Committee Report: JCI-TC152A

Technical Committee on Performance Based Design and Maintenance Scenario with Controlling ASR Deterioration

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Abstract:

This technical committee "Technical Committee on Performance Based Design and Maintenance Scenario with Controlling ASR Deterioration", for the purpose of establishing a scenario on link between design and maintenance oriented to alkali silica reaction (ASR) controlling according to importance of structure, evaluated the ASR occurrence possibility, and investigated the advancement of concrete prism tests (CPT) for predicting expansion behavior. Also, we proposed a revision proposal for JCI's ASR-related criteria (former AAR-3 and DD 2). On the other hand, regarding the structural performance evaluation of the ASR degradation member, numerical analyses by several institutes were conducted on a common ASR specimen, and in addition to summarizing information necessary for evaluation, we showed the problem of performance prediction based on expansion prediction. Additionally, based on interviews with managers, the actual tasks of maintenance management for ASR were summarized, and the design and maintenance management linked scenarios that consider ASR were shown.

Keywords: ASR control, design and maintenance management linked scenario, concrete prism test, structural performance evaluation

1. Introduction

In regards to the alkali silica reaction (hereinafter, ASR), a design of "suppression" type assuming not causing deterioration on the design has been carried out, based on the aggregate alkali reactivity test which hasn't necessarily been fully sufficient up to now, and control measures for concrete formulation. However, ASR-suspected structures are still reported, and with many technical problems in checking, evaluating, and predicting in maintenance

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management, the current status of post maintenance management is inevitable. Additionally, the long-term evaluation and feedback for actual structures in regards to ASR repair and reinforcement measures were insufficient, creating difficulties in countermeasures.

Therefore, this research committee evaluates the degree of influence on the structure when ASR occurs in structures that are designed as a risk level in advance, and through the establishment of a linked scenario of design and maintenance management of ASR “control” type, according to the required performance, including structural performance, and structural importance, our objective is to propose a technical frame to simplify the measures for dealing with ASR. This research committee’s structure is shown in Table 1.

Table 1 – Committee Structure

Committee Chair　Kazuo Yamada, NIES	Secretary General　Takashi Yamamoto　Kyoto University
WG1 (Test/Prediction Method) ◎Yasutaka SAGAWA, Kyushu University Tadatsugu KAGE, NILIM Yasuhiro KODA, Nihon University Natsuki YOSHIDA, GBRC	◎: Chief Investigator Go IGARASHI, Tohoku University Yuichiro KAWABATA, PARI Ippei MARUYAMA, Nagoya University
WG2 (Diagnosis/Countermeasure) ◎Yoshimori Kubo Kanazawa University Eiji IWATSUKI, Aichi Institute of Technology Koji TSURUTA, Railway Technical Research Institute	◎: Chief Investigator　○: Deputy Investigator ○ Shoichi OGAWA, Taiheiyo Consultant Co.,Ltd. Hirohisa KOGA, Public Works Research Institute Naoki HAGIWARA, Nippon Expressway Research Institute Co., Ltd.
WG3 (Performance Evaluation) ◎Naoshi UEDA, Kansai University Yuya TAKAHASHI, The University of Tokyo Yoshihiko TODA, JIP Techno Science Tomohiro MIKI, Kobe University	◎: Chief Investigator Hiroki Goda, Kyushu Institute of Technology Atsushi TERAMOTO, Hiroshima University Jun TOMIYAMA, University of the Ryukyus

In WG1 (test/prediction method), a test method for the realization of ASR occurrence possibility and expansion prediction was discussed. Here, we focused on the concrete prism test (hereinafter, CPT), which found usefulness in the “Technical Committee on Diagnosis of ASR-affected Structures (TC 115FS, 2011-2013)”[1)]. Based on a round robin experiment by several laboratories in Japan, we considered the quantification of the acceleration ratio and environmental dependency, set out to standardize the test method, and examined the applicability of expansion behavior prediction. Also, we proposed contents of a revision for JCI's ASR-related standard test methods (former AAR-3 and DD2).

In WG2 (diagnosis/countermeasure), in order to clarify the actual state of diagnosis and countermeasures of ASR degradation structures, we collected opinions, focusing on road managers. We also gathered domestic and overseas guidelines, and examined the practicality of maintenance management flow when the level of engineers is not particularly high.

Additionally, we gathered the durability data after countermeasures, which can be used for the durability design of repair and reinforcement measures.

In WG3 (performance evaluation), deformation of member, stress analysis, and the performance evaluation method when ASR occurred or progressed. In this context, in order to extract the issues of the procedures from information input to output when using an analysis tool for structural performance evaluation, a round robin analysis was conducted for examples of ASR deteriorated specimens. Additionally, we investigated technical issues for problems of structural performance prediction that incorporates the predictability of expansion.

2. Evaluation for ASR Occurrence Risk and Technological Issues Regarding Prediction

2.1 Test Method

(1) Significance of the Test Method using Concrete

Previous studies have revealed that the expansion of concrete due to ASR is influenced by various factors, such as the aggregate type and particle size distribution, cement type, water/cement ratio, aggregate combination, etc. Also, recently the existence of aggregates whose reactivity cannot be detected by the chemical method or the mortar bar method has been identified. Therefore, at present, as a method of correctly evaluating the swelling and inhibiting measures of concrete by ASR, concrete specimens are prepared based on the materials and mixture proportions used for actual concrete, which is considered to be the most reliable in conducting the test.

JCI has already specified JCI AAR-3 “Test Method for Alkali Silica Reactivity of Concrete (Concrete Method)”. This is based on the investigative research results takes from the “Technical Committee on Alkali Aggregate Reaction (AAR Committee)” established in 1983, and the ensuing “Technical Committee on Test Method for Alkali-Aggregate Reaction by Concrete Method” (established in 1989). Although JCI AAR-3 summarized the most advanced information available at the time, but based on recent research results, there are some parts which should be required to be revised. Therefore, including the considerations in TC-115FS, in this WG we will propose several revisions; a) alkali addition amount and test period, b) test period when using mineral admixtures, c) specimen size, d) controlling the water amount of wrapping paper, e) measurement of mass change, and f) specimen storage method.

(2) Examination Regarding Appropriate Acceleration Test Condition

Overseas, in order to judge the aggregate reactivity, the tests that uses concrete prism specimens (CPT: Concrete Prism Test) are standardized by CSA, ASTM and RILEM. These tests set the total amount of alkali in concrete from 5.25 to 5.5kg/m^3, and implement the one-year acceleration test. In CSA and ASTM, by increasing the total alkali amount to 5.25kg/m^3, and by curing at 38°C for one year, this results in a high correlation with the expansion of concrete blocks exposed to outdoor conditions for 10 years, and is allowing for a reliable result to be obtained[2)].

For CPT, there are concerns regarding drying and alkali leaching during the test period. Also, it has been pointed out that these factors increase the coefficient of variation of the measurement results[3)]. As a method for solving these problems, a method called "alkali wrapping CPT (AW-CPT)", in which CPT is coated with non-woven fabric impregnated with an alkaline solution which has a concentration close to that of the alkaline concentration in a concrete pore solution has been proposed, and its applicability has been reported as follows[4)]. ASR is, basically, a reaction between reactive silica in an aggregate and alkali in pore solution, and the rate of expansion becomes high at high temperatures as well as when the alkali amount is more. However, for relatively moderate condition such as when the temperature is lower than 40 °C, the expansion ratio does not become high in a short period, but the expansion ratio exceeds at 60 °C in long period. It has been suggested that the cause of this is, depending on the acceleration conditions, the alkali silica gel is lost outside of the test specimen, and the expansion rate will not increase. Therefore, it is necessary to set appropriate acceleration conditions according to the reactivity of the aggregate. Additionally, especially for concrete that uses aggregate with the pessimum phenomenon, uniformity is suspected for the aggregate content in the test specimen, so it is necessary to accumulate further test data in regards to the variations in the expansion ratio measurement results and the test reproducibility.

2.2 Prediction of ASR Expansion

In recent years, there's been an increase in activity in the research for predicting ASR expansion in concrete structures, and to predict the deformation and load-carrying capacity of structures. Within the ASR expansion prediction research, how to model the ASR expansion of concrete has become the focus of discussion, and the investigative results in regards to that are as follows.

As an expansion prediction model, there have been several proposals for various scales as the target. The Larive equation[5)] has been the most recognized internationally as a macroscopic expansion model, shown as follows (Figure 1, equation (1)).

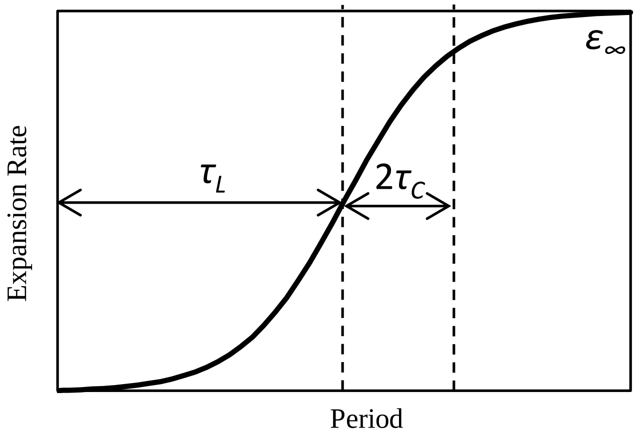


Figure 1 – Larive Inflation Model [5)]

$$\varepsilon_t = \varepsilon_\infty \frac{1-\exp\left(\frac{-t}{\tau_c}\right)}{1+\exp\left\{-\frac{(t-\tau_L)}{\tau_c}\right\}} \qquad (1)$$

Here, ε_t: expansion ratio at time t (%), ε_∞: final expansion ratio (%), τ_c, τ_L: constant that shows time (days).

The three constants (ε_∞, τ_c, τ_L) are obtained by fitting the equation (1) to the experimental value of unrestrained expansion, obtained by CPT, etc. For use in expansion prediction for actual concrete structures, it will be converted into actual expansion behavior by utilizing a model related to temperature dependency, humidity dependency, and stress anisotropy. These macro models are primarily developed by IFSTARR, and their models are summarized in the reference[6)].

The macro expansion model has few constants to be determined, and is simple, but there may be cases where it does not reflect the actual phenomenon. Therefore, meso-micro scale expansion models have also been developed in recent years. Multon et al. in Toulouse University has researched vigorously and developed the LMDC model [7)]. The model includes several reaction parameters in ASR deterioration process; the aggregate dissolution, gel formation in concrete, expansion pressure of ASR gel in constraint pressure, release of expansion pressure due to damage based on fracture mechanics, and alkaline leaching from the test specimen. Although it has not been published at present, this model has been extended to macroscale analysis in recent years. Also, Saouma et al. have attempted to treat the process of basic chemical reactions, kinetics and gel formation related to ASR[8)].

Many of these studies refer to the model proposed by Uomoto, Furusawa, Oga (U.F.O. Model) in Japan[9)]. This U.F.O. Model is based on the reaction progression by diffusion rate-limiting, and is an initial study of numerical analysis on ASR that organizes reactions at each particle size of aggregate to expansion. Recently, Kawabata and Yamada have investigated alkali interaction of cement hydrate and pore water is implemented in the U.F.O. model, and used to elucidate the mechanism by which fly ash's ASR suppression effect decreases under pessimum condition[10].

As a multi-scale approach, through combining the generated ASR gel calculation model with ASR-related chemical reactions, moisture/alkali mass conservations laws, and concrete nonlinear structure analysis models, Takahashi[11] proposes an expansion model that can reproduce the anisotropy of ASR expansion under constraint conditions (Figure 2). According to the model, it has been shown that appropriate expansion anisotropy and cracking occurrence can be calculated with uniaxially-restrained specimens and RC beams[11), 12)], and currently studies on the influence of ASR expansion for structural performance, such as the fatigue lifetime for RC floor slabs, are progressing. However, with respect to the formation rate of ASR gel, alkalinity concentration and temperature/humidity dependencies, etc. are taken into consideration, but since reactivity (reaction rate coefficient) of aggregate greatly differs for each aggregate, it will be necessary to obtain values for each aggregate. Therefore, the results of an acceleration test such as CPT is required to obtain reaction parameters.

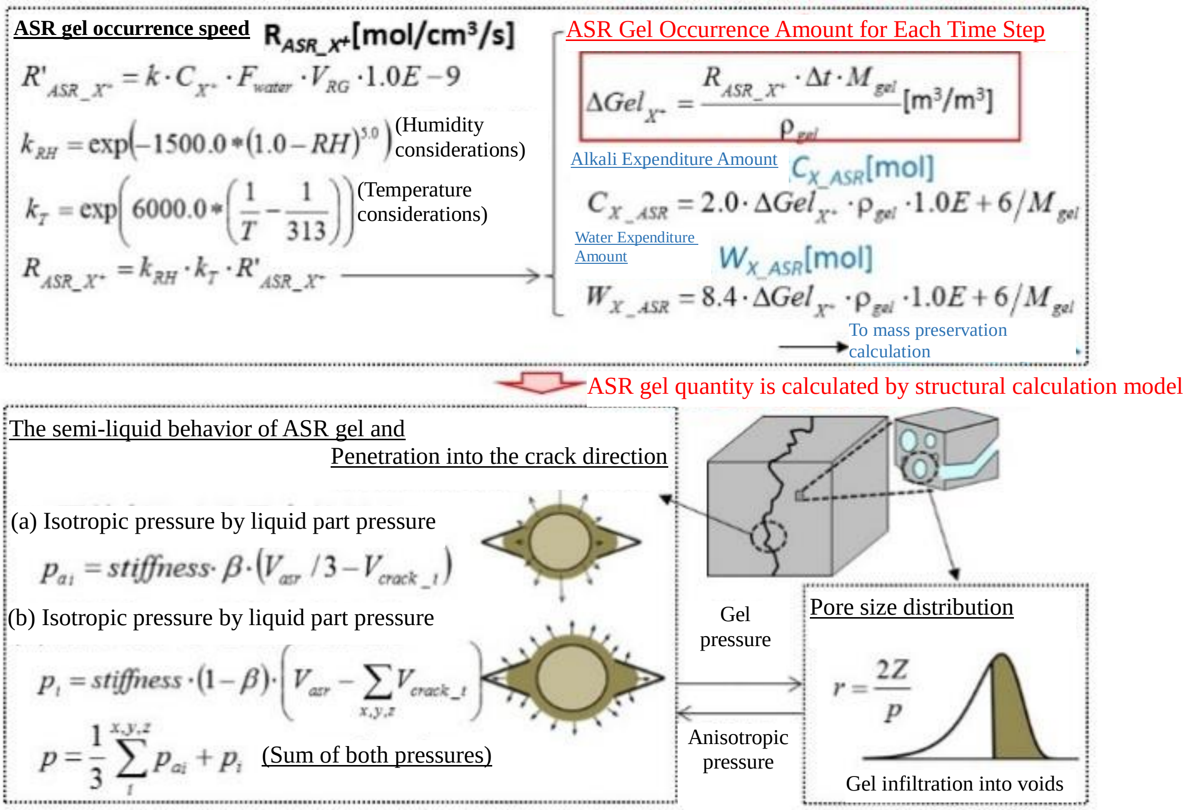


Figure 2 – Expansion Model by DuCOM-COM3[11),12),13)]

3. Structural Performance Evaluation of ASR Deteriorated Structures

3.1 Current Status of the Performance Evaluation Analysis for ASR Deteriorated Structures

It is known that mechanical properties, such as elastic modulus and compressive strength of concrete, deteriorate due to ASR. On the other hand, there is knowledge that the structural performance does not decrease significantly if the reinforcing bars were sound. Conventionally, the performance of ASR deteriorated concrete structures has been studied for member level primarily by experiments, however for the real structure, conducting the experiments is not easy due to the large scale. Additionally, in order to understand the changes in performance over the future, it is difficult to obtain sufficient information only from experiments. Therefore, it is desirable to evaluate the performance of ASR deteriorated structures by analysis.

Recently attempts to evaluate the ASR initiation and expansion issues by analysis have been carried out in Japan as well as overseas. Particularly for overseas, as ASR occurs in electric power-related facilities, which is a serious problem[14)]. In order to maintain and manage these structures, it is necessary to evaluate and predict the stress state inside and overall deformation of the structure, for which the analysis plays an important role. Here, we are concentrating on predicting the structural changes in accordance with ASR progression. Numerous structural models formulated on the microscopic scale or semi-microscopic sale, such as aggregate chemical reaction and gel modeling, have been proposed[15)]. Modeling is also performed in response to the influence of environmental actions such as moisture and temperature, and time-dependent behaviors such as creep. On the other hand, recently studies on structural performance against external forces have also been carried out[16)].

In Japan, ASR deterioration have been observed in bridge pier beams and pillars, and the subject of research has been focused on the view of change in the structural performance rather than deformation due to ASR deterioration. The primary objective is the evaluation of structural performance, and structural analysis which considers the degradation of material properties due to ASR deterioration is being carried out[17)]. Though these analyses do not directly model the phenomenon of ASR, they can give for a partial understanding in the evaluation of the safety of ASR deteriorated structures, giving us a certain amount of knowledge. However, evaluating changes in structural performance along the time axis is difficult quantitatively by these manner. In recent years, analysis considering the time axis is also being carried out, for example, the analysis considering the influence of ASR expansion[18], and the analysis considering the effect of gel formation caused by ASR[19].

3.2 Round Robin Analysis on the Performance Evaluation of ASR Deteriorated Members

In the performance evaluation WG, we conducted a round robin analysis targeting ASR deteriorated members by using various analytical codes, understanding the analysis level in the current analysis, and discussed important point in the analysis issues.

(1) Analytical Codes

Different codes were used for round robin analysis (two commercial software and two independent developed codes). All of them are three-dimensional finite element analyses. Characteristics of the analytical codes are shown in Table 2. There are differences in ASR modeling for each analytical method, and a characteristic model is especially used in independent development programs.

Table 2 – Analytical Code Features

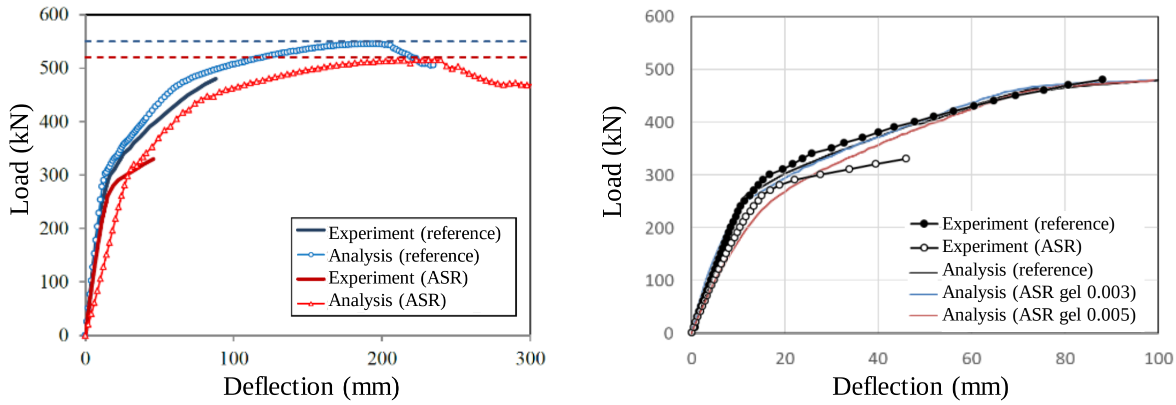
		Analysis Method A	Analysis Method B	Analysis Method C	Analysis Method D
Basic Info	Analysis Code	Midas FEA	DIANA	Independent Development	Independent Development
	Concrete Composition Rule	Total Strain Crack Model	Total Strain Crack Model	Lattice Equivalent COntinuum Model[19]	Elasto-plastic Fracture Model[20]
	Rebar	Discrete Element	Embedded Steel Reinforcement Element	Discrete Element	Definition by RC Element
ASR Modelization	ASR Expansion	Considered as Thermal Strain	Not Considered For PC Structure, Considered as PC Steel Stress	Expansion Prediction Model based on Damage Theory[21]	Model Based on Biot's Solid-Liquid Two-Phase Model[18]
	Material Deterioration	Not Considered	Considered Based on the Core Materials Test (Consider the Surface and Interior Separately)	Considering Principal Axis Independence from the Deterioration Degree in the Expansion strain	Considerations for Cracking due to Expansion Pressure
	Other Features	–	–	The Initial Stress and Strain Occurring in the Concrete and Rebar, considering the ASR Expansion	Changes in Crack Width and Tensile Softening Coefficient Related to Shear Transmission by ASR Gel Occupancy Ratio During Cracking

(2) Analytical Target

In the analysis, Prestressed Concrete (PC) beams, which can be regarded as a uniaxial stress field, and RC walls, which are planar stress fields, are targeted. For PC beams, an ASR deteriorated PC hollow girder[20] that is actually used was selected. Although there is no information ASR expansion of the PC girder, information such as crack pattern and core strength has been obtained. For the RC walls, an experiment of ASR deteriorated shear walls[21] were selected. In the experiment, the ASR acceleration test was conducted, and information such as the free expansion strain and dynamic characterizes after ASR deterioration was obtained.

(3) Important Points of Performance Evaluation of ASR Deteriorated Structures

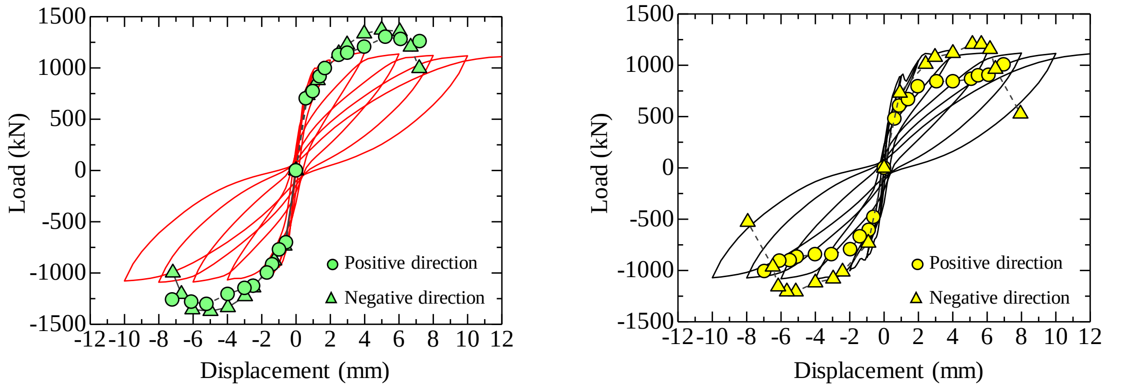
An example of the analytical results is shown in Figures 3 and 4. The details of the analyses are omitted in this report, however, it was shown that the changes of structural behavior of ASR deteriorated member could be evaluated to some extent using either analytical code if considering the ASR effects properly. In other words, any analytical code can predict the performance of ASR deteriorated structures by properly considering of the deterioration state. Of course, how to understand the ASR deterioration state, and how to incorporate it into the analysis varies depending on the individual analytical code. Sufficient consideration is needed and its difficulties depend on the analytical codes. In particular, the anisotropy of ASR deterioration, the decrease in strength, elastic modulus, etc. are often associated with the expansion strain in the analysis. In the experiment, it is possible to obtain the expansion history from the initial stage of ASR deterioration, however, in the actual structure, since the past expansion history in unknown, it is quite difficult to know the deteriorated state. As one solution, there exists a means of estimating the deteriorated state, for example, from the core strength and the crack density. Further discussion is needed regarding how to incorporate such information into the analysis.



(a) Load-deflection relationshipsults, Code B

(b) Load-deflection relationshipsults,Code D

Figure 3 – Analytical Results of PC Beam by Code B and D



(a) Load-displacement relationships, Reference

(b) Load-displacement relationships, ASR

Figure 4 – Analytical Results of the RC Wall by Code C

3.3 Corporation Between Analysis and Monitoring

As mentioned above, in evaluation the performance of real structures, an appropriate understanding of the current state of the structure is important. On the other hand, predicting the deterioration state is necessary in order to predict the future performance of the ASR deteriorated structure. In understanding the current state, monitoring data that will be mentioned in Section 4 might be useful and in prediction of the deterioration, utilization of expansion prediction by CPT as mentioned in Section 2 might be efficient. Thorough discussion on the appropriate method is necessary.

A Corporation between numerical analysis and monitoring is desirable in the maintenance and management of concrete structures. Comparing past predictions and actual behaviors, it is possible to confirm the validity of the analysis method, and to modify the analysis parameters such as inverse analysis. By this manner, it will be possible to estimate the progress of expansion and deterioration over the future even by using the current numerical analytical method. By properly incorporating the monitoring information into the analysis, simulation with high validity will be possible such as data assimilation[22)]. On the other hands, if the preliminary analysis makes it possible to judge the characteristics of expansion behavior and areas that will become critical, it will be possible to propose the measurement positions and items. Of course, necessity of monitoring or numerical analysis would depend on the importance of the structure and the risk of expansion. There are various countermeasures for ASR, numerical analysis for performance evaluation is preferred to become one of them.

4. State of Existing ASR Deterioration Structures Maintenance Management Scenario

4.1 Activity Policy Towards the Maintenance Management Scenario

For the maintenance management for ASR deteriorated structures, the deterioration mechanism is complicated and unclear points remain, and at present a countermeasure method has not been established. Meanwhile, at academic associations and structural manager organizations, many reports, maintenance management policies, manuals, etc. have been put together, and the countermeasures for the deterioration situation, repair/reinforcement, and the maintenance management method, are gradually improving. WG2 discussed the methodology for the introduction of performance type maintenance management that targets ASR. As a result, we concluded that to grasp the ASR expansion and its prediction of the target structure and set the scenario based on these are important. Therefore, it was decided to arrange the actual situation of the utilization of monitoring and knowledge of countermeasures to know the expansion behavior, and to propose maintenance management scenarios to solve technical problems. The term monitoring as used here includes not only changes in length, such as expansion rate, but also increases and progressions of cracks, and an understanding of environmental conditions.

Until now, at JCI, the two committees of “Suppression of Alkali Aggregate Reaction Considering Action Mechanism Measures and Diagnosis Research Committee” and “ASR Diagnosis Current Status and Ideal Situation Research Committee” have been implementing activities for the resolution of the current status of maintenance management and diagnosis, and their issues. Here, diagnosis methods of general and advanced levels have been presented, and the latest methodologies on identifying the cause in ASR diagnosis is shown. However, in actual maintenance management, many problems remain in the understanding of ASR expansion and its progression, as well as implementing countermeasures. In order to solve the current problems in maintenance management such as these, we gathered information of maintenance management methods from the main methods of overseas agencies such as FHWA (US Federal Highway Administration), IFSSTAR (French Central Laboratory of Roads and Bridges), as well as domestic highway and road management departments. Additionally, we conducted hearing surveys on the current state of maintenance management of the Hanshin expressway and the Nagoya expressway with the cooperation of both respective managers.

4.2 Comparison of Domestic and International Maintenance Management Methods

(1) Case of the Hanshin Expressway

Figure 5 shows the outline of the ASR pier maintenance management manual[23)] for the Hanshin Expressway, with in-house engineers with extensive knowledge of ASR. For items that have reached a certain level of cracking status (S, A rank) from daily, regular, and temporary inspections, we will decide whether or not it is ASR mainly from the crack extension. After that, based on the judgment of the countermeasure grade from the appearance deterioration degree, a detailed investigation, countermeasures, monitoring, and a tracking inspection will be carried out. We will accumulate experience on ASR crack growth up to now, and evaluate ASR and countermeasure level judgments, and difficult ASR evaluations, based on experience and through clear judgment criteria. On the other hand, when the general manager will respond to ASR, judging whether or not it is ASR is not easy, and we can guess that in reality, other deterioration may be mixed in. Also, regarding the countermeasure level, when there is no back data on what kind of expansion progress exists, currently there is no way to predict the future expansion behavior for structures with a high degree of accuracy.

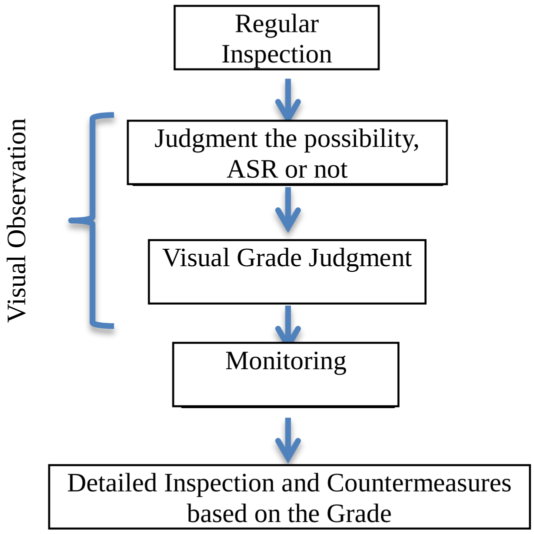


Figure 5 – Maintenance Management Flow at the Hanshin Expressway

On the Hanshin Expressway, the results of follow-up inspection regarding expansion, and the monitoring experience after countermeasures[24), 25)] have been reported. Among these, understanding for expansion progression and crack growth progress, and the local expansion leading to reinforcement bar rupture have been carried out, and this back data makes the judgment of maintenance management judgment explicit. Furthermore, regarding ASR bridge piers where repair and reinforcement have been carried out, monitoring should be considered, and in principle follow-up surveys will be carried out for deterioration grade 1 (grade with the least amount of deterioration). Under these concepts, we can consider that 1) the progress of the expansion of ASR is difficult to predict, and 2) the follow-up to repair/reinforcement measures is essential. Additionally, even for the Hanshin Expressway, a management agency with a lot of back data, we are confirming by interviews that an understanding of the expansion as a structure is essential.

(2) Comparison with the IFSSTAR, FHWA Maintenance Management Methods

A comparison of maintenance management methods is shown in Figure 6. In japan, ASR judgment is performed when the possibility of ASR is suspected from the regular inspection, primarily based on periodic visual observation. However, when there is not a lot of back data, a detailed inspection is carried out, and in many cases a comprehensive evaluation, including ASR judgment, is carried out. Afterwards, it becomes a flow of countermeasure selection and implementation.

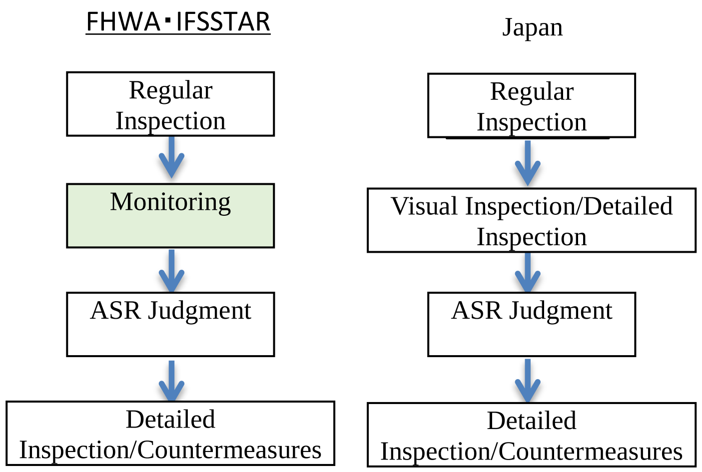


Figure 6 – Comparison of Maintenance Management Methods

At IFSSTAR[26)] and FHWA[27)], they also utilize the flow of regular inspection, ASR judgment, judgment of the necessity of detailed inspection and level, detailed inspection, and countermeasure selection. However, a characteristic is that in the initial judgment stage, a procedure is included to understand the expansion tendency through somewhat long-term monitoring. At FHWA, expansion measuring is performed for 2-3 years at a minimum, and at IFSSTAR it's performed for a minimum of 1 year, and performing maintenance management upon ascertaining the expansion rate is a basic principle. Also, they are prepared to perform crack width measurement for understanding the current expansion rate for any period. Details of this monitoring method were introduced in the committee report. For actual crack width measurement, issues with accuracy and work time such as differences depending on the crack status, such as precipitates, items with large crack width dynamics, or personal errors, have been pointed out in the discussion. In FHWA, in addition to the crack width, several methods for understanding the expansion of the current state are shown. However, this is not definitive, and it can be said that this method is still in the trial and error stage.

As shown in section 2, knowing the expansion and its rate at the present point is an important factor in understanding the performance by analysis. In regards to the technology for obtaining the expansion, although this is an issue for the future, comprehensive feedback with the ASR expansion analysis can be obtained by first understanding the temporal changes, such as monitoring, or the change state (cracked state), and will lead to ASR maintenance management based on structural performance, and expansion control due to future ASR expansion. In that sense, monitoring to appropriately understand the expansion behavior is essential.

4.3 Verifying Countermeasures and Monitoring Method

WG 2 conducted a literature survey on the current situation of ASR measures. Changes in countermeasures are shown in Figure 7. At the initial stage of the ASR early deterioration problem, emphasis was placed on shutting off the water supply, which is the cause of the ASR expansion, and surface protection work with crack compliance was implemented as the primary countermeasure. However, after ten to fifteen years have elapsed, cases where re-transformation occurred due to swelling after countermeasure were also reported, and the application of a silane/siloxane-based impregnate, which is a surface treatment of a water-repellant system capable of dissipating moisture, or a combined use with a moisture permeable polymer cement system, is carried out. Meanwhile, countermeasures are also being taken by the surface coating of an elastomeric rubber system with a high elongation ability in order to prevent re-changes. After the effects of countermeasures by the surface protection work, there are significant differences depending on the part dimensions, the water supply conditions, the expansion margin at the time of countermeasure, etc. However, the implementation of tracking surveillance and monitoring are not numerous, so it cannot be said that the verification has been done sufficiently. Also, besides the coating system surface protection, FRP sheet and cross section restoration may be applied for the purpose of preventing peeling, etc., but there are few cases of pursuit. For any countermeasures, aside from the countermeasure locations, re-expansion is a problem - for example, the moisture that remains in the part when the moisture supplied from the back and the part thickness is large. However, it is difficult to fully grasp these situations, and here again, the importance of monitoring to verify the effect of the measures was suggested.

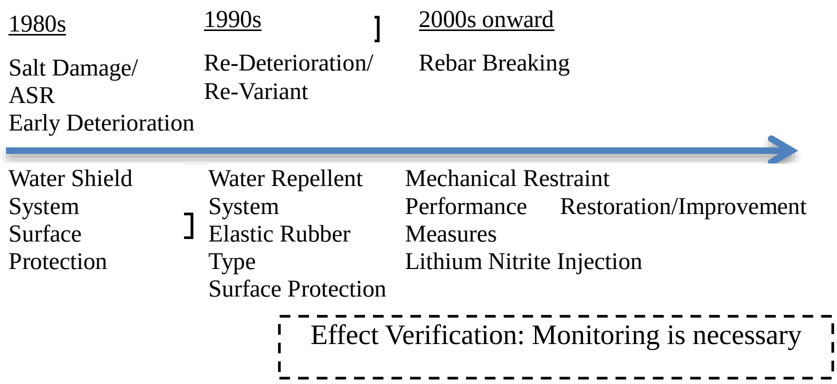


Figure 7 – Countermeasure Method Transitions

Meanwhile, since the 2000s, reports on rebar breaking have led to concerns about the influence on structural performance. For this reason, reinforcement measures, including improvement of structural performance such as measures by mechanical restraint (prestress introduction, steel material restraint, restraint by FRP seat, etc.), or earthquake resistance measures, have been implemented. Additionally, methods such as a lithium pressuring impregnation method that's intended to stop the ASR reaction itself have also been developed. According to the report of the subcommittee of the Japan Society of Civil Engineers, the idea of classifying the countermeasure scenario into two was presented depending on whether or not there was a necessity to respond to the reinforcement rupture.

Unlike traditional repair concepts, monitoring and other measures are being carried out on mechanical constraints or countermeasures for improving structural performance, and verification of these measures is currently continuing. However, since standard methods for understanding these expansion behaviors have not been established, it's still in the trial and error stage. WG 2 gathers information on current monitoring technologies (equipment and methods) regardless of whether it's domestic or from overseas, and compiles the results and methods of monitoring them in a report.

4.4 Maintenance Management Scenario Proposal for Existing ASR Deterioration Structures

(1) Preconditions

The maintenance scenario shown here is based on a management system in which there is little or no accumulation of back data on ASR, and no in-house technician with ASR experience, for the maintenance management of existing structures. Additionally, based on the bridge periodic inspection procedure[28], it is assumed that periodic inspections will be carried out by close visual inspection once every five years. Under these conditions, from the inspection results of WG2, conducting petrological and promotion tests that are shown to be effective is not always realistic, and it is inevitable that understanding the status and progression of expansion through the structure and parts will be central to maintenance management.

(2) Maintenance Management Scenario Proposal

Figure 8 shows the outline of the maintenance management scenario proposed by the committee. The feature is, if ASR is suspected, to understand the progress of expansion of ASR by detailed inspection and monitoring, and implement follow-up monitoring after countermeasures.

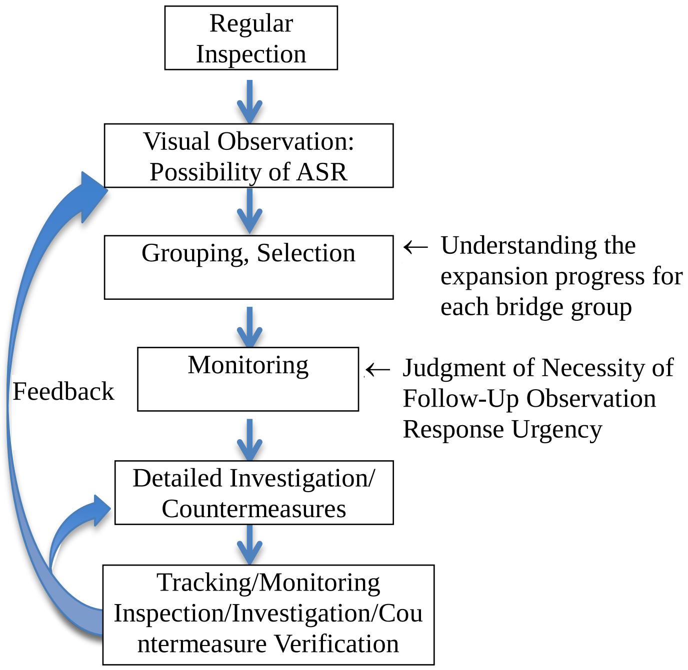


Figure 8 – Maintenance Management Scenario (Committee Proposal)

For regular inspections (daily/periodic inspections), for example in a bridge, since it is implemented based on the bridge inspection procedures, at this stage the variations of cracks, etc. is recorded. When ASR characteristics are confirmed in these variations, or the deterioration mechanisms cannot be confirmed as ASR but the variations are recognized as progressive, grouping is performed as something that’s required for ASR judgment. Because there is a high possibility that ASR will occur in similar structures in the surrounding area, a documentation inspection (documentation) will be carried on commonality and characteristics of the construction year, occurrence parts and structures, materials (in particular, formulation and aggregate), and the environment. Representative items that are in the same state will be extracted (selected). Although monitoring is costly, due to representative extraction such as this, the monitoring data can be utilized for the target structure group. Additionally, when an emergency response such as the prevention of peeling off is necessary, consideration for the countermeasure is necessary, and judgment regarding whether follow-up observation is possible will be made in advance.

At the areas selected for monitoring, monitoring will be performed every 2-3 years to ascertain whether or not expansion has progressed, and if there is progression, to understand the speed of the progression. If possible, environmental conditions (temperature, moisture supply) will also be monitored at the same location. After confirming the progress of expansion, based on these the necessity of a detailed inspection and countermeasures, and the selection of countermeasures will be performed. If countermeasures will be implemented, as a basic principle monitoring will be performed to verify the effects. Even when monitoring is impossible, it is desirable to perform a follow-up inspection in a way to allow the understanding of the expansion progression.

5. Scenario on Link between Design and Maintenance Oriented to ASR Controlling

5.1 Structure Severity Level and Risk Level Evaluation

Table 3 shows the severity level considering the degree of influence when ASR occurs according to the importance of the structure as proposed by the "Research Committee on Current Status of ASR Diagnosis and the Ideal Situation "[1)] and the required performance, etc. Level S4 is a structure that requires a high performance for a very long service period, so that ASR must be strictly suppressed. In contrast, Level S1 is a structure where even if ASR occurs there's very little influence on performance, and easy maintenance such as exchanging the deteriorated members can be performed as necessary.

Table 3 – Structure Severity Level[1)]

Level	ASR Acceptance	Structural Influence	Category
S1	Some deterioration due to ASR is acceptable	The ASR effect on the performance, economy, and environment of the structure is small or negligible	The material can be exchanged relatively easily (ex: <30 years)
S2	Moderate ASR risk is acceptable	If ASR is the primary deterioration, performance, economy and environment of the structure are affected	Can be repaired as needed (ex: 30-100 years)
S3	Small-scale ASR risk is acceptable	Even though the ASR is small, it has a great influence on the performance, economy and environment of the structure	
S4	ASR is unacceptable	Even though the ASR is small, it has a great influence on the performance, economy and environment of the structure	ASR is unacceptable (ex: > 100 years)

For each structure level, evaluate the risk level regarding the occurrence and progression of ASR. Table 4 also shows the risk level evaluation (here, referred to as detailed risk evaluation) as proposed by the " Research Committee on Current Status of ASR Diagnosis and the Ideal Situation". In this evaluation, a petrological test or a concrete prism test for practical concrete mixture must be performed to clarify the presence or absence of "aggregate reactivity" and "pessimum concrete mixture". Namely, it's assumed to be a structure that requires material selection at a high level (costly), which is greatly affected when ASR occurs, and the risk level evaluation in Table 4 is considered to be limited to structures of severity level S4. On the other hand, for S1 to S3 structures, it's often difficult to be that costly from the material selection stage. Here, the preliminary risk level evaluation is shown in Table 5. For S1 to S3 structures, it's considered to be realistic to set the expansion possibility level based first on actual results and experiences (aggregate map), etc. From that result, for S3 structures with high preliminary ASR risk, implementation of the petrology and concrete prism tests for practical concrete mixture will be considered again. From the test results, if the reactivity of the aggregate becomes clear (concrete expansion ability), Table 4 will be applied for a detailed risk level evaluation.

Table 4 – Detailed Risk Level Evaluation[1)]

			Aggregate Reactivity			
			None	Low	Mid	High
					Rapid Expansion (non-pessimum mix)	Rapid Expansion (pessimum mix)
				Delayed Expansion (Metamorphic rock type)	Delayed Expansion (Sedimentary rock type)	
Dry	No alkali supply	Small member	1	1	2	2
	No alkali supply	Mass Concrete	1	2	3	4
Moist	No alkali supply (Contact with fresh water/soil)	Mass Concrete	1	2	4	4
	Alkali supply (Frost damage/sea water/deicing salt)	Mass Concrete	1	3	4	5

Table 5 – Preliminary Risk Level Evaluation

			Expansion Possibility		
			Low	Mid	High
Dry	No alkali supply	Small member	1	1	2
	No alkali supply	Mass Concrete	1	2	3
Moist	No alkali supply (Contact with fresh water/soil)	Mass Concrete	2	3	4
	Alkali supply (Frost damage/sea water/deicing salt)	Mass Concrete	3	4	5

5.2 Design/Maintenance Management Link Scenario Considering ASR

Based on the severity level of the structure, and the risk level evaluation when considering ASR, a scenario on link between the design and maintenance of structures (committee proposal) is shown in Figure 9.

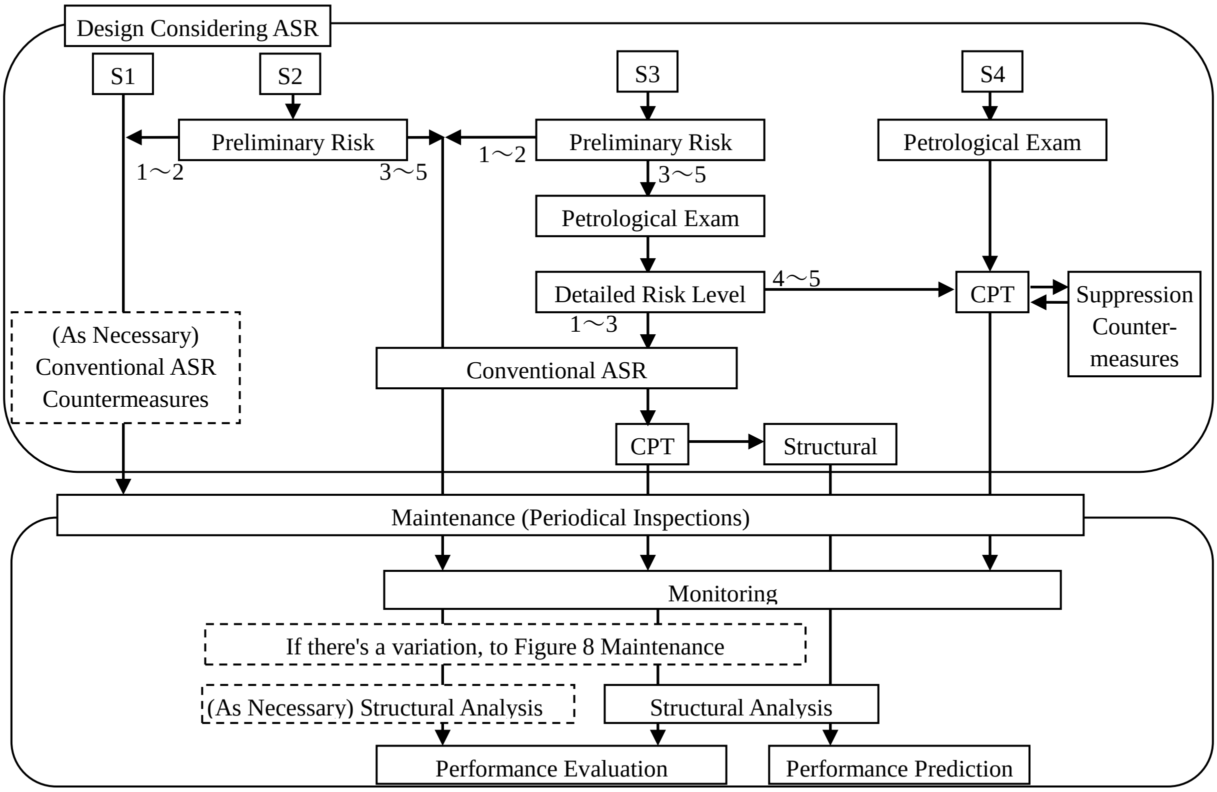


Figure 9 – Proposal Scenario on Link between Design and Maintenance withASR Considerations

(1) Severity Level S4

Regarding structures of severity level S4, for control that does not allow ASR, in other words suppression is required, a petrological test will always be performed. In accordance, an expansion test with the mixture planned to be used will be carried out by CPT, and if necessary, the suppression countermeasures such as the application of admixture will be considered. Also, monitoring at the maintenance stage will be essential, and it’s best to select and implement particularly important members in advance. At this time, if it becomes possible to analyze stress and deformation by assuming expansion by finite element analysis (hereinafter, FEM), it will be useful for selecting the focal point for monitoring.

(2) Severity Level S3

When there is a high outline risk level evaluation at severity level S3, it's best to do a detailed risk level evaluation with a petrological examination, considering the large impact on the structure's performance. If it's determined that the detailed risk level is high, then the design and maintenance will be the same as level S4 structures. On the other hand, if the detailed risk level is low, then we can consider that the conventional ASR countermeasures will be sufficient. However, if the effect on performance is significant upon occurrence, we propose the preparation of CPT with the actual mixture for the use in continued monitoring for maintenance. If the expansion possibility is gained through CPT, if the FEM analysis can be carried out based on the CPT expansion prediction, it will be possible to predict stress, deformation, and structural performance, and we can expect developments in predictive maintenance.

At the maintenance stage, the implementation of monitoring is necessary in order to estimate expansion due to prior CPT, and to verify and correct the FEM analysis result. Through an understanding of environmental conditions such as water supply, it is possible that the advantages of FEM analysis, such as changing the expansion characteristics for each member or part, can be utilized. Also, if a change is confirmed through monitoring, in addition to complying with the maintenance scenario introduced in Figure 8, performance evaluation can be performed through the input of monitoring data into FEM.

(3) Severity Level S2 and S1

If the preliminary risk level evaluation is high at severity level S2, monitoring will be implemented at the maintenance stage in addition to applying the conventional ASR countermeasures. If the variation can be confirmed, respond with the maintenance serious in Figure 8, and perform a performance evaluation by FEM analysis as necessary.

If the preliminary risk level evaluation for severity level S2 is low, or is severity level S1, we can consider the possibility that general maintenance is a sufficient response, together with considerations for conventional ASR countermeasures as necessary.

As described above, the suppression-type design that does not allow for the occurrence of ASR conventionally has been lacking in a link with maintenance, but through the understanding of the risk of ASR occurrence, a design system that plans for maintenance beforehand can be expected. This indicates the possibility that preventative maintenance can be applied to the ASR degradation mechanism that had to be maintenance after deteriorating. However, although specific values for the risk level evaluation are shown, currently quantitative grounds cannot be given to these numerical values. It should be understood that these numerical values are purely a qualitative point of view for the magnitude of the risk level. Also, in order to realize this scenario for design and a maintenance management linked scenario, the continued establishment and reliability improvements for the test and prediction methods in Section 1, the performance evaluation and predictive technology in Section 2, and the realization of maintenance management in Section 3 will be necessary.

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