to choose the suitable material that complies with the repair and strengthening method. In choosing, the characteristics of the method and the materials should be understood. Also, the causes of the deterioration and damage should be understood.

Repair and strengthening materials can be divided roughly into the following four types for which the characteristics and important points are described in this guideline:

- cementitious materials;
- polymer materials;
- metals;
- fibrous material;
- others.

6.6 Repair and Strengthening Works

Contractors should note the items below when executing the repair and strengthening works:

(1) The contractors should obey the related laws;

(2) The contractors should complete work plans after carrying out necessary pre-investigation;

(3) The contractors should understand the characteristics of the materials and determine the ranges of temperature and humidity to ensure the required performances of the materials. Also, they should determine reasonable work schedules;

(4) The contractors should give necessary explanations to the users of the structures and neighborhood publics (public involvement) before the work. Moreover, they should make and submit necessary documents to the authorities;

(5) The contractors should control the construction works in every stages;

(6) The contractors should make records of works and completion.

6.7 Inspections

(1) The owner should make the inspection plan with the consideration of the importance of the structure, the expected remaining life and the cost/benefit, and the owner should inspect the designs and works of repair and strengthening of the construction;

(2) For the design inspection, the owner should check whether the design is appropriate to satisfy the required performances of the members (structures) during the expected remaining life, based on the investigation, causes estimation and judgment;

(3) For the work inspection, the owner should check whether the repair and strengthening works are done as designed;

(4) If the owner judged the design or the works are not satisfied, the designer or the contractor should make appropriate measures.

6.8 Records and Interim Observations

The recommended inspections are to be executed periodically after the repair and strengthening, and the records are to be saved.

7. Conclusions

A guideline of JCI (Japan Concrete Institute): Practical Guideline for Investigation, Repair and Strengthening of Cracked Concrete Structures, is briefly introduced. If you are interested in this guideline, reading of the original guideline is strongly recommended. Owners or managers of the concrete structures will correspond effectively if this guideline was used, maintenance management can be performed rationally and efficiently, thus and so, also related to decrease of LCC (life cycle cost) in the near future.

References

[1] JCI (Japan Concrete Institute). 2009. *Practical Guideline for Investigation, Repair and Strengthening of Cracked Concrete Structures—2009.* Japan: JCI.