Committee Report : JCI TC053A

Technical Committee on the Probability of Risk in Concrete Construction

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Abstract

Actual state of various defective events and job stoppages occurring in concrete construction for limited types of structures (bridge superstructures, bridge substructures, middle- and high-rise collective housing, and box culverts) was investigated in terms of probability of occurrence, causing factors, countermeasures, and cost of countermeasures. With the aim of collecting basic information for formulating a risk management system for concrete construction, this investigation was carried out by questionnaire to experienced engineers. The Committee Report discusses the results of the questionnaire survey and presents a technique of risk assessment for concrete construction based on the collected basic information. Risk analysis of the concrete construction process was also conducted in regard to the structures covered by the questionnaire.

Keywords: concrete structure, defect, execution, risk assessment, risk management.

1. Introduction

The JCI Technical Committee on the Risk Management for Concrete Structures, which was completed in 2004, investigated the framework for applying the concept of risk management to the process sequence related to the construction of concrete structures. The investigation included the following: (a) a current situation survey of risk-related studies; (b) sorting out of risk factors in all phases of the planning, design, execution, and maintenance of structures; (c) discussion on the risk factors and measures for the case involving different methods of contract and bidding; (d) analysis of risks and their factors at each stage of research, design, and execution; and (e) investigation into the frameworks of risk assessment for structures assuming earthquake and material deterioration. Case studies of risk assessment were also conducted for items applicable[1)].

The former Committee constructed fault trees (FTs) of the risk factors in the research/design and execution stages, which have significant effects on the performance of structures. However, it did not attain the level of formulating a risk management system, as the probabilities of the occurrence of risk factors, such as defective events during execution, were not clear. Also, the probabilities of the occurrence of risk factors during execution were found to strongly affect the risk management of contract, bidding, and maintenance.

Accordingly, the present Committee limited its scope to risk factors including various defective events and job stoppages during concreting. On that basis, the Committee conducted research activities primarily intended to collect, organize, and provide basic data for formulating a risk management system for concrete structures by carrying out a fact-finding survey on the causes and probabilities of such risk factors, proactive and post-incident measures, as well as their cost. The subject structures were limited to superstructures and substructures of bridges, middle- and high-rise reinforced concrete collective housing, and box culverts, since the probability and the cost of measures against defective events widely vary depending on the type of structure. The Committee also presented a technique of risk assessment for concrete construction using the obtained basic data and attempted an assessment of the risk of subject structures. A fact-finding survey regarding defective events was conducted by means of a questionnaire to engineers having extensive field experience.

This report summarizes the achievements of the above-mentioned research activities of the Committee.

The Committee, which was active for 2 years from April 2005 to March 2007, consisted of Working Group 1 for research into the probabilities of the occurrence of construction risks (manager: Takafumi Noguchi, assistant manager: Tohru Fukawa), Working Group 2 for measures against construction risks (manager: Toshiharu Nakamura, assistant manager: Sakae Ushijima), Working Group 3 for construction risk assessment (manager: Gaku Shoji, assistant manager: Ryuichi Chikamatsu). **Table 1** gives the constitution of the Committee.

2. Composition of Committee Report

The Committee Report consists of 6 chapters.

Chapter 1~3 summarizes the activities of the Committee and defines the terms used in the report.

Chapter 4 explains the background and contents of the research items of the questionnaire survey conducted to collect information on the risk of concrete construction.

Chapter 5 presents major information obtained from the questionnaire survey, such as the probability of occurrence of various factors related to construction risks and losses incurred by such risks using figures and tables.

Chapter 6 introduces the current state of risks in concrete construction and then proposes a specific new risk assessment technique. Also, this technique is applied to the results of the questionnaire survey, in an attempt to make risk assessment of concrete construction of various structures covered by the questionnaire.

Chapter 7 describes methods of dealing with construction risks, giving specific examples, including avoidance/reduction, damage insurance, and quality assurance in view of the Housing Quality Assurance Act as future issues.

Chapter 8 summarizes the achievements of the committee activities, as well as challenges for the future.

Various concepts of risk in the construction of concrete structures have been organized through the activities of the Committee into a form of a risk management system in concrete construction, though not complete. Also, the activities have provided part of fundamental information for formulating a risk management system for each stage of planning, design, and maintenance of concrete structures. For details, see the Committee Report.

Table 1: Members of the Committee

Chairperson of Committee	Yasuhiko YAMAMOTO	University of Tsukuba
Assistant Chairperson of Committee	Shigeyuki SOGO	Obayashi Corporation
Chief secretary	Sakae USHIJIMA	T-NET JAPAN Co.,Ltd
Chief of Subcommittee	Takafumi NOGUCHI	The University of Tokyo
Chief of Subcommittee	Gaku SHOJI	University of Tsukuba
Chief of Subcommittee	Toshiharu NAKAMURA	Taisei Corporation
Chief of Subcommittee	Tadahiro KAKIZAWA	Takenaka Corporation
Chief of Subcommittee	Ryuichi CHIKAMATSU	Obayashi Corporation
Chief of Subcommittee	Tohru FUKAWA	Taisei Corporation
Member	Hideaki AGETA	Asunaro Aoki Construction Co.,Ltd
	Tatsumi OOTA	Shimizu Corporation
	Yoshitaka KATO	The University of Tokyo
	Hirotaka KAWANO	Kyoto University
	Goro SAKAI	Kajima Corporation
	Takahiro SAMESHIMA	University of Tsukuba
	Kazuaki SUGAYA	Toda Corporation
	Ritsu SUGIYAMA	Hazama Corporation
	Yuji TAKAHASHI	Building Research Institute
	Hideaki TANIGUCHI	Sumitomo Mitsui Construction Co., Ltd.
	Suguru TOKUMITSU	Fuji P.S Corporation
	Masahiro TOMITA	Nishimatsu Construction Co., Ltd
	Takaaki NAKAMURA	Shinozuka Research Institute
	Masashi FUNAHASHI	Maeda Corporation
	Mamoru MIZUTANI	Modern Engineering & Design
	Ayaho MIYAMOTO	Yamaguchi University
	Katsumi YANAGIDA	Kajima Corporation

3. Terms used in Committee Report

Some of the principal terms used in the Committee Report are given in **Table 2**.

Table 2 Definitions of terms used in Committee Report

Risk: A combination of an uncertain loss or disadvantage in the future and its probability of occurrence. Construction risk: A combination of an economic loss incurred in regard to items that must be considered at the time of construction from the aspects of the performance/function of the concrete structure, ambient environment, construction period, and labor safety and the frequency or probability of occurrence of the loss. Number of projects experienced: The number of projects a respondent to the questionnaire experienced for the construction of structures covered by the questionnaire. This is the parameter (denominator) in the calculation of the frequency of defective events and the frequency of defect prevention. Number of projects involving defective events: The number of projects involving defective events in the construction of structures covered by the questionnaire. This is the numerator in the calculation of the frequency of defective events. Number of projects involving proactive measures: The number of projects in which potential defects were prevented by proactive measures in the construction of structures covered by the questionnaire. This is the numerator in the calculation of the frequency of defect prevention. Fault tree analysis: An analysis method in which a potential defect/job stoppage is defined first and a tree-shaped diagram is formed to find out the combinations of conditions to lead to such a defective event/job stoppage. In the questionnaire survey described in the Committee Report, direct and independent factors immediately below the potential defect/job stoppage were extracted, and their frequencies of occurrence were asked. Risk response: An act of dealing with the assumed risk by one or more of the following: risk retention, risk avoidance, risk reduction, and risk transfer. Risk retention: An option of risk response to accept the resulting loss. This is generally applied to a risk with a slightly high probability of occurrence and a small loss or a risk with a relatively large loss and a low probability of occurrence. Risk avoidance: An option of risk response to avoid the risk by stopping the act or method causing the risk or changing to a totally different act or method. This is generally applied to a risk with a very high probability of occurrence and very large loss and the assumed results or loss cannot be accepted. Risk reduction: An option of risk response to reduce the risk to an acceptable level by reducing the assumed probability of occurrence and/or loss. Risk transfer: An option of risk response to transfer all or part of the risk to insurance or other means. The application of risk transfer is investigated when the probability of occurrence is very low but the loss incurred by the risk or the cost to reduce the risk exceeds the acceptable level.

4. Questionnaire survey

4.1 Overview of questionnaire

When conducting the questionnaire survey for grasping the factors of construction risks, the questionnaire was sent to 352 member companies (gross number including members of multiple associations) through four associations: the Japan Civil Engineering Contractors' Association, Inc. (JCECA), Building Contractors Society (BCS), Japan Prestressed Concrete Contractors Association (JPCCA), and National General Contractors Association of Japan (ZENKEN). It was then asked that the questionnaire be filled in by those having experience as site manager or engineers having similar managerial and field experience. Also, five such people each were to answer per company in JCECA and BCS, whereas two were to answer per company in JPCCA and 47 prefectural associations under ZENKEN, with the distribution totaling 920, in which 474 were collected, with the collection rate being 51.5%.

The questionnaire was sent to each association as of July 25, 2006, with the deadline set about one month later at September 8, 2006.

The construction risk factors covered by the questionnaire included defects or job stoppages of 22 items in concreting of bridge superstructures, bridge substructures, middle- and high-rise reinforced concrete collective housing, and box culverts. These items were selected as minimum essential items for making risk assessment of concrete construction. Also, the respondents were asked to answer in regard to only one type of structure for which they worked longest in the last 10 years, so as to ease their strain. The contents and form of the questionnaire were also made as easily answerable as possible.

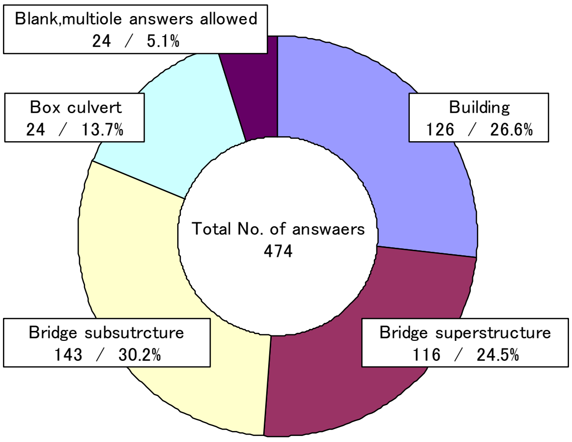


Fig.1 No. of answers by structure type

Figure 1 shows the composition of the types of structures as subjects of the responses. As seen from the figure, similar numbers of answers were obtained for all types of structures at 25 to 30%, excepting the answers for box culverts, which were about half of the others.

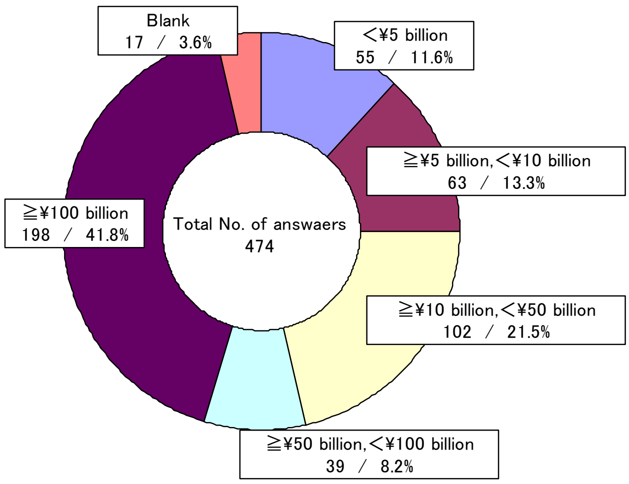


Fig.2 No. of answers by annual amount of completion

Figure 2 shows the composition of the amounts of annual completion by the companies the respondents belong to. The companies with an annual completion amount of 100 billion yen or more and less than 50 billion yen are nearly equal in number, together accounting for 88% of the total number of companies. It is therefore inferred that the results of the questionnaire to be described below represent the average state of concreting in Japan without being biased toward large-scale projects or large contractors.

5. Frequencies of occurrence and prevention of job stoppages/defective events

5.1 Likely job stoppages/defective events

Figure 3 shows the number of projects in which any defective event was experienced for each type of structure and defective event. Whereas the numbers of such events as 'insufficient strength,' 'rebar corrosion,' and 'abnormal setting of concrete' are around 10 by adding up all structure types, such events as 'inability to arrange rebars,' 'insufficient cover depth,' 'incorrect bar arrangement,' 'cracking,' 'inadequate filling,' 'water leakage,' 'cold joint,' and 'improper finishing' are as many as around 150 or more in number.

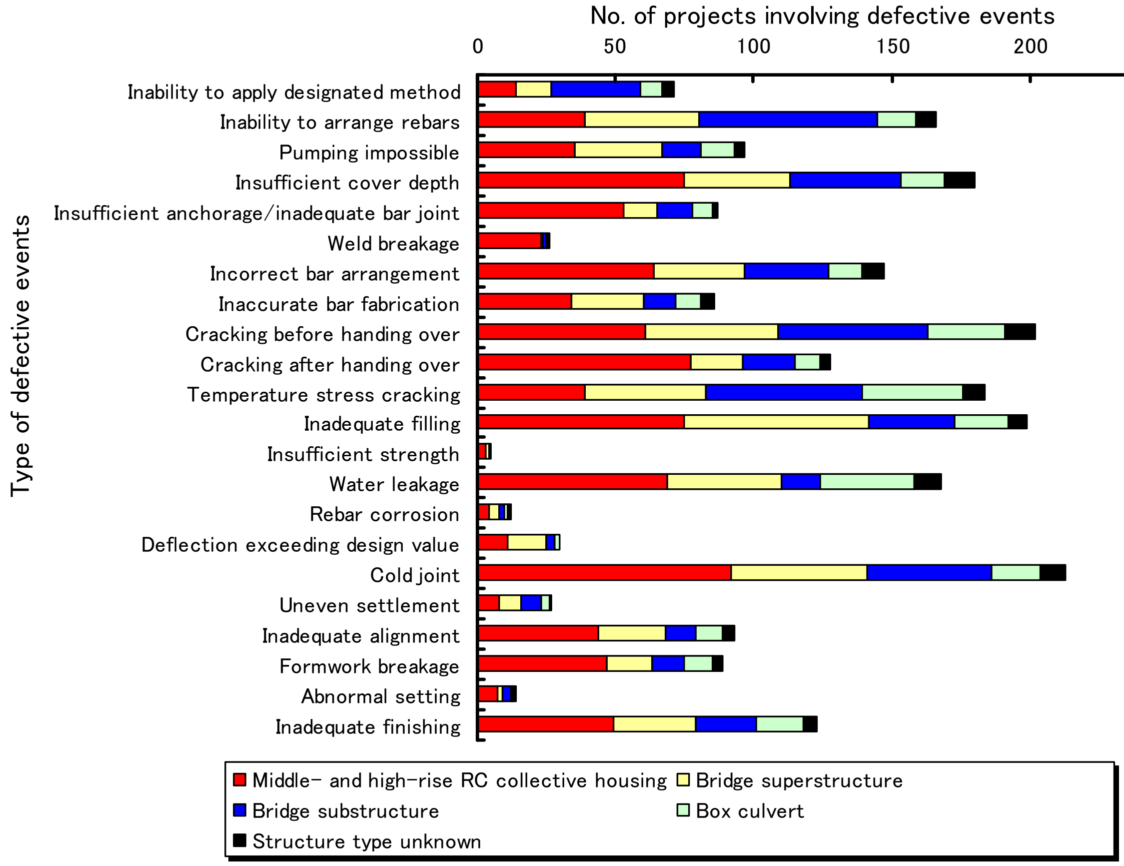


Fig. 3 Number of projects involving defective events

5.2 Causes of job stoppages/defective events

Since it is difficult to present all causes of 22 items of job stoppages/defective events because of space limitations, the causes of 'inability to arrange rebars' in medium- and high-rise reinforced concrete collective housing is taken up here as an example. As shown in **Fig. 4**, the number of 'inadequate bar arrangement drawing' is overwhelmingly larger than others as a cause of job stoppages by 'inability to arrange rebars.' This can be attributed to disagreement between structural drawings and bending schedules. The beam depth, particularly of middle- and high-rise collective housing, tends to be reduced to increase the number of stories within a given height, causing unreasonable structural design, which can lead to insufficient consideration to the details of rebars at level differences for water piping. This can be a cause for the above-mentioned disagreement.

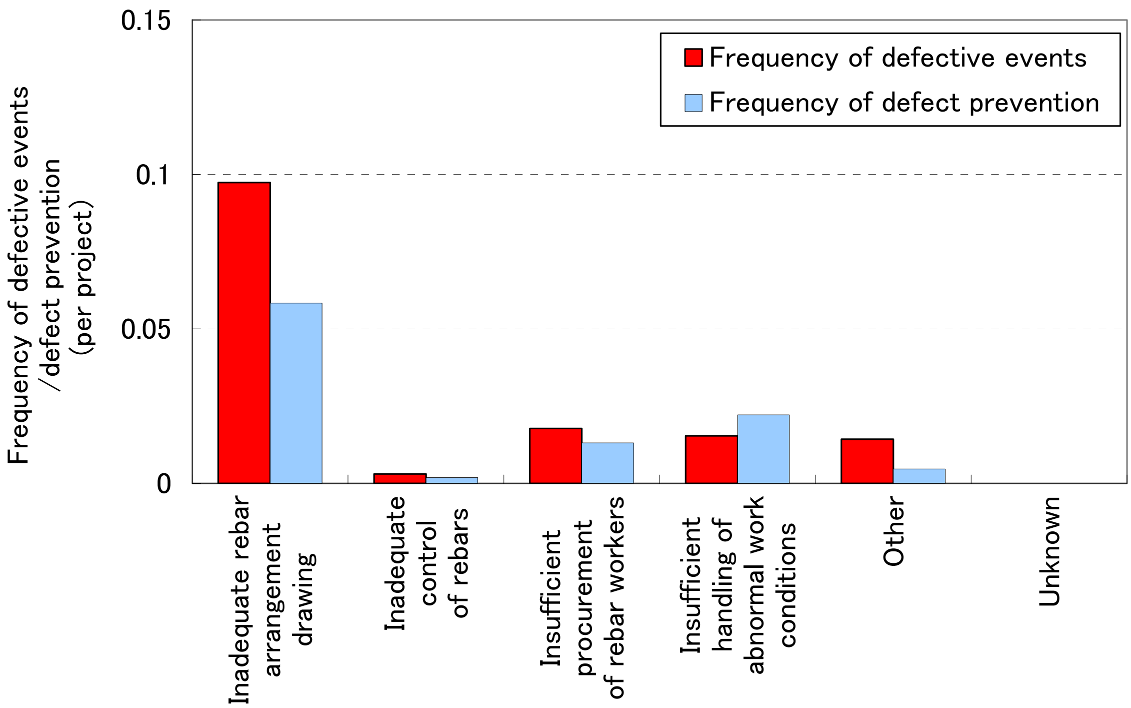


Fig. 4 Frequency of 'inability to arrange rebars' by causes

5.3 Relationship between frequencies of prevention and occurrence

The relationships between the frequency of prevention of job stoppages/defective events from occurring by proactive measures and the frequency of occurrence of job stoppages/defective events regardless of whether or not proactive measures were taken can be expressed by four types of graphs as shown in **Fig. 5** (a), (b), (c), and (d). **Figure 5** (a) shows absence or failure of proactive measures against the job stoppage/defective event, suggesting the necessity for technical development or adoption of an alternative method so as to prevent such job stoppage/defective event beforehand in the future. **Figure 5** (b) shows the absence of proactive measures against the job stoppage/defective event despite the availability of effective measures, suggesting that such measures should be adopted when the occurrence of the job stoppage/defective event is anticipated. **Figure 5** (c) shows that the job stoppage/defective event is unimportant and scarce, suggesting that it is normally ignorable but could require proactive measures depending on the situation. **Figure 5** (d) shows that the job stoppage/defective event is recognized as not requiring proactive measures due to effective measures currently being implemented, suggesting that it is sufficient to continue the ongoing measures.

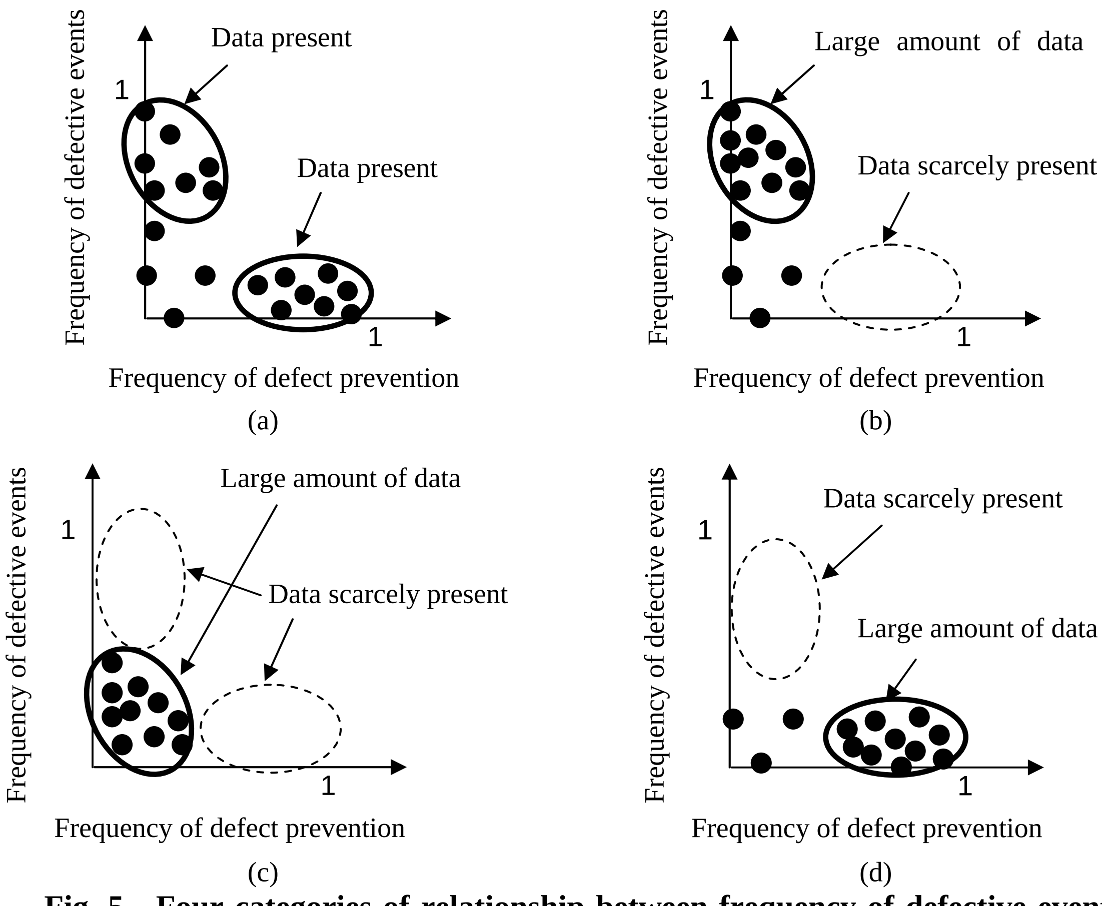


Fig. 5 Four categories of relationship between frequency of defective events and frequency of defect

Because of space limitations, only ‘cracking before handing over’ in the superstructures of bridges is taken up here to show the relationship between the frequencies of prevention and occurrence of the defective event in **Fig. 6**. While there are cases with high frequencies of prevention showing effective proactive measures, there also are cases with high frequencies of occurrence where cracking could not be prevented beforehand. This suggests that the frequency of the occurrence of the defective event can be reduced by proactive measures and that it is important to ensure such measures.

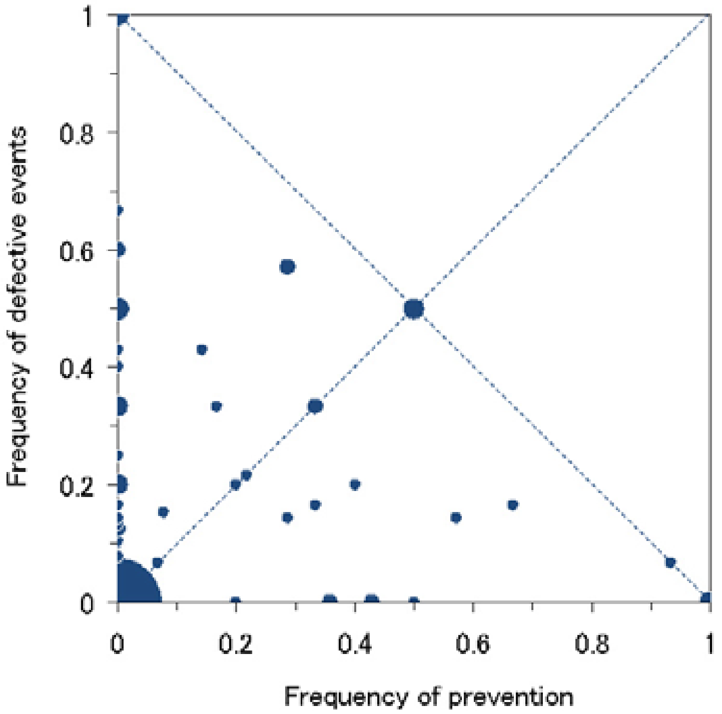


Fig. 6 Frequencies of prevention and occurrence in cracking before handing over

5.4 Effects of number of years of engagement and amount of completion

Whether or not job stoppages/defective events of concrete structures can be controlled is also considered to depend on the experience (number of years of engagement in jobs of the same type) of operators and the technical level of the contractor (annual amount of completion). Taking up 'insufficient cover depth' and 'cold joint' as examples, **Figs. 7** and **8** show the effects of the number of years of engagement and annual amount of completion on the frequency of occurrence of job stoppages/defective events. When the number of years of engagement is less then 10 years, the frequency of 'insufficient cover depth' is 0.25 to 0.3, but when the period of engagement exceeds 10 years, the frequency of occurrence decreases to around 0.16. On the other hand, the frequency of prevention increase from less than 0.1 to approximately 0.15 when the experience exceeds 10 years, showing a tendency that longer experience leads to more proactive measures taken. Also, the frequency of prevention of 'cold joint' is 0.1 or less regardless of the amount of completion, but the frequency of occurrence is higher for companies with an annual amount of completion of 100 billion yen or more. This is presumably because large companies with a large annual amount of completion tend to undertake large or complicated projects.

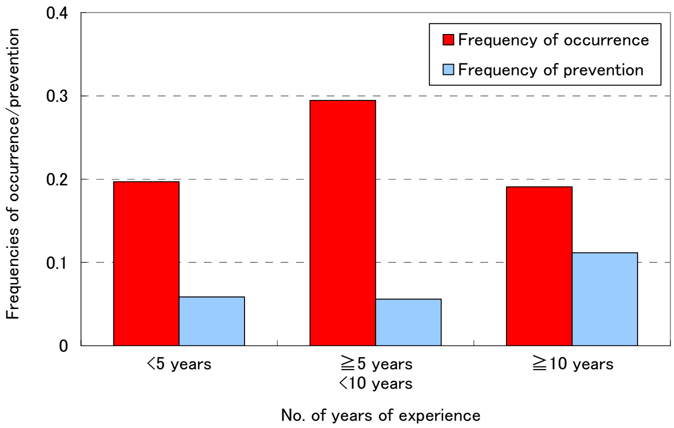


Fig. 7 Relationship between No. of years of experience and insufficient cover depth

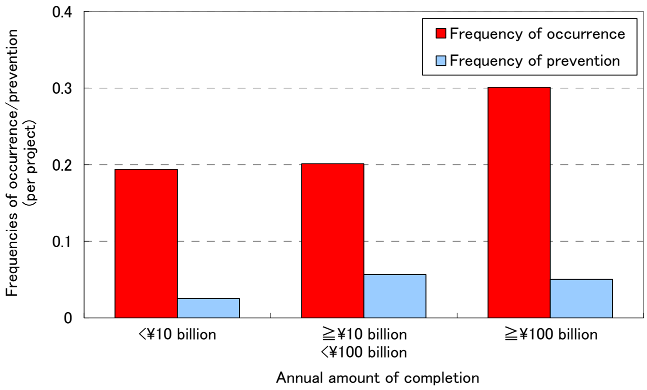


Fig. 8 Relationship between annual amount of completion and cold joint

5.5 Amount of loss

(1) Effect of each defective event on the amount of loss

Figures 9 and **10** show the cost of measures for each defective event/job stoppage (percent of the contract amount) obtained from the questionnaire in regard to middle- and high-rise reinforced concrete collective housing and bridge superstructures, respectively. The cost of measures referred to here includes both proactive measures (cost incurred beforehand in expectation of the occurrence of defective events) and post-incident remedial measures (cost incurred after the occurrence of defective events).

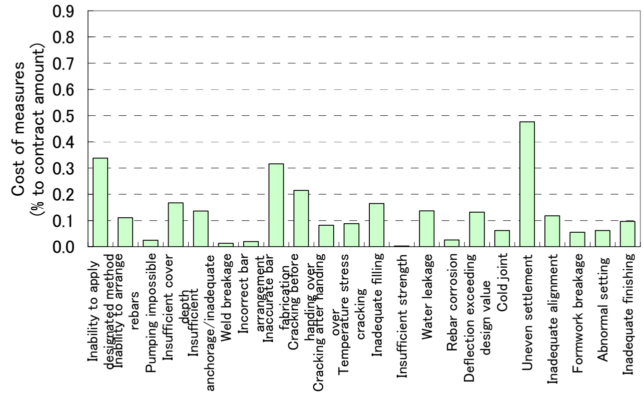


Fig.9 Cost of measures for middle-and high-rise RC collective housing

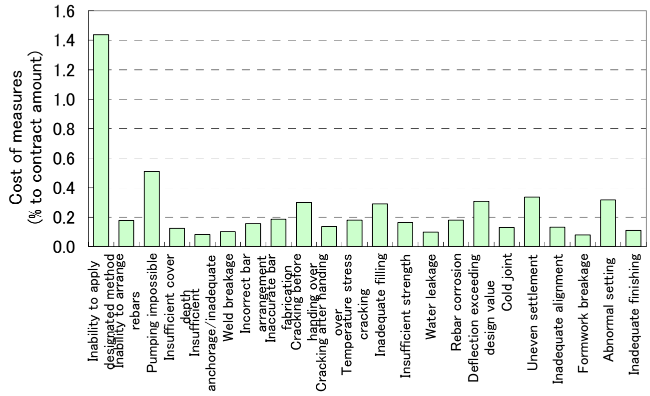


Fig.10 Cost of measures for bridge superstructures

For collective housing, the cost of measures is highest with ‘uneven settlement’ (0.48%), followed by ‘inability to apply designated method’ (0.34%), and ‘insufficient accuracy of rebar fabrication’ (0.32%). Recent collective housing is constructed even on week ground, requiring a large cost of measures on site unless properly treated in the design stage. This also applies to ‘inability to apply designated method.’

On the other hand, the cost of measures for ‘inability to apply designated method’ is highest for bridge superstructures (1.44%), followed by ‘inability of pumping’ (0.51%), and ‘uneven settlement’ (0.34%). The high cost of measures for pumping troubles may be due to the greater amount of concrete used and longer pipelines for bridges than for collective housing, which would lead to greater damage in the event of blockage.

Though not shown in figures, the cost of measures for ‘inability to apply designated method’ is highest for bridge substructures (2.96%), followed by ‘rebar corrosion’ (2.35%). For box culverts, both ‘inability to arrange rebars’ and ‘water leakage’ are highest (0.74%), showing the features of these structures.

Note that the low percentages of cost for collective housing compared with those of civil structures can be attributed to the fact that the inclusion of utility cost and interior/finishing cost in the contract amount of collective housing reduces the percentage of concreting cost.

(2) Effects of timing of taking measures on the amount of loss

Figures 11 and **12** compare the costs of proactive measures and remedial measures for middle- and high-rise reinforced concrete collective housing and bridge superstructures, respectively.

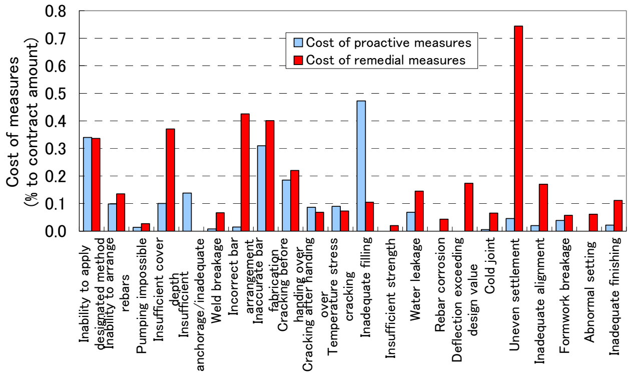


Fig. 11 Costs of proactive measures and remedial measures formiddle- and high-rise RC collective housing

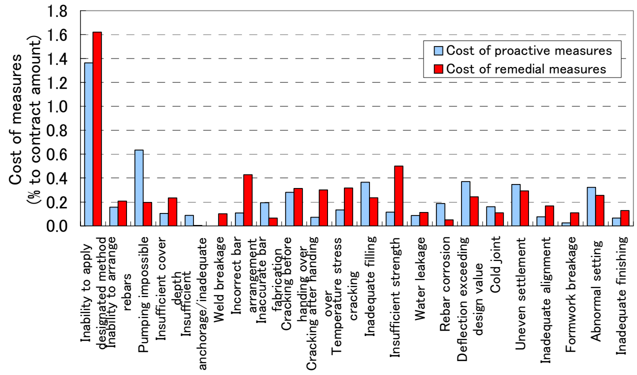


Fig. 12 Costs of proactive measures and remedial measures for bridge superstructures

In regard to collective housing, the costs of proactive measures for most defective events are equal to or lower than those of remedial measures, suggesting that the construction risk can be improved by taking proactive measures. Note that the cost of proactive measures for 'insufficient filling' is nearly 5 times that of remedial measures. Because of the low cost for correcting insufficient filling as shown in **Fig. 9**, proactive measures are taken in few cases, presumably by judging that measures after the event are preferable. Also, the cost of proactive measure for 'uneven settlement,' which incurs the highest cost of measures, is very low, suggesting that this is scarcely dealt with beforehand or no appropriate proactive measures are taken.

In regard to bridge superstructures, the cost of proactive measures exceeds that of remedial measures in half of the defect items. It is therefore hard to say that construction risk can be reduced simply by proactive measures. Focusing on 'inability of pumping,' for which the cost of measures is second highest, the cost of proactive measures is three times that of remedial measures and similar to the cost of measures shown in **Fig. 10**. This indicates that measures are taken beforehand to prevent 'inability of pumping,' though measures taken after the occurrence of the event are less expensive. In other words, judgment is made based on factors other than the cost of measures. Such a phenomenon is also found in research results on other civil structures. This is considered to be characteristic of public structures in contrast to private buildings (including collective housing) for which priority is given to economic efficiency.

6. Construction risk assessment

6.1 Framework of construction risk assessment technique

Figure 13 shows the framework of the construction risk assessment technique proposed by the Committee. Constructors directly involved in decision making on construction projects are assumed as users of the proposed technique. More specifically, they are site managers and other staff in charge of concreting and quality control, including chief engineers.

The purpose of construction risk assessment is to provide information for making a decision on proactive measures for preventing/reducing the occurrence of defective events/job stoppages related to the concreting work. The proposed technique consists of five phases as shown in **Fig. 13**.

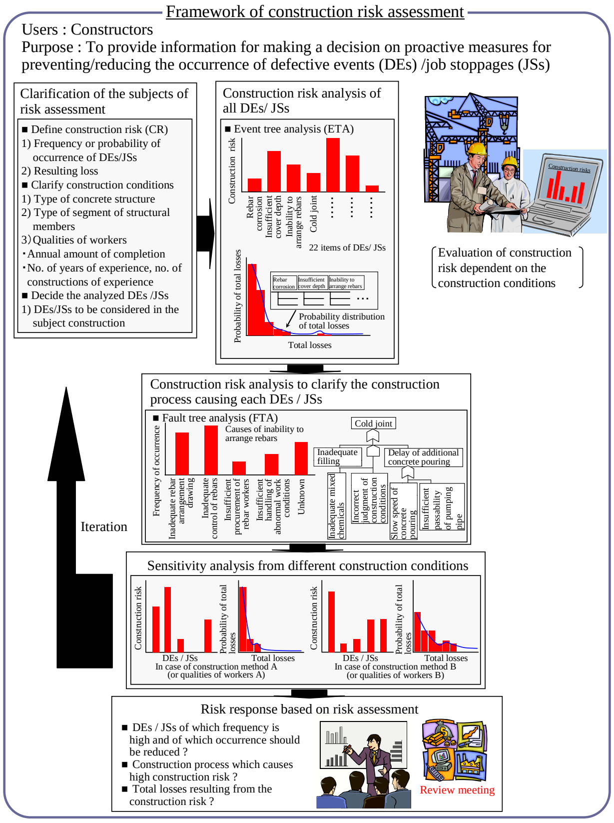


Fig. 13 Framework of construction risk assessment

When applying the proposed technique, it is necessary first to establish the problems of the project under assessment to clarify the subjects of risk assessment. In this regard, it is necessary to define the index expressing the frequency or probability of occurrence of defective event/job stoppage *i* and the index expressing the resulting loss, thereby defining the construction risk accordingly. The construction risk, *Ri*, is defined here as the product of the average frequency of defective event/job stoppage *i* per constructor (construction site), $\bar{f}_i$ (hereafter referred to as frequency of defective event and frequency of job stoppage), and the weighted average loss per event, $\overline{C}_i$ (hereafter referred to as cost of remedial measures for defective event and cost of remedial measures for job stoppage) to be interpreted as the average cost per constructor resulting from the occurrence of defective event/job stoppage *i*. Also, the product of the frequency of prevention of defective event/job stoppage *i* by proactive measures, $\overline{f}_i'$ (hereafter referred to as frequency of defective event prevention and frequency of job stoppage prevention) and the weighted average of the cost of proactive measures for such event, $\overline{C}_i'$ (hereafter referred to as cost of proactive measures), is included in the definition of construction risk, R'_i. Though this means the average cost of proactive measures against defective event/job stoppage *i*, the economic burden of proactive measures can be interpreted as a construction risk for the constructor in the framework of execution control.

The construction conditions related to the job under study should then be clarified. The essential construction conditions include the type of concrete structure, segment of structural members, construction method, qualities of workers, time of construction, environmental conditions, and surrounding conditions. It is also necessary, along with such setting of construction conditions, to extract defective events/job stoppages to be considered in the job under study. The 22 items of defective events/job stoppages affecting the performance and function of concrete structures are dealt with here as stated above.

As a second step, construction risk analysis of all defective events/job stoppages related to the job under study should be conducted based on the problem setting for construction risk assessment. Assuming that the occurrence of the above-mentioned defects/job stoppages is independent of one another in a single site, the propagation and sequence of such occurrences, which are regarded as events, are elucidated by event tree analysis (ETA). Three branches are assumed for each event *i* (occurrence of defective event/job stoppage *i,* its prevention by proactive measures, and its inoccurrence), and their relative frequencies in a job site are regarded as the probabilities of the branches. Simultaneously, the cost of remedial measures for the defective event, cost of remedial measures for the job stoppage, and cost of proactive measures are associated with the branches of each event, thereby elucidating the relationship between their totals obtained as results of 3^{22} combinations of event sequences (total losses) and their probabilities of occurrence. The curve representing this relationship is referred to as a risk curve. It provides the constructor a quantitative view of the scale of total losses and their probabilities of all defective events/job stoppages to be considered in construction risk analysis, as well as the maximum value and expected value of the total loss for a construction job.

The differences in the branch probabilities of each event *i* in ETA result from the construction process (work) causing each event *i*. From this aspect, fault tree analysis (FTA) is conducted as a third step to clarify the construction process causing each event *i*. This analysis enables the constructor to clarify the construction process affecting the occurrence of a defective event/job stoppage, thereby providing a specific image of effective proactive measures in a context of construction process flow.

Information obtained from ETA and FTA is related to specific construction conditions as mentioned above, representing the current state of the job site. For this reason, the branching probabilities of each event *i* and the resulting cost in ETA change if the construction conditions change, leading to a different risk curve. By analyzing the sensitivity of the risk curve, the construction conditions required to reduce the construction risk can be clarified. For instance, this clarifies the most effective proactive measure for reducing the construction risk from among such alternatives as (1) selecting an alternative method, (2) recruiting experienced operators, and (3) changing the time of construction. Such a sensitivity analysis of parameters governing the construction risk is an important task leading to construction risk response to be described later.

Changes of the risk curve can also be analyzed by changing the branch probabilities of events in ETA on the assumption of implementing proactive measures to reduce the occurrence of each defective event/job stoppage based on the information obtained from FTA. This quantitatively shows the effectiveness and efficiency of proactive measures for construction processes causing defective events/job stoppages. It can also be regarded as a sensitivity analysis of risk curves similar to the above-mentioned sensitivity analysis of the given construction conditions.

Information obtained from the proposed technique can be utilized on the occasion of decision making, such as execution review meetings, to enable the implementation of effective risk responses.

6.2 Example of construction risk assessment

In this section, only the construction risk assessment of defective events/job stoppages related to middle- and high-rise reinforced concrete collective housing is presented as an example because of space limitations.

Figure 14 shows the construction risks related to defective events/job stoppages of middle- and high-rise reinforced concrete collective housing (expressed as “construction risks" in the figure). Note that a construction risk of 0.5% means that, in a project with a contract amount of 1 billion yen for instance, the occurrence of a defective event/job stoppage entails an average cost of 5 million (0.005 billion) yen for remedial measures.

The construction risk of 'insufficient cover depth' is highest in this type of structure, followed by 'incorrect bar arrangement,' 'inaccurate bar fabrication,' 'cracking before handing over,' and 'inadequate filling' in this order. These are all defects related to reinforcement work, suggesting that the occurrence of defects related to reinforcement can cause substantial costs for correction (repair), because a wide range of work is required for such correction, including chipping of cover concrete, adjustment of bar alignment or replacement of rebars, and concrete patching. **Figure 15** shows the construction risks related to proactive measures against defective events/job stoppages of middle- and high-rise reinforced concrete collective housing (similarly expressed as "construction risks" in the figure). Note that a construction risk of 0.5% means that, in a project with a contract amount of 1 billion yen for instance, an average cost of 5 million (0.005 billion) yen is incurred for proactive measures against a defective event/job stoppage.

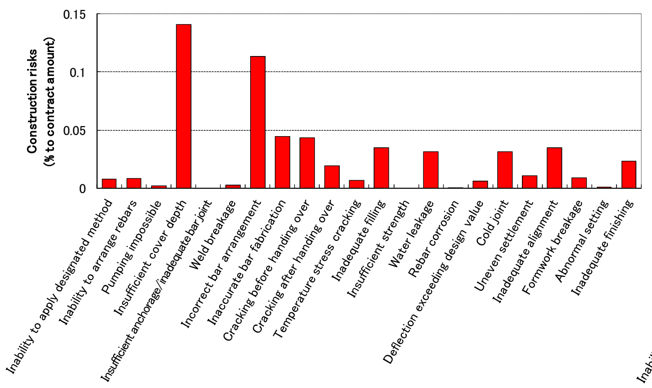


Fig. 14 Construction risks related to defective events/ job stoppages of RC collective housing

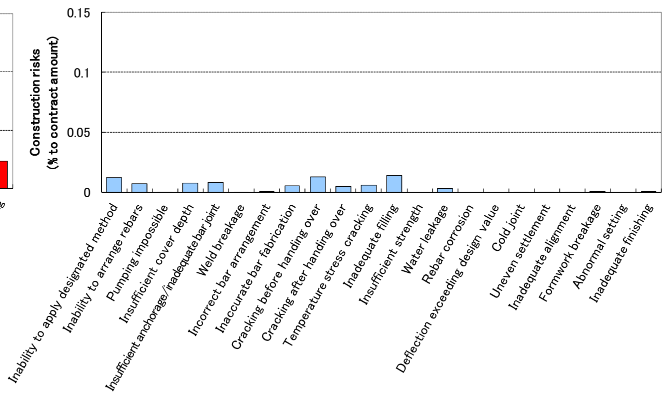
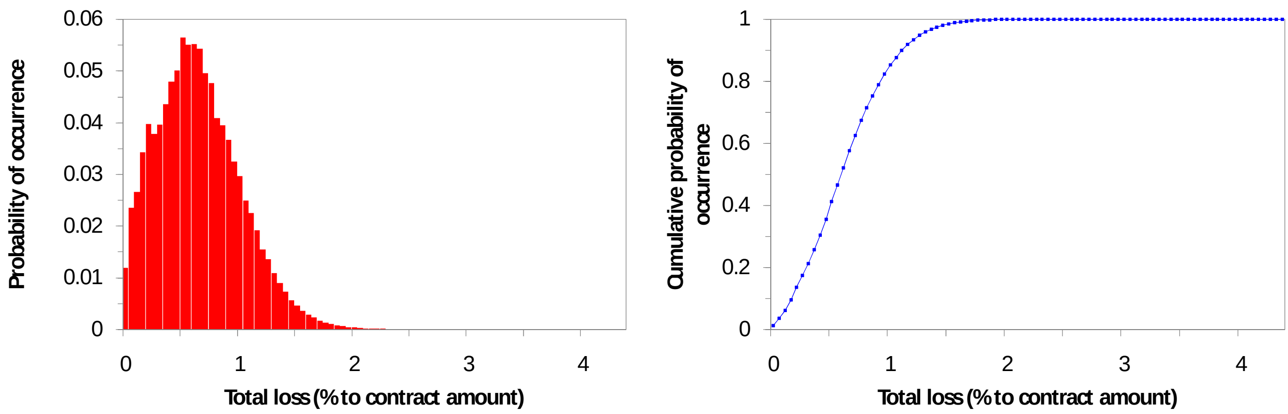


Fig. 15 Construction risks related to proactive measures for defective events / job stoppages of RC collective housing

The construction risk related to proactive measures against defective events/job stoppage is highest regarding 'inadequate filling,' followed by 'cracking before handing over,' 'inability to apply designated method,' 'insufficient anchorage/inadequate bar joint,' 'insufficient cover depth,' and 'inaccurate bar fabrication' in this order. The risk of 'inadequate filling' is particularly high at 0.023%, suggesting that proactive measures are taken at many construction sites of middle- and high-rise reinforced concrete collective housing to prevent inadequate filling. It is inferred that certain proactive measures are empirically taken when concreting in segments prone to inadequate filling, such as handrails of stairways and walls under openings, of which there are many in reinforced concrete collective housing. **Figure 16** shows the risk curve of total loss related to defective events/job stoppages of middle- and high-rise reinforced concrete collective housing. This figure reveals that the possibility of occurrence peaks near a total loss of 0.7% and progressively decreases as the total loss increases, converging to nearly zero at around a total loss of 2.2%. From the aspect of cumulative probability of occurrence, the total loss converges to 1.0 at around a total loss of 2.2%. Though the total loss reaches the maximum later at 4.35%, the probability of occurrence at this point is as low as 3.40×10^{-24}. Also, the expected value of the total loss becomes 0.72% of the contract amount. These values can be regarded as guides for construction risk in consideration of all defective events/job stoppages during construction of reinforced concrete collective housing.



(a) Relationship between total loss and probability of occurrence

(b) Relationship between total loss and cumulative probability of occurrence

Fig. 16 Risk curve of total loss related to defective events / job stoppage of RC collective

7. Construction risk response

7.1 General concept of risk response

Risk response is roughly classified into four methods: retention, avoidance, reduction, and transfer. The relationship among these responses is shown in **Fig. 17**.

"Risk retention" refers to the case where no particular measures are taken. This is a sort of risk response. It should be noted that the absence of measures does not mean to disregard the risk but to be able to handle the resulting damage without any particular measures (area 1 in the figure). The risk response described in this chapter aims to eventually bring all risks to this area.

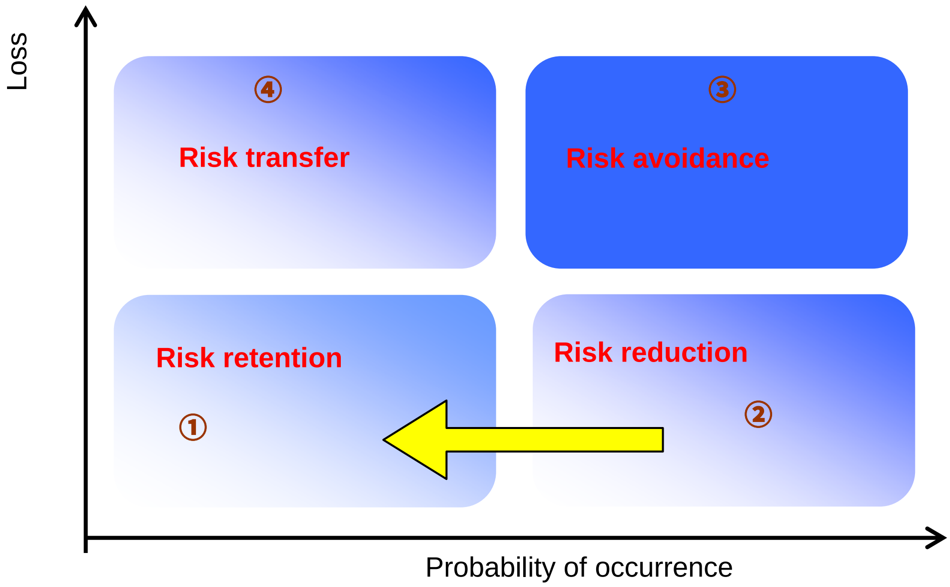


Fig. 17 Conceptual diagram of construction risks and responses

"Risk reduction" is a response to potential risks in area 2 in the figure with a small potential loss but high probability of occurrence. Measures are taken to reduce the probability of occurrence, thereby making the risk retainable (area 1). Most proactive measures taken against risks identified beforehand in concrete construction may be included in this category.

"Risk avoidance" is a response to potential risks in area 3 in the figure with a high probability of occurrence and large potential loss. Potential defects in this area should basically be avoided. Most defective events in concrete construction are not considered to fall in this category, but the case of 'iii An alternative method was adopted' in response to 'Q1 Inability to apply the designated method' is included in risk avoidance.

"Risk transfer" is a response to potential risks in area 4 with a low probability of occurrence but large potential loss. It is an option to have a third party take over the large loss incurred by an incident, instead of spending a large cost to prepare for the incident that scarcely occurs. A representative method is to purchase a damage insurance policy.

In view of the current social trend toward stronger demand for self-responsibility, risk responses by avoidance and transfer are expected to increase. The research results regarding risk reduction are excluded from this report, as most measures taken for risk reduction overlap the items and measures for quality control. The results of research on risk transfer are presented in the following section.

7.2 Risk transfer

General techniques for risk transfer include the purchase of an insurance policy and bank loans. This section reports on insurance, the most frequently chosen option for risk transfer.

Insurance related to construction is divided into insurance during construction and insurance after completion by the period covered. Insurance during construction is roughly classified into “construction insurance” covering building construction and “civil work insurance” covering civil engineering work. Others include “contractors’ liability insurance” covering losses incurred by contractors bearing legal liabilities for damage, and “assembly insurance” covering, for instance, the fabrication and erection of steel structures and ancillary works including electrical, sanitary, and air-conditioning works.

On the other hand, insurance after completion includes “defect liability insurance,” “civil structure insurance,” and “product liability insurance.” As for “defect liability insurance,” warranty against defects of residences is currently available, and a system of warranty against defects is operated by certain associations of contractors. For public works, performance bond insurance policies including warranty against defects as a special contract are commercially available.

Among these insurance types, the Committee investigated the scope of insurance of “construction insurance” and “civil work insurance” by visiting websites of nine damage insurance companies and interviewing damage insurance companies and reinsurance companies. As a result, the following losses and costs were found to be uncovered by insurance:

(1) Losses due to intention/gross negligence

(2) Damage due to earthquake, rain/wind leakage, cold air/ice, etc.

(3) Damage due to wars, disputes, etc.

(4) Losses due to the quality, defects, etc. of the purpose

(5) Cost for removal of deficiencies of design/execution/fabrication

(6) Cost of sealing/drainage of water ingress

These damage items are judged as “not being caused by unforeseeable and accidental incidents.” Defects of concrete construction dealt with in this report apply to items (1), (4), and (5) above, being uncovered by insurance.

In the investigation into conditions for having construction risks in the Committee Report covered by insurance, a report of “Workshop on the concept of warranty”[2)] summarized by the Ministry of Land, Infrastructure and Transport was referred to. According to this report, the following six items can be regarded as conditions for having construction risks of concrete structures be covered by insurance or requisites for insurance business to be financially feasible:

(1) Improvement of the one-sided contract relationship between the owner and the contractor.

(2) Clarification of the definition and judgment procedure of defects to be insured in each object structure

(3) Preparation of a conflict resolution scheme accepted by the owner, contractor, and guarantor

(4) Documentation of data necessary for the insuring body to calculate the risk

(5) Measures to keep the warranty system sound

(6) Resolution of the problems of the guarantor's limits and reinsurance

It is particularly necessary to strengthen the data documentation (probabilities and losses incurred) for the establishment of a calculation technique and calculation of construction risks, as given in (4) above, and to maintain close communication with the insurance industry.

8. Summary

During its active period from 2005 to 2007, the Research Committee on the Risk Management of Concrete Structures carried out fundamental investigation related to an attempt to apply the concept of risk management to concrete structures, while sorting out risk factors in the stages of research, design, execution, and maintenance.

Based on the achievements of the above committee, the present Committee surveyed the probability of occurrence of risk factors in concrete construction of limited types of structures by questionnaire to field engineers. The questioner also included questions as to whether or not measures were taken against risk factors, specific methods and costs for such measures, types of structures experienced and years of experience, and the scale of the organization. The Committee then formulated and proposed a prototype model of a construction risk assessment system based on the survey results. The Committee Report also includes topics regarding construction risks and measures against such risks, such as results of research on insurance systems, issues of operating ISO quality management systems, the current state and problems of the public works quality assurance system and technical inspection, as well as examples of construction defects.

In order to construct a reliable concrete structure, it is vital to properly understand construction risks assumed in the construction stage and appropriately avoid or reduce such risks. The Committee hopes that the Committee Report will assist assessment and examination of risks related to concrete construction.

Acknowledgment

The authors extend their gratitude to the committee members for their dedicated efforts for the committee activities, and to the associations, companies, and construction engineers who actively and seriously cooperated in the questionnaire survey, which formed an essential part of the achievements of the Committee.