Committee Report : JCI- TC115FS

Technical Committee on Diagnosis of ASR-affected Structures

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Abstract

Aiming to organize views on the risk of alkali-silica reaction (ASR) of concrete structures, and present rational diagnostic methods and control measures, the Technical Committee on Diagnosis of ASR-affected Structures investigated ideal diagnosis and control of ASR. First, cases in which ASR influenced the serviceability of affected structures were organized, and the need to clarify the relationship between ASR and usability was pointed out. The present state of ASR diagnosis, control measures and their issues in Japan were also presented based on the latest information in and outside Japan. The Committee proposed ideal diagnostic methods for each importance level of structure, concrete prism test and control measures.

Keywords: ASR, risk, diagnosis, petrological diagnosis, control measure, concrete prism test

1. Introduction

Views of the diagnosis of alkali-silica reaction (ASR) and control measures are undergoing large changes in and outside Japan. In Japan, measures have been implemented to control ASR since 1986, but some structures still undergo ASR, showing that current control measures have limitations. With such a background, some business entities have recently deployed new ASR control measures.

The need to revise ASR control measures has been already indicated by scientific societies such as JCI-TC062A, "Technical Committee on Mitigation and Diagnosis of Alkali Silica Reaction Considering the Action Mechanisms (chair: Kazuyuki Torii)". However, new and ideal control measures have not much been discussed quantitatively, possibly because of several reasons. One of the reasons is that actual damage by ASR is not clear. Even when ASR is diagnosed based on crack patterns in a structure, it is not further investigated in detail as to why ASR occurred. Nor has its methodology been fully worked out. Establishment of an appropriate diagnostic method is indispensable for taking rational control measures. Another reason is because the risk of ASR development is not clear. Although taking a control measure

Table 1: Committee Members

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Advisors	Kazuyuki TORII	Kanazawa University
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Secretaries	Yoshimori KUBO	Kanazawa University
	Hiroki GODA	Kyushu Institute of Technology
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Cooperative Member	Hiroyuki NAKAGAWA	Shikoku Research Institute

incurs additional costs, its effect in reducing risk is not clear, or in other words, the cost-performance ratio is not clear. The risk does not need to be reduced uniformly in all structures, but it is better to determine measures that can be implemented depending on the importance of each structure. However, people are scarcely aware of this.

ASR is not a phenomenon observed only in Japan. Today, Japanese construction technologies are actively deployed in overseas countries. ASR is strongly affected by geological features, and thus it is highly risky to execute works in overseas countries based on the same ideas used in Japan.

With such a background, four working groups were established under this Committee. Aiming to present a new flow of ASR diagnosis, control measures and testing methods based on the latest information on ASR, the Committee has worked for three years together with the Feasibility Study Committee.

2. Risk of ASR and control measures

2.1 Risk of ASR in concrete structures

The Committee first assessed the risk of ASR in concrete structures. Based on the definition of risk, the risk of ASR in a concrete structure can be defined as the expected value (costs and human life) calculated from the probability of ASR occurring in the structure, and costs for repair or costs of damage by deformation caused by ASR or the effects of ASR on relevant systems in the said structure. Therefore, to discuss the risk of ASR, it is necessary to clarify the probability of ASR in a structure, and damage accompanying the deformation of the structure as a consequence of ASR. However, these have not been clearly discussed.

Although the author stated “the probability of ASR” in the preceding paragraph, the risk should originally not be discussed from the viewpoint of whether ASR occurs or not. As long as ASR expansion in a structure cannot be appropriately controlled with existing technologies, it is just assumed that ASR will not occur by material design, and this Committee also follows the view based on the present technological level. In future, technologies should be developed for predicting ASR expansion, and assessing whether a structure meets required performance criteria or not.

Today, it is still not possible to determine the probability of ASR in a concrete structure. At present, the probability is assumed by detecting reactive aggregates as a risk source. In most cases, reactive aggregates are detected by the chemical and mortar-bar methods, which are included in JIS standards. However, the methods have limitations. Within the range of current technology, it is important to minimize the probability of ASR to zero. Therefore, the Committee discussed control methods based on the latest information and future goals, aiming not to inhibit ASR, but to control ASR (**2.3**).

The loss caused by the deformation of the structure by ASR is not clear either. Most studies in the past have been on elements. Based on the study results, the safety of an element is considered to be ensured if the reinforcement bars are not fractured even when the concrete suffers ASR. On the other hand, there have been structures in which ASR caused various problems, particularly loss of serviceability. The effects of ASR expansion on the serviceability of a structure have not been fully discussed. The Committee collected information on actual structures that have suffered ASR, and summarized the effects of ASR expansion on the serviceability of structures (**2.2**).

Originally, it should be possible to know the risk of ASR in each structure, and take appropriate countermeasures if the risk of ASR can be quantitatively discussed. However, in reality it is very difficult. Therefore, the Committee classified the importance levels of structures, organized the allowable risk for each class, and discussed ideal ASR diagnosis and control measures.

2.2 Importance of structure and allowable ASR risk

A questionnaire survey was conducted on concrete engineers, asking whether ASR in structures is acceptable or not, or whether strict control measures need to be implemented or not [1)]. The results are shown in **Fig. 1**. In the questionnaire, the majority of the engineers answered that “important structures require more precise measures than ordinary structures”, and about one-forth answered that “exceptional cases are unavoidable”. The questionnaire on ASR control measures revealed that most engineers think that ASR is acceptable in ordinary structures. It was found that control measures should be taken depending on the importance and risk levels of each structure, rather than implementing strict measures uniformly in all structures.

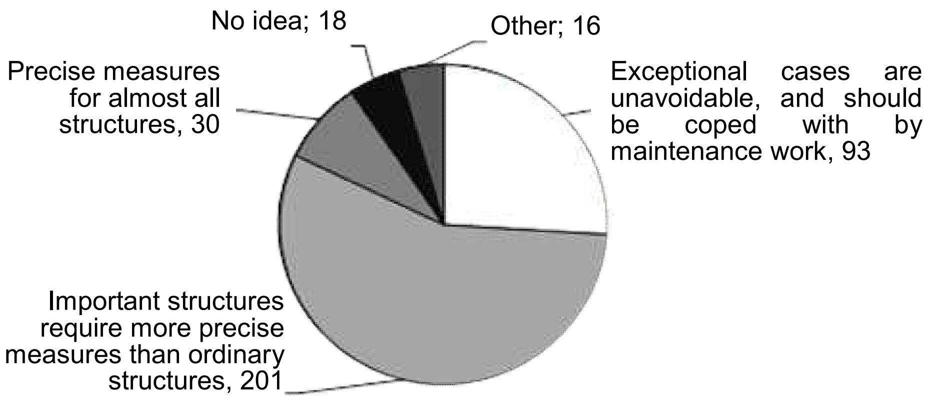

Fig. 1: Views toward ASR

Control measures depending on the importance level of each structure have already been presented in RILEM[2)] and AASHTO[3)]. As an example, the classification of structures based on the consequences of ASR in AASHTO PP65 is shown in **Table 1**. AASHTO PP65 is based on the fundamental idea of giving a large degree of freedom to the designer or owner in selecting control measures. For example, let us assume constructing a long-span bridge with a service life of 100 years in an area where reactive aggregates are produced. In such a case, ASR cannot be tolerated because ASR reduces the service life of the structure, and leads to the need for early repair work. Therefore, measures should be taken such as increasing the amount of admixture and limiting the total amount of alkali in the concrete. On the other hand, in a pedestrian path constructed using the same aggregates, the consequences of ASR are not so serious. Therefore, such a structure can be constructed by using a small amount of admixture without limiting the amount of alkali.

Table 1: Structures classified on the basis of the severity of consequences should ASR occur (AASHTO PP65)[3)]

Class	Consequences of ASR	Acceptability of ASR	Examples
S1	Safety, economic or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	Non-load-bearing elements inside buildings, temporary structures (e.g. < 5 years)
S2	Some safety, economic or environmental consequences even if major deterioration	Moderate risk of ASR is acceptable	Sidewalks, curbs, and gutters, service-life < 40 years
S3	Significant safety, economic or environmental consequences if minor damage	Minor risk of ASR acceptable	Pavements, culverts, highway barriers, rural, low-volume bridges, large numbers of precast elements where economic costs of replacement are severe, service life 40 to 75 years
S4	Serious safety, economic or environmental consequences even if minor damage	ASR cannot be tolerated	Major bridges, tunnels, critical elements that are difficult to inspect or repair, service life > 75 years

AASHTO PP65 was prepared exclusively for highways, but the concept is applicable to other structures. For example, RILEM TC 191-ARP classifies the risk into three levels, and mentions nuclear installations, dams and tunnels as high risk structures (**Table 2**).

Tables 1 and **2** mention only safety as the performance required for structures. However, endangered safety occurs rarely as a consequence of ASR. Even fracture of reinforcement is rare. On the other hand, loss of serviceability in elements and structures as a consequence of ASR has been little discussed. ASR expansion has been reported to seriously affect the serviceability of structures due to deformation of elements. However, the effects of ASR on the serviceability of a structure are not sufficiently recognized, not only among ordinary engineers but also among experts. Since RILEM established the "Technical committee on prognosis of deterioration and loss of serviceability in structures affected by alkali-silica reaction" in 2014, it is globally recognized as important to understand the effects of ASR on the serviceability of affected structures.

Table 2: Structural risk by ASR (RILEM TC 191-ARP) [2)]

Class	Structure
S1	Non-load-bearing elements, temporary or short life structures, small numbers of easily replaceable elements, most low rise domestic structures
S2	Most civil engineering structures and buildings
S3	Nuclear installations, dams, tunnels, exceptionally important bridges and viaducts, structures retaining hazardous materials

Table 3: Concrete prism test (draft)

Temperature	60°C
Storage environment	Wrapped in cloth wetted with 1.5mol/l NaOH + plastic film
Mix proportion	Actual mix proportion
Total alkali content	5.5 kg/m^3
Specimen dimensions	(75±5) ×(75±5)×(250±50) mm

As such there are many cases in which ASR affects the serviceability of structures. Although only few cases have been published, the Committee points out the importance of assessing the loss of serviceability of the structure as a future topic.

2.3 Control measures

Outside Japan, control measures depending on risk level are widely implemented. To use them in Japan, special care should be taken as to the difference in reactivity of aggregates. A flow (draft) of selecting ASR control measures for reactive aggregates in Japan is shown in **Fig. 3**[4)]. First, the reactivity of aggregates to use is to be determined among four classes, based on the reactivity of the aggregates and the environment where the structure is to be used. Then, the ASR control level is selected from six levels based on the importance and service life of the structure. Finally, the alkali content and the minimum required admixture content are determined based on the control level.

ASR damage to structures in which control measures have been implemented is mostly caused by highly reactive aggregates that produce pessimum and late expanding aggregates. Particularly, highly reactive aggregates in a pessimum proportion have been cited to reduce the ASR control effects of admixtures [5)]. **Fig. 3** considers such ASR in Japan.

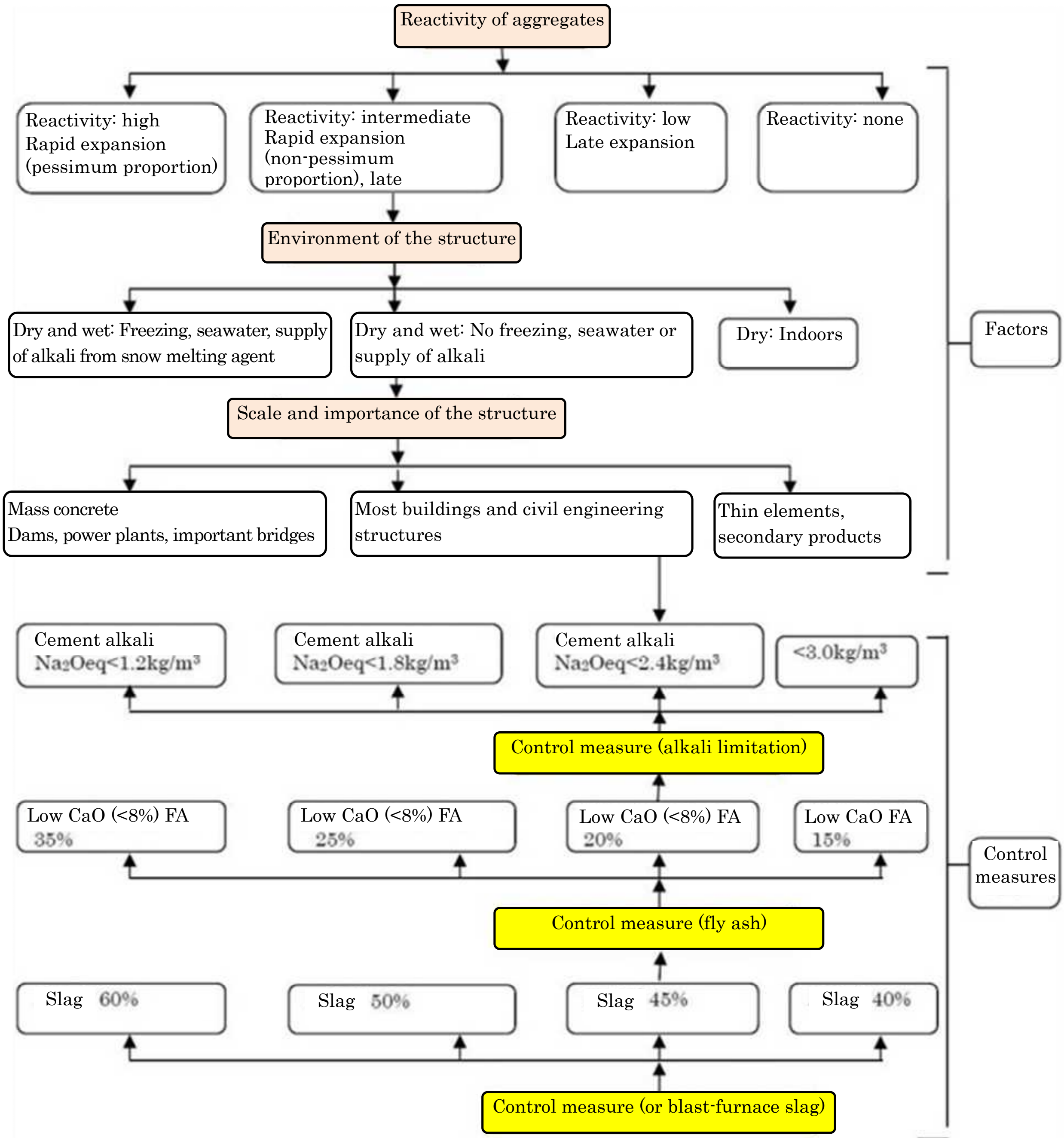

Fig. 3: Flow of selecting control measures [6)]

2.4 Concrete prism test

Today, the ASR reactivity of aggregates is judged by the chemical and mortar bar methods. Although the criterion may differ by entity, the same testing methods are used. On the other hand, the tests have been pointed out to have limitations. With such a background, the concrete prism test (CPT) is increasingly used instead of the chemical and mortar bar methods, for example in North American countries. Advantages of CPT include:

1) Aggregates that cause pessimum phenomena of various kinds and late expansion can be detected. Particularly, the effects of particle-size pessiumum phenomena can be eliminated because the method does not require aggregate particle size adjustment.
2) The appropriate mix rate of admixture can be understood.
3) Because the test is conducted on a relatively large cross section compared to mortar, the effects of alkali elution during the test period can be mitigated.
4) The test results are in relative conformity with exposure tests.

Also in Japan, JCI AAR-3 has been standardized as a method for the concrete prism test. Although the testing method was cutting-edge at the time of standardization, it has various defects today. For example, it involves adding a total amount of 2.4kg/m^3 of alkali, and testing each specimen for a period of a half year. However, compared to current testing methods used outside Japan, JCI AAR-3 has several technical problems, such as it may fail to sufficiently accelerate ASR accompanying decreases in the amount of alkali in Japanese cement, and a testing period of a half year is insufficient for accurately detecting late expansive aggregates. These need to be urgently corrected, and the Committee proposed a revision plan (total alkali content: 5.5kg/m^3, testing period: 1 to 2 years).

RILEM is now establishing a test method (RILEM AAR-4) that can judge ASR quickly by raising the temperature to 60°C. It involves setting the total alkali content at 5.5 kg/m^3 and exposing the specimens to 60°C for 20 weeks. It has been questioned for applicability to overseas aggregates, but it has recently been reported that aggregates that cause pessimum in Japan can also be detected[7)].

As described above, AAR-4 is possibly effective for aggregates in Japan, but it tests aggregates and not the performance of concrete. It has also been said that the water supply is insufficient and alkali elution may occur. [7)]. Therefore, the Committee proposes the testing method shown in **Table 3**. The testing method is characterized by maintaining water supply, wrapping the concrete surface with cloth wetted with an alkali solution to prevent alkali elution, and further wrapping the surface with a water-shielding plastic film. The Committee has performed common tests, and refined the testing method (**Fig. 4**). The common tests also helped us extract points to be improved in the CPT method (draft) proposed by the Committee. Investigations will be continued to further improve the accuracy of the test methods.

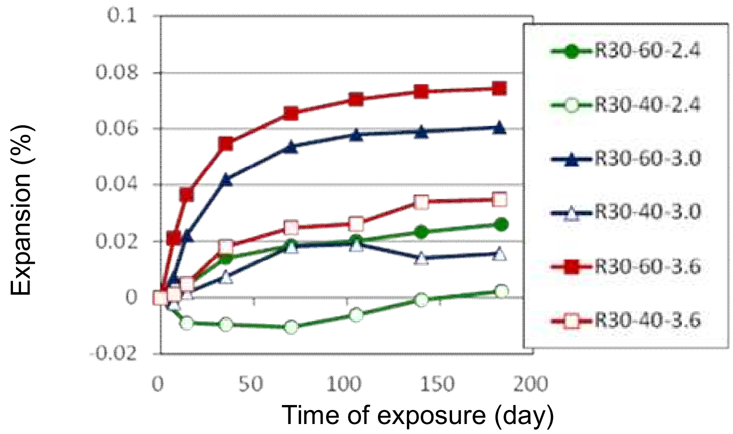

Fig. 4: Example of common concrete prism test

Studies on simple prediction of long-term ASR expansion by using CPT have also been reported (**Fig. 5**) [8]. A quantitative assessment method was also proposed that involved converting the ASR control effects of admixture into alkali content in advance[9]. They may help rational design of ASR control measures. The Committee reviewed these studies, and discussed future ideal ASR control measures.

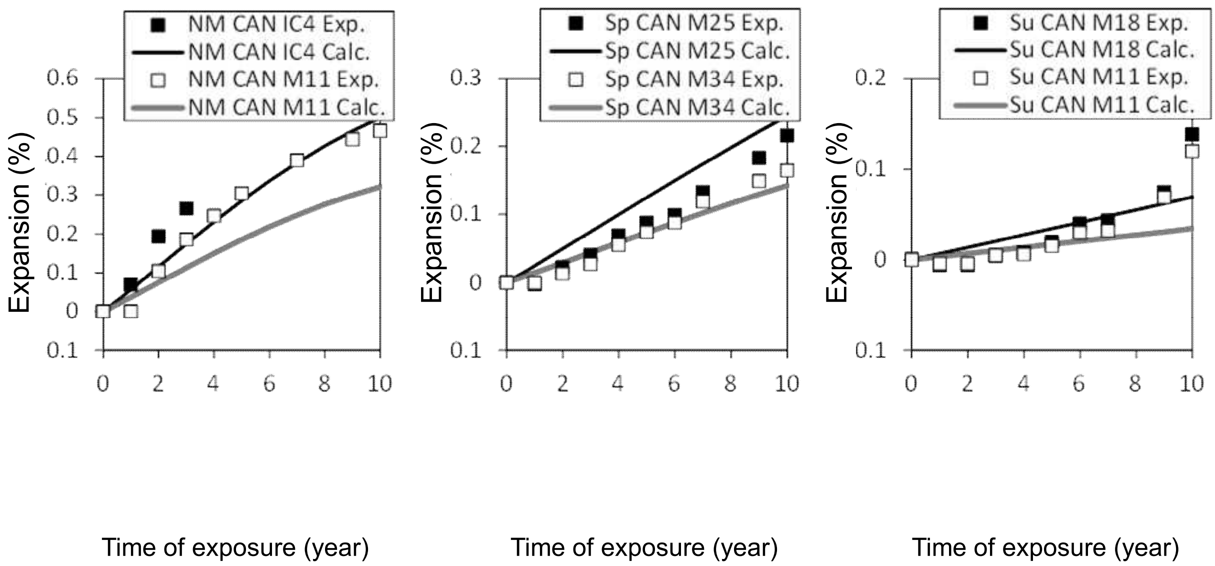

Fig. 5: Example of simple expansion prediction using CPT [8]

3. Flow of ASR diagnosis in structures

3.1 Present state of ASR diagnosis and required technologies

(1) Definition of diagnosis

Diagnosis may involve various viewpoints and objectives. In a broad sense, ASR diagnosis involves i) detecting ASR and specifying causes, ii) determining the degree of deterioration, iii) knowing the possibility of whether expansion progresses or not, iv) assessing the effects on structural performance, and v) judging the need for countermeasures. The Committee prepared a flow of diagnosis to achieve these objectives. Originally, diagnosis aims to i) detect ASR and specify causes, and this was defined as ASR diagnosis in a narrow sense.

(2) Summary of present state of ASR diagnosis and required technologies

One of the problems of ASR in maintaining structures is that the ability of an engineer to diagnose ASR highly depends on his or her experience. A schematic diagram of setting a diagnosis level depending on the importance of the structure and the level of managers and engineers is shown in **Fig. 6**. For example, not a few managers or engineers can detect ASR just by observing the external appearance of a structure if they are experienced in studying precise survey data of ASR structures and/or taking measures. On the other hand, managers who are little experienced in diagnosis or in the region are more likely not able to discriminate ASR by visual observation, and require precise investigation. The flowchart shows the required or recommended diagnosis level for each experience level in ASR management (including back data), aiming to rationalize diagnosis technologies in maintenance and repair work. For important structures and cases in which diagnosis of ASR is particularly important, an advanced diagnosis based on petrology should be implemented.

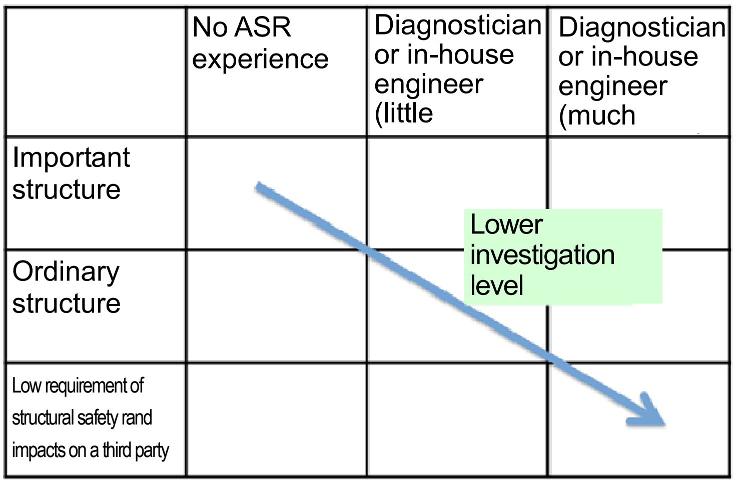

Fig. 6: Schematic diagram of setting diagnosis level based on the importance of structures and level of engineers

(3) Framework of ASR diagnosis

A framework of ASR diagnosis in a broad sense is shown in **Fig. 7**. This section outlines the framework and mainly describes “specifying the cause of ASR” in Phase 1 of **Fig. 7**.

The risk of ASR is to be first determined from the importance of the structure, including required performance and service life. The risk is as exemplified in **Tables 1** and **2.** Then, based on the risk of ASR, the level of diagnosis is determined. The technological abilities required for each level of diagnosis are as described above. For example, for an element or structure that can tolerate ASR risk, a simple ASR diagnosis may be performed. It is important to rationally explain the causes of ASR in the structure. For example, back data and survey references that show the state and development of ASR in structures near the target structure will help diagnosis of ASR in the structure. On the other hand, if ASR has not developed in nearby structures, and existing records show non-reactive aggregates and use of control measures (total alkali content, mix cement), it is necessary to specify the cause of the ASR. To identify the cause, high technological skills may be required, and advanced petrological diagnosis should be implemented when necessary (**Fig. 8**[4)]). When ASR is suspected in an element or structure that cannot tolerate ASR, advanced petrological diagnosis is indispensable.

In Phases 2 and 3, existing simple technologies are used for simple diagnosis. For advanced diagnosis, investigation should be done based on the flow shown in **Fig. 8**.

Procedures in Phases 4 and 5 are not described here because they are stated in other standards. In the final step of the phases, the performance of the structure is assessed, and the need to take countermeasures is decided.

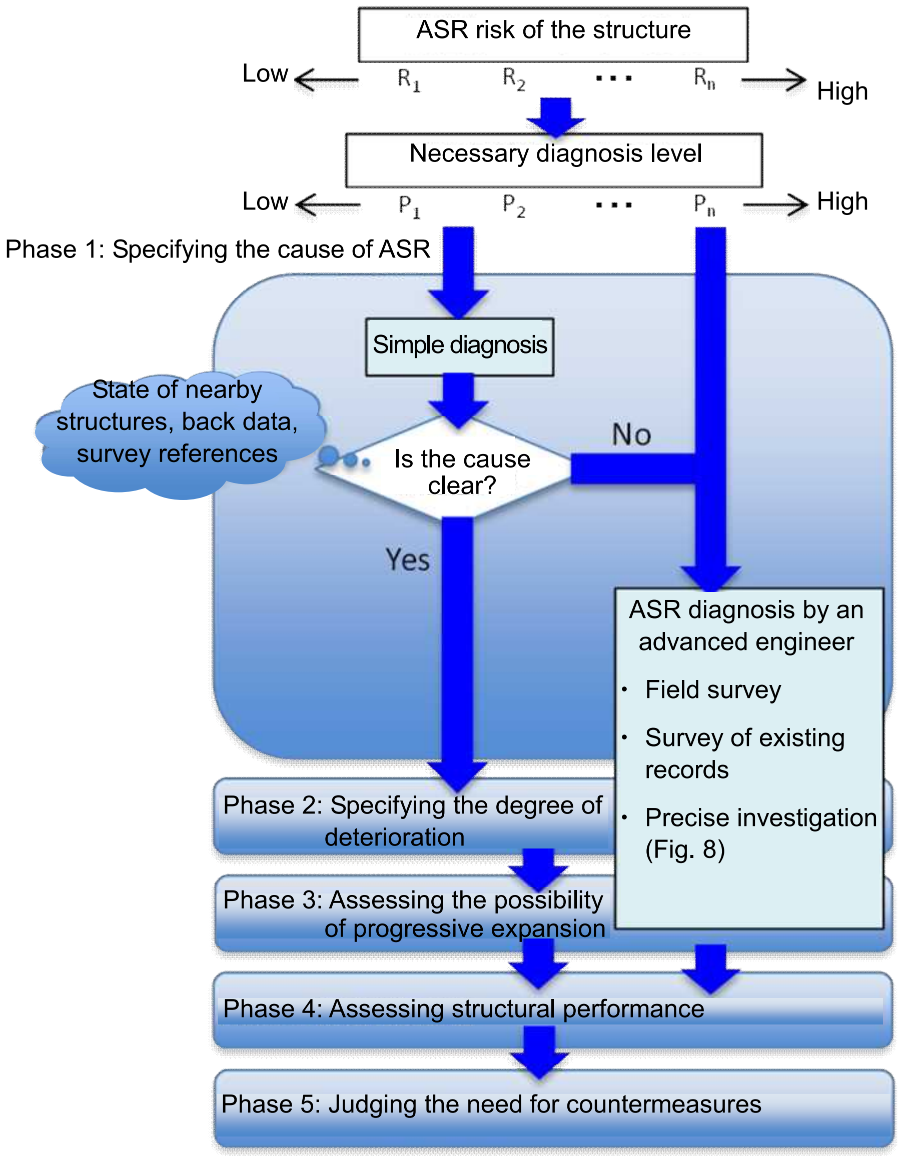

Fig. 7: Framework of ASR diagnostic flow

In the diagnostic flow presented by the Committee, it is most important to classify the risk to the target structure as consequences of ASR, and to set the level of diagnostic technology of an engineer based on the risk level. This is grounded on the fact that precise technologies related to ASR require knowledge of petrology, and there are many cases in which even concrete diagnosticians may have difficulty interpreting the results. However, in Phases 4 and 5, knowledge of structural design is also required, and overall judgment should be made by an appropriate expert.

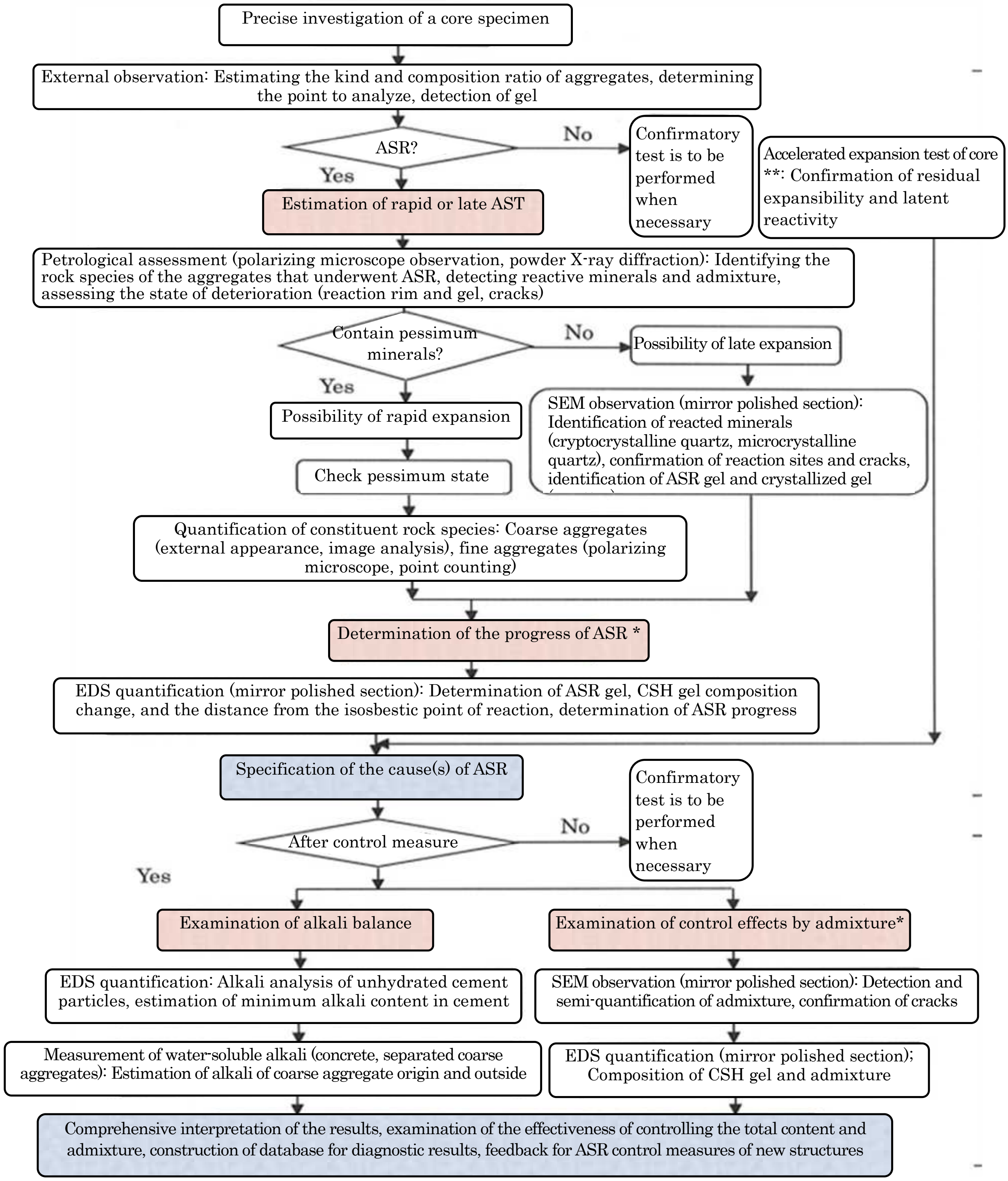

Fig. 2.2 (cont.) ASR diagnosis flow for concrete structures (draft)
* Katayama et al. (2004, 2008), EDS: energy dispersive spectroscope
** Method by Katamaya et al. (2004) (φ5cm × L13cm, immersed in 1M NaOH at 80°C) or JCI-

Fig. 8: Flow of petrology-based ASR diagnosis [4)]

3.2 Latest petrological diagnosis

The Committee shows a technically ideal flow of ASR diagnosis for observing and analyzing sampled concrete core specimens, and correctly diagnosing ASR, which uses the latest technologies and contains the maxim executable contents (**Fig. 8**) [4), 10-13)]. In the Committee Report, each item of the advanced diagnostic flow was described for methodology, acquirable information, and scientific content.

4. Summary

The Technical Committee has discussed future ideal ASR diagnosis and control measures from the viewpoint of risk of ASR in concrete structures. To answer the question of what the risk of ASR is, diverse problems need to be solved, including the importance of the structure and regional characteristics related to aggregates. The Committee has tested a new approach and presented a certain level of results. However, the results contain many problems. We, researchers and engineers involved with ASR, will continue studying and discussing ASR to establish advanced control measures in Japan.

The circumstances surrounding ASR are undergoing major changes both in and outside Japan. We expect that the results of the discussions by the Committee will be widely reflected, and help accelerate rationalization of ASR measures.

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