Committee Report : JCI- TC094A

Technical Committee on Performance Evaluation of High Performance Expansive Concrete and System for Crack Control

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Etsuo SAKAI, Toshiharu KISHI

Abstract

In the recent state of the growing need for crack control, the committee summarized the latest findings on expansive additives, the product of a technology that Japan can be proud of. It proposed and theoretically explained a simple test method for restrained expansive strain using lightweight steel molds as a substitute for the method specified in JIS A 6202. Quantitative methods of evaluating the crack-controlling effect of expansive concrete were then systematically analyzed with their incorporation into architectural and civil engineering standards in mind. Proposals were also made regarding crack control in the architectural and civil engineering fields by referring to the crack control system established and employed in Yamaguchi Prefecture.

Keywords: expansive concrete, crack control, performance evaluation,
simple test method for restrained expansive strain,
crack suppression system

1. Introduction

In 1968, a calcium sulfoalminate-based expansive additive was made available on the market. The world’s first lime-based expansive additives were also developed and have been widely used for actual structures in Japan. The development of low content-type expansive additives promoted their use in construction. Certain data also suggest that the ratio of expansive concrete to total ready-mixed concrete increased fourfold from 0.4% in 1994 to 1.6% in 2006. Also, expansive additives are expected to assume a more important role as a shrinkage-inhibiting material, as awareness of cracking in concrete has been growing since the enforcement of the Housing Quality Assurance Act in 2001, and both JSCE and AIJ (JASS5) established specifications for the shrinkage ratio.

With this as a background, JCI organized the “Technical Committee on the Performance Evaluation of High Performance Expansive Concrete and Crack Control System” chaired by

Table 1: Committee Members

Chairman	Etsuo SAKAI	Tokyo Institute of Technology
Vice Chairman	Toshiharu KISHI	The University of Tokyo
Secretary General	Akira HOSODA	Yokohama National University (WG3 Secretary)
Member	Tae-Ho AHN	The University of Tokyo
	Kei-ichi IMAMOTO	Tokyo University of Science
	Norio IYOTA	Myojo Cement Co. Ltd.
	Tatsuya USUI	Taisei Corporation (till mid FY 2010)
	Hitoshi TAKEDA	Taisei Corporation (from mid FY 2010)
	Doyeon KWAK	Taiheiyo Materials Corporation (WG1 Secretary)
	Tetsushi KANDA	Kajima Corporation (WG3 Convener)
	Junichi KINO	East Japan Railway Company
	Tetsuo KOBAYASHI	Sumitomo Osaka Cement Co.,Ltd.
	Kazuhide SAITO	Takemoto Oil & Fat Co.,Ltd
	Naoyuki SUGIHASHI	Shimizu Corporation
	Hisashi SUGIYAMA	Utsunomiya University
	Kentaro SUHARA	Denki Kagaku Kogyo Kabushiki Kaisha
	Makoto TANIMURA	Taiheiyo Cement Corporation (WG2 Convener)
	Takahiro TAMURA	Tokuyama College of Technology
	Kenichiro NAKARAI	Gunma University
	Nobukazu NITO	DC Co.,Ltd.
	Takafumi NOGUCHI	The University of Tokyo
	Hiroshi HASHIDA	Shimizu Corporation
	Ippei MARUYAMA	Nagoya University (WG2 Secretary)
	Shinichi MARUYAMA	Central Japan Railway Company
	Shingo MIYAZAWA	Ashikaga Institute of Technology
	Minoru MORIOKA	Denki Kagaku Kogyo Kabushiki Kaisha (WG1Convener)
	Yasuaki ISHIKAWA	Meijo University
	Masashi OOSAKI	Ube Industries, Ltd.
Cooperate Member	Hidetoshi KURAUCHI	Taiheiyo Consultant Co., Ltd.
	Haruki MOMOSE	Kajima Corporation
	Yuji MITANI	Taiheiyo Cement Corporation
Communication Member	Akihiro HORI	Denki Kagaku Kogyo Kabushiki Kaisha

Prof. Etsuo Sakai of Tokyo Institute of Technology in 2009. Its activities lasted two years with three working groups: WG1 for material performance, WG2 for methods of evaluating crack-suppressing effect, and WG3 for crack control systems. Major achievements of this committee include the establishment of a simple test method for an expansion coefficient and the formulation and review of quantitative evaluation techniques for crack-suppressing effect in architectural and civil engineering fields with their incorporation into the standards in mind. A proposal for a future crack control system is also included, referring to a pioneering system used in Yamaguchi Prefecture. A briefing is scheduled for September 2011 on the details of the activities of the committee.

Note that, in 2003, JCI published a report by the Technical Committee on Expansive Concrete for High Performance Durable Structures chaired by Prof. Yukikazu Tsuji of Gunma University. The achievements of the present committee summarize the progress of technology in this area since 2003.

2. Investigation by WG1 for material performance

The activities of WG1 primarily centered on the following three subjects:

(1) Clarify the conditions and scope of application for expansive concrete

(2) Propose a simple technique of quality control for expansive concrete

(3) Investigate the JIS requirements for expansive additives

Subject (1) was selected to ensure the performance of expansive concrete. Demarcation of the conditions and scope of application was also deemed vital from the aspect of risk assessment. These activities were primarily carried out by literature search. Since a similar literature search was summarized in 2003 at the time of the committee report/symposium for the first stage[1)], documents published after 2003 were investigated and inventoried.

Factors affecting the performance of expansive concrete include the water-binder ratio (W/B), cement type, temperature dependence, expansive additive content, member thickness, and cement content. The latest findings regarding each of these factors were summarized in the report. One such example of recent findings regarding the effect of W/B is described as follows: It was formerly pointed out that, when the W/B is 30% or less, the expansive additive partially remains unreacted, sustaining expansion for a long time to cause delayed expansion[2)]. However, Guo et al. reported that, with a low W/B, the use of an expansive additive having a higher fineness is effective in accelerating its hydration, thereby eliminating the unreacted part of the additive[3)].

In regard to the proposal for a quality control technique for expansive additives (Subject (2)), simple measurement techniques were explored to find a substitute for JIS A 6202, the currently established quality control method. A simple measurement technique is necessary because measuring equipment specified in JIS A 6202 is not available at many ready-mixed concrete plants and the environment in such plants is not sufficiently suitable for the specified measurement method. Measurement samples are currently sent to the manufacturers of expansive additives to be tested at a limited number of testing institutions. In order to meet the growing demand for expansive concrete, it is a pressing need to investigate a measuring method that allows evaluation anywhere by anyone.

Moreover, JIS A 6202 requires that the datum length bar be measured under thermo-hygrostatic conditions and specimens be brought back for re-measurement under thermo-hygrostatic conditions. Measurement cannot be made in-situ. The purpose of using expansive concrete is not to make concrete expand but to control cracking. It is therefore important to grasp the behavior of expansive concrete in the environment in situ, in order to carry out quality control for controlling the cracking of concrete structures on site.

For subject (3), problems of the current standards were investigated. The committee expressed particular concern about the fact that ignition loss is recognized as an index to the degree of weathering of an expansive additive and the organic components of a hydration heat-suppressing-type expansive additive are measured as part of ignition loss. Additionally, the committee proposed measurement conditions for ignition loss that enable appropriate measurement of the degree of weathering of a hydration heat-suppressing-type expansive additive containing organic components.

This paper outlines subject (2), a proposal for a simple method of quality control for expansive concrete, in the following section:

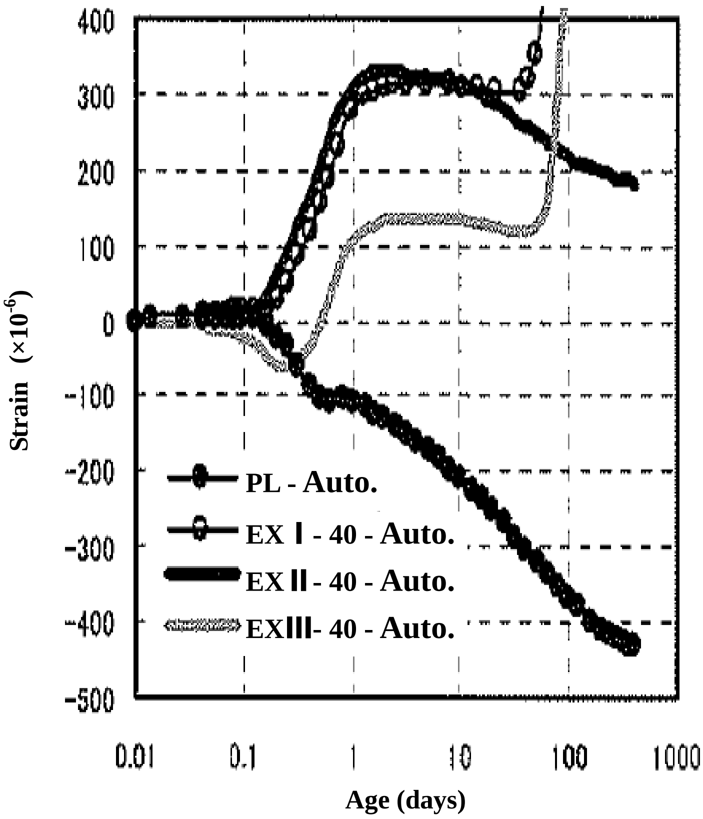

Fig. 1: Autogenous dimension changes of ultrahigh strength concrete containing various expansive additives[3)]

2.1 Proposal for a simple method of quality control for expansive concrete

Tsujino et al. proposed a simple method of restrained expansion testing using lightweight steel molds that are used for measuring compressive strength[4)]. This is a method in which a strain gauge is glued in the circumferential direction at mid-depth of a lightweight steel mold to measure the strain of the mold under expansive pressure from the inside. **Figures 2** and **3** show the measurement setup and typical measurement results, respectively. The expansive strain is found to increase as the expansive additive content increases, with the tendencies being similar regardless of the W/B.

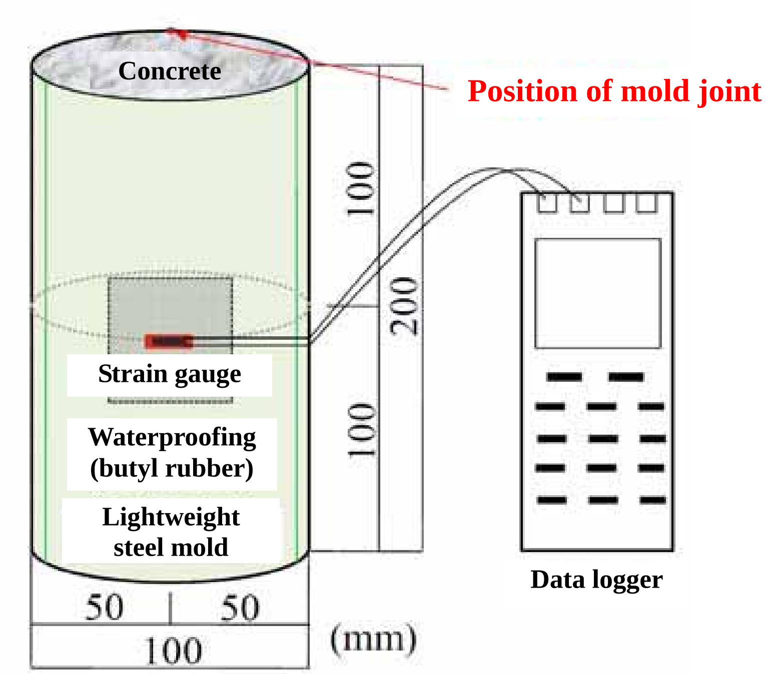

Fig. 2: Outline of simple test [4)]

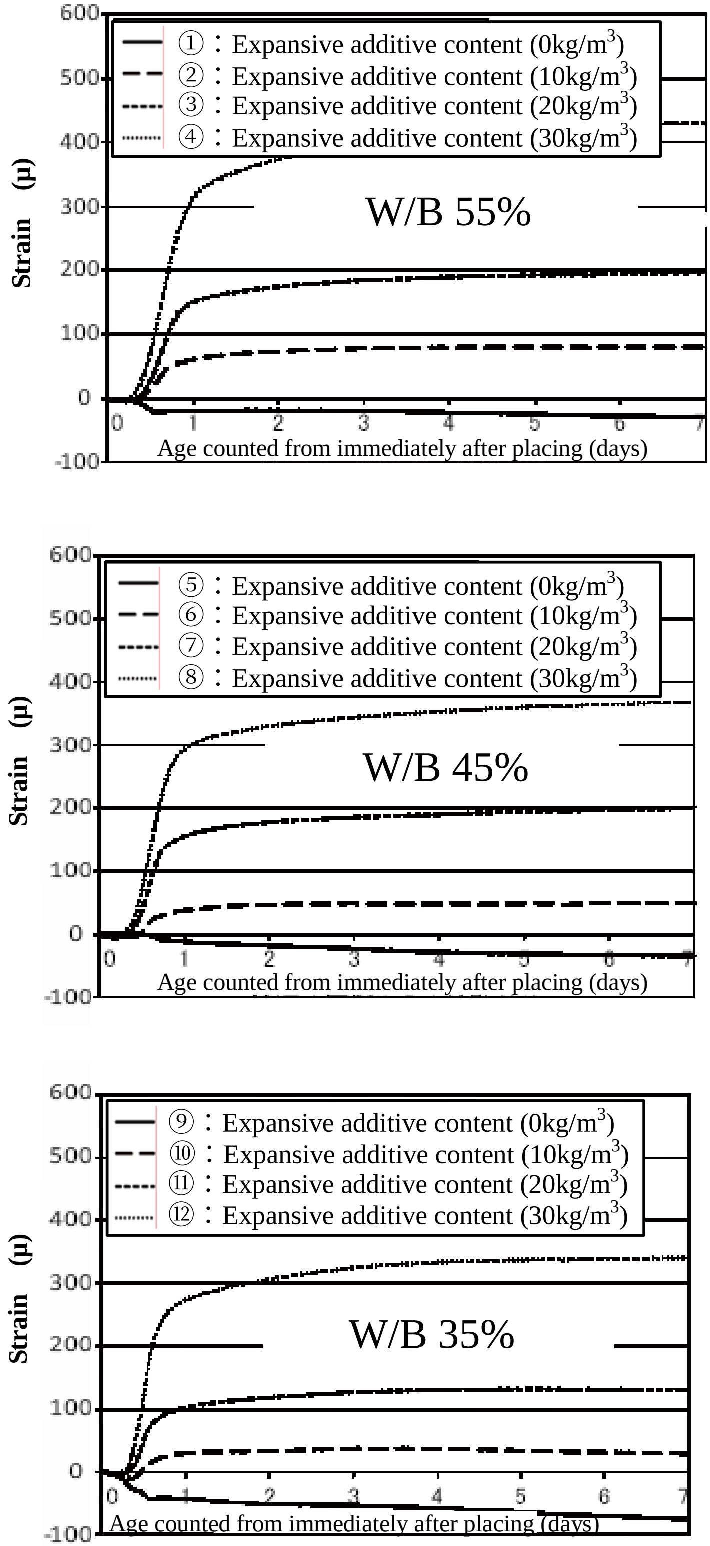

Fig. 3: Typical expansion behavior by simple test method

2.2 Verification of the validity of the simple measurement method

Tsujino et al. advocate that the method of measuring expansion using lightweight steel molds can be treated as a thin-wall hollow cylinder model subjected to internal expansive pressure[5)] and investigated the validity of the simple measurement method based on this model. **Figure 4** outlines the thin-wall hollow cylinder model. Circumferential and axial components can be expressed by Eqs. (1) and (2), respectively. Note that the internal expansive pressure can be determined from the strain generated in the lightweight steel mold by using the thin-wall hollow cylinder model.

Figure 5 shows the relationship between the stresses determined by JIS A 6202 and the simple test method. The stress generated by uniaxial restraint expansion testing specified by JIS A 6202 and the present simple testing can be expressed by linear functions regardless of the expansive additive content.

Circumferential

$$\left.\begin{aligned} 2ht\sigma_\theta &= 2Rhp_\theta \\ \sigma_\theta &= \frac{p_\theta R}{t} \\ \varepsilon_\theta &= 1/E_s\ (\sigma_\theta - \nu\sigma_z) \end{aligned}\right\} \quad (1)$$

Axial

$$\left.\begin{aligned} 2\pi Rt\sigma_z &= \pi R^2 p_z \\ \sigma_z &= \frac{p_z R}{2t} \\ \varepsilon_z &= 1/E_s\ (\sigma_z - \nu\sigma_\theta) \end{aligned}\right\} \quad (2)$$

σ_θ : Circumferential stress
ε_θ : Circumferential strain
σ_z : Axial stress
ε_z : Axial strain
E_s : Young's modulus of steel wall: 2.1×10^5 (N/mm^2)
ν : Poisson's ratio of steel wall: 0.3
p_θ : Circumferential pressure (N/mm^2)
p_z : Axial pressure (N/mm^2)
R : Mold radius: 50 (mm)
t : Wall thickness: 0.28 (mm)

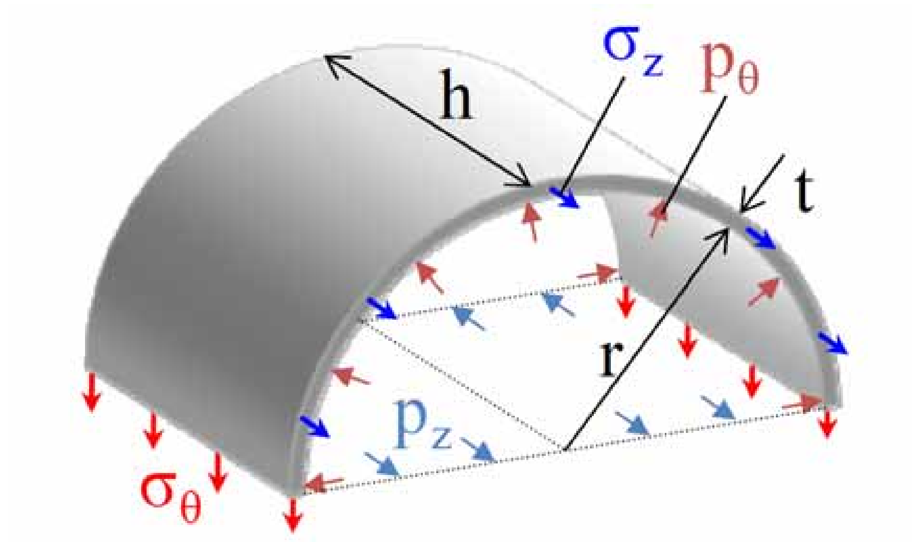

Fig. 4: Outline of thin-wall hollow cylinder model

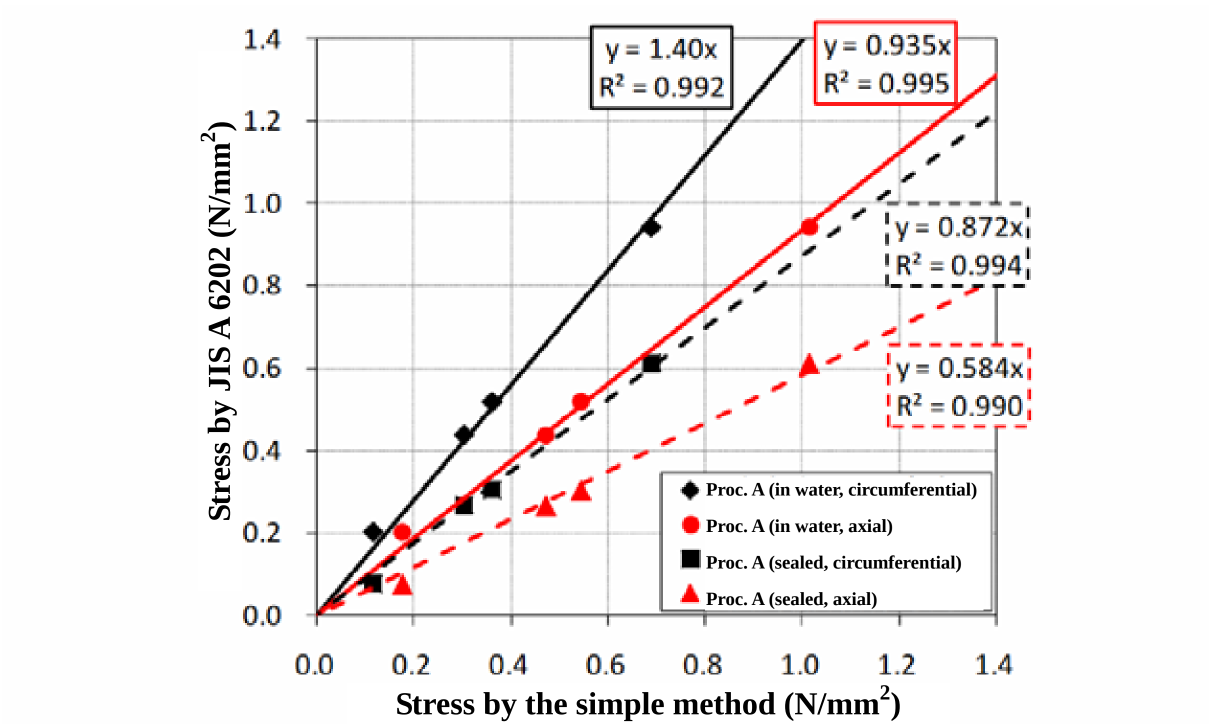

Fig. 5: Relationship between stresses by JIS A 6202 and the simple method

2.3 Comparison between JIS A6206 and the present simple method

For comparison between conventional JIS A 6202 and the present simple method, WG1 conducted a round-robin test at five testing institutions. Two types of expansive additives were used, while the institutions used cement and aggregate available at each institution. The W/B was fixed at 50%, and the same chemical admixture (air-entraining and high-range water-reducing admixture) was used at all institutions.

Figure 6 shows the relationship between the strains measured by JIS A 6202 and the proposed simple method. The ratio of measurements by both methods is nearly 1:1, suggesting that the proposed method is capable of substituting the method of JIS A 6202.

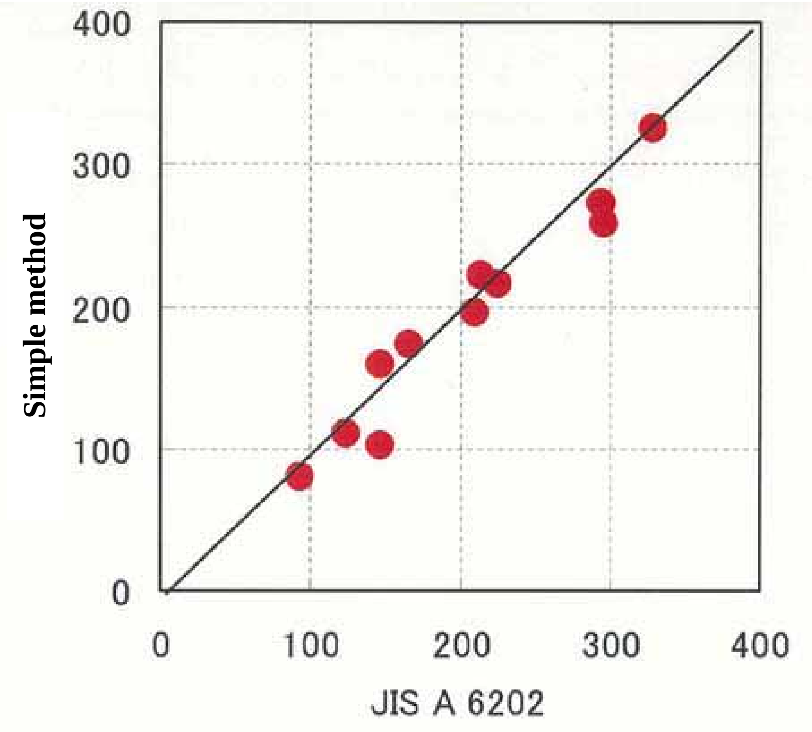

Fig. 6: Comparison between measurements by JIS A 6202 and the simple method

3. Achievements of WG2 for method of evaluating crack-suppressing effect

WG2 carried out studies with the aim of contributing to enhancement and generalization of methods of evaluating the performance of expansive concrete on the member and structure levels. The WG's main subjects are listed as follows:

- Definition of restrained expansive strain ($\geq 150 \times 10^{-6}$)
- Method of evaluating stress related to the early cracking problem
- Method of evaluating member utility performance such as flexural crack width
- Treatment of the expansive effect corresponding to standardization of shrinkage
- Method of evaluating concrete factory products
- Examples of performance verification on the actual structure level

Also, ACI standard related to shrinkage-compensating concrete (Guide for the Use of Shrinkage-Compensating Concrete (ACI 223)) was investigated to survey requirements regarding structural design. Case study analysis was conducted as well on concrete structures and building structures to examine the effect of using expansive concrete. Findings from this research are summarized in the following sections:

3.1 Definition of restrained expansive strain

Recommendations published by JSCE and AIJ in the 1970s were surveyed. JSCE recommendations require that the strain be in the range of not reducing the strength even without restraint and that the standard expansive strain of shrinkage-compensating concrete by application testing (the value at an age of 7 days by restrained expansion testing specified in Appendix 2 of JIS A 6202) be 150 to 250 × 10^{-6} [6]. AIJ recommendations require that (1) the limit value of drying shrinkage strain for crack prevention be 500 × 10^{-6}; and (2) the drying shrinkage strain of expansive concrete be not more than 640 × 10^{-6} (that of normal concrete be not more than 800 × 10^{-6}). The difference between (2) and (1) is required to be not less than 150 × 10^{-6} after rounding off (**Fig. 7**)[7]. According to the Recommendations for Shrinkage Crack Control[8], a drying shrinkage-reducing effect of at least 150 × 10^{-6} can be expected by the use of expansive concrete, while ignoring the effect of (2) to be on the safe side.

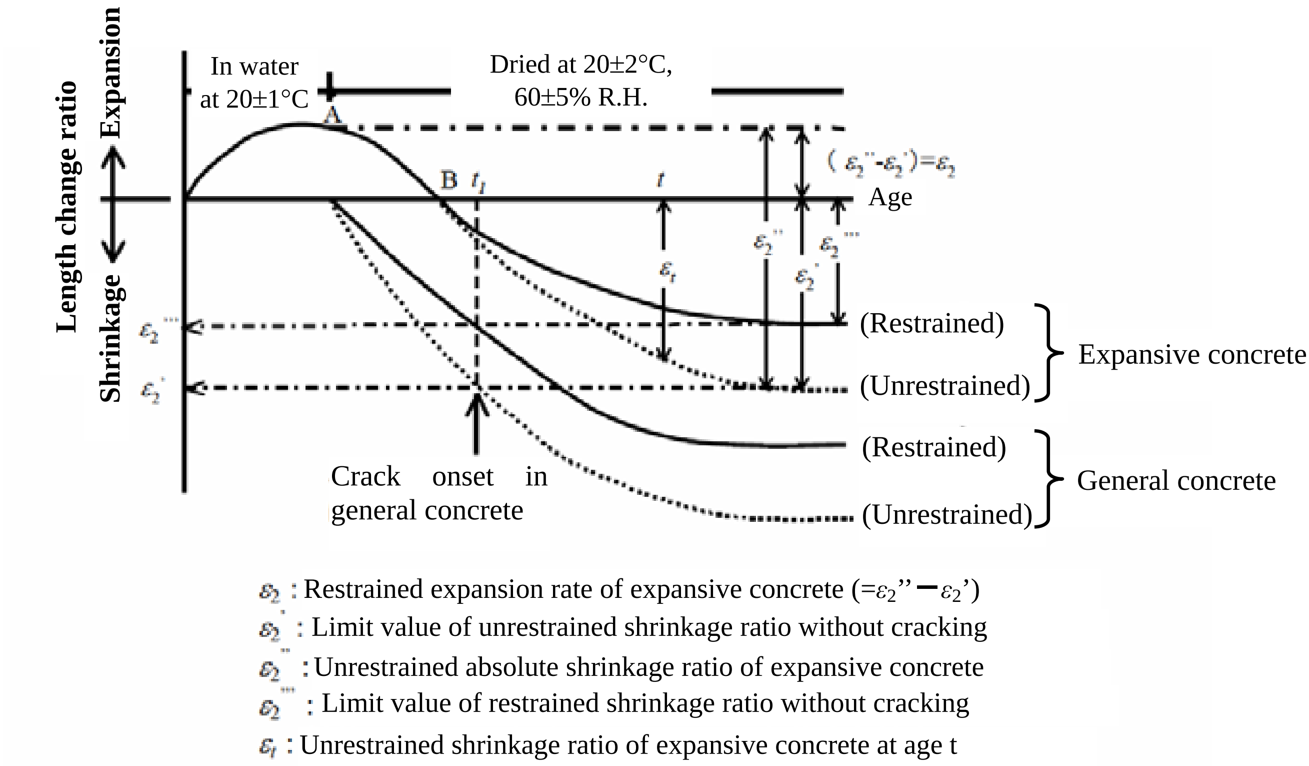

Fig. 7: Restrained expansion/shrinkage property model

3.2 Method of evaluating stress related to early cracking problems

In order to treat the early crack-suppressing effect of expansive concrete in a reasonable manner, it is necessary to precisely predict the stress-strain behavior of members, as the effect varies depending on the structural conditions including the shape and cross-sectional size and environmental conditions including ambient temperature. With the recent progress of analytical technology, analytical methods of quantitatively evaluating the effect of expansive concrete have been developed. “JCI Guidelines for Crack Control of Mass Concrete” (2008) is an example of documents presenting specific methods of analytically evaluating the effect of expansive concrete. Also, JCI Committee on Computer Code Development for Crack Control in Massive Concrete presented a method of calculating expansive strain by the law of constant energy, in contrast to the conventional law of constant work, and incorporated the method in JCMAC3, its temperature stress analysis software. As to analytical techniques, increment-type finite element creep analysis based on the law of linear creep is currently the mainstream.

Meanwhile, the material models of expansive concrete used for analysis are not standardized, as many of the institutions propose their own models. These were therefore surveyed and inventoried. The models were classified into several types in regard to the treatment of expansive strain: those using expansive strain under low restraint with a reinforcement ratio of 0.1%; those in which the expansive strain under no restraint is assumed based on strains with different reinforcement ratios; those in which the expansive strain is varied depending on the expansive restraint pressure; those in which the expansive strain is considered by changing the linear expansion coefficient, etc. Proposed models also include one that is capable of expressing the maximum expansive strain and changes in the rate of strain development according to the temperature distribution and temperature history of members in consideration of the temperature dependence of expansive strain. In regard to the effect of creep, most models incorporate creep by multiplying the elastic modulus by a correction factor (reduction coefficient). The values of correction factors tended to be set at a lower level than those specified in existing recommendations. Another model derives a creep equation for expansive concrete from creep measurement data at early ages.

3.3 Method of evaluating flexural crack width

JSCE adopts a method of explicitly incorporating the flexural crack width-controlling effect of expansive concrete. Its recommendations for design and construction of expansive concrete structures[9)] present an equation for calculating the flexural crack width in reinforced expansive concrete. This equation takes account of the fact that an increase in the steel strain due to an increase in the load from zero to a level greater than the flexural cracking load is reduced nearly by a margin of the applied chemical prestrain. The latest JSCE standard specifications[10] are in line with this concept, expanding the treatment of the effect of autogenous shrinkage in the equation for calculating flexural crack width. For the case of using shrinkage-compensating concrete, these specifications present an evaluation method incorporating steel strain in the phase where the stress of concrete at the reinforcement level changes from compressive to zero (the sum of steel strains corresponding to chemical prestrain and chemical prestress) (**Fig. 8**)[11]. In regard to methods of calculating chemical prestress and prestrain applied to reinforced concrete members, the committee summarized those utilizing the rule of constant work and calculation examples (**Fig. 9**). As to this treatment in the architectural field, the committee examined design equations currently in use and investigated the methodology for explicitly incorporating the effect of expansive concrete. Latest findings regarding the displacement/deformation and shear behavior of expansive concrete were also surveyed, with the methodology of structural performance evaluation being investigated.

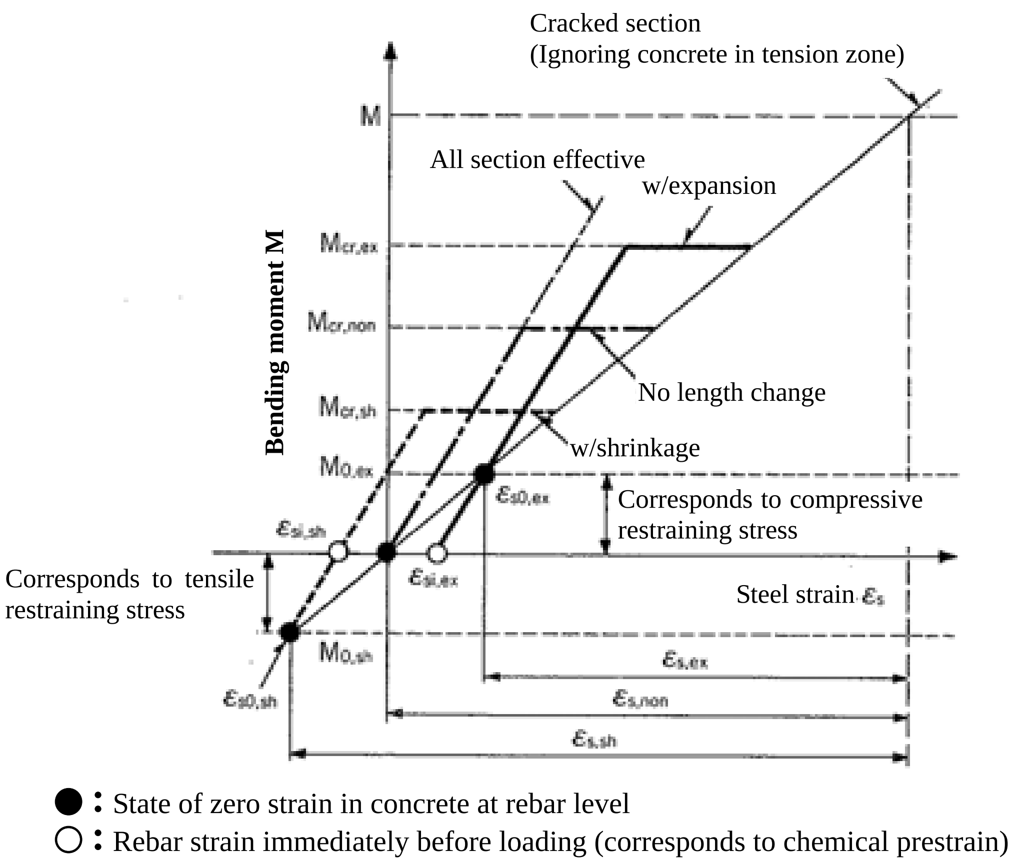

Fig. 8: Effect of shrinkage/expansion on the change in steel strain

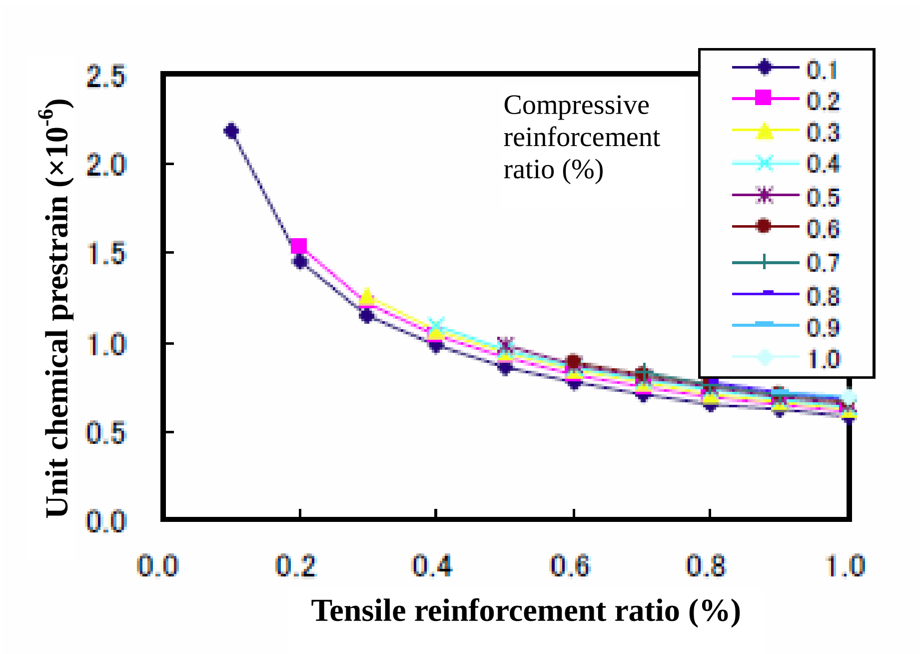

Fig. 9: An example of chemical prestrain calculation

3.4 Treatment of expansive effect to adapt to standardization of shrinkage

Partly because the limit value of drying shrinkage was specified in JASS 5 (the value after drying for 6 months by drying shrinkage testing specified by JIS A 1129), shrinkage and shrinkage cracking control have been attracting attention, with high expectations being placed on expansive additives. Since the test method specified in JIS A 1129 measures shrinkage at an age of 7 days and later, the effect of an expansive additive, which develops earlier, cannot be evaluated by this method. Meanwhile, techniques to convert early expansive stress to the effect of reducing drying shrinkage strain have been investigated in consideration of the restraining conditions of building members. It has been reported that a reduction corresponding to 100 to 150 × 10^{-6} may be expected for general buildings (**Fig. 10**[12)]).

Also, revised Base and Murray's formulae[8)], whereby the number and width of shrinkage cracks are calculated from the concrete shrinkage, reinforcement ratio, and the degree of member restraint, have been used for design practice. WG2 has conducted original restrained cracking tests using the concrete shrinkage and presence/absence of an expansive additive as test factors. If the results are found useful, then the WG will consider the incorporation of the expansive effect in Base and Murray's formulae and include it in the committee report.

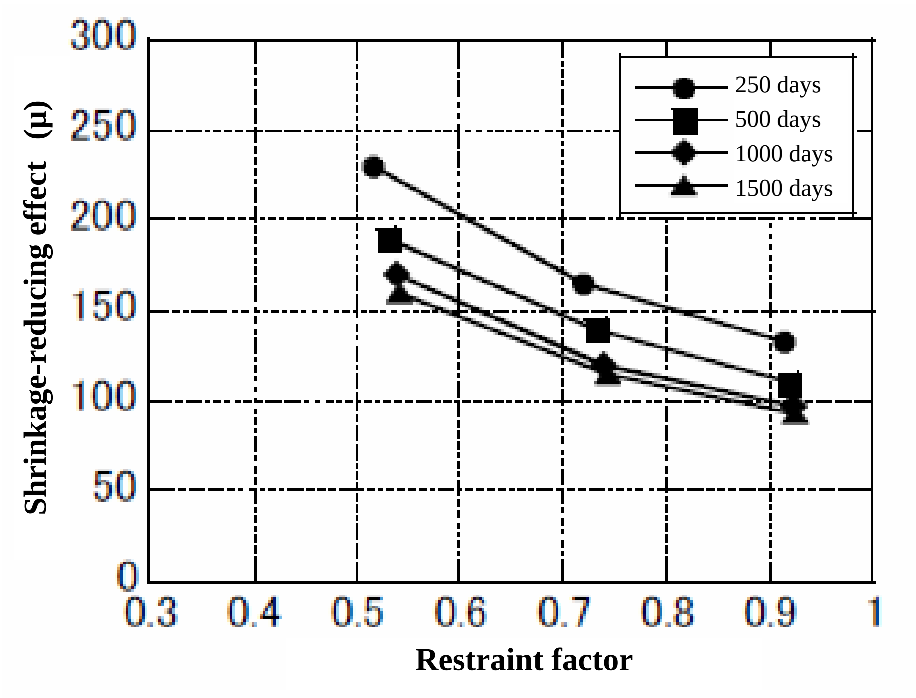

Fig. 10: Example calculation of shrinkage-reducing effect of expansive concrete

3.5 Method of evaluating concrete plant products

Chemical prestressed concrete, which is made by applying compressive forces to concrete to improve the concrete's capacity against cracking, has been in use for concrete plant products including hume pipes, box culverts, and steel-concrete composite pipes. Despite its use for more than 40 years, unified techniques have yet to be established to quantitatively evaluate its effects and feedback the results to design. Recently, however, a technique was proposed to calculate chemical prestress and prestrain in such products as box culverts by combining the assumption of the rule of constant work, cross-section analysis based on a layered model, and matrix frame analysis (**Fig. 11**[13)]). It is expected that this technique will develop as a method of verifying the performance of expansive concrete.

3.6 Verification examples and case studies on the use effect

(1) Examples of performance verification on an actual structure level

Model examples of civil structures to which expansive concrete was applied were summarized partly from an aspect of analysis evaluation. These included a full scale model of a wall placed on footing, a box-girder steel slab model, specimens of concrete placed in lifts simulating a wall, a large-scale prestressed concrete tank, and a massive slab structure.

For building structures, expansive concrete is used primarily to suppress shrinkage cracking at segments prone to cracking, such as those having openings or of complicated

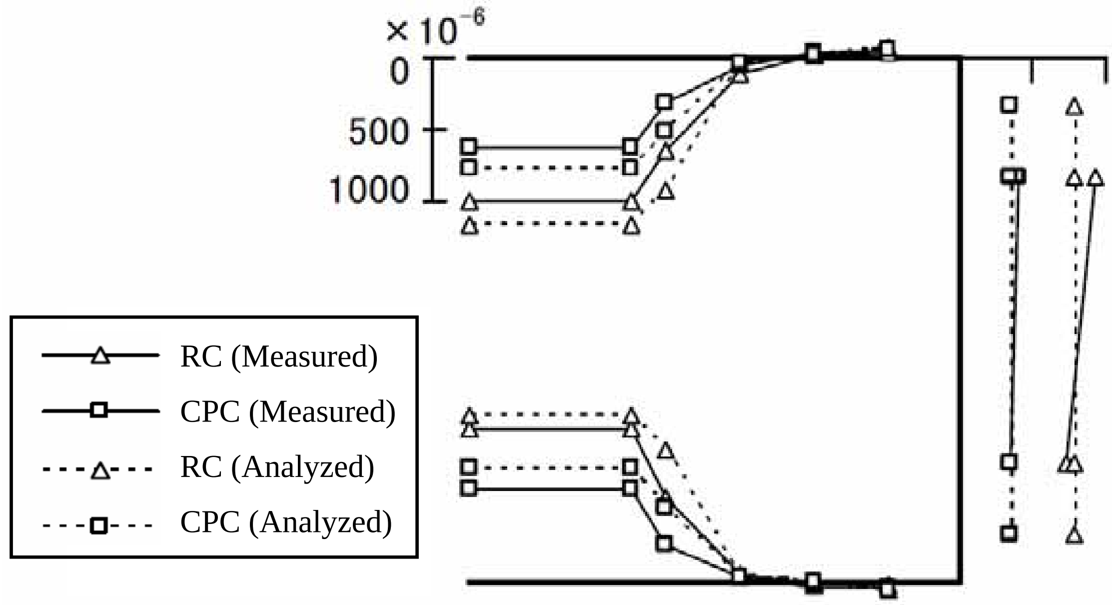

Fig.11: Distribution of tensile reinforcement strain in a box culvert

shapes, as well as where crack-inducing joints are avoided for aesthetic reasons. Application examples to building structures summarized in the report include wall members having small thickness, such as a window back, an exterior wall having irregular openings, and an arch-shaped wall member, and floor members, such as a deck slab and slab on grade. The report also includes the latest findings regarding crack control of reinforced concrete columns made of ultrahigh strength concrete.

(2) Case studies on use effect

The effect of the use of expansive concrete on early crack control was analytically investigated. In an analysis to numerically demonstrate the qualitative tendencies of use effect, wall structure models placed on very general existing slabs were used to compare the thermal crack index of expansive concrete with that of normal concrete. The findings were summarized as shown in **Fig. 12**[14]. These include the following: From the aspect of surface cracking during the phase of temperature rise, the use of expansive concrete could aggravate cracking; and the effect of expansive concrete is evaluated relatively lower as the wall thickness increases, but an effect of a certain level tends to be ensured.

Case studies on building structures focused on expansive concrete wall members placed in multiple lifts to analytically investigate the effects of restraint by adjacent lifts and placing procedure. The findings of these studies include the following: A chemical prestress of around

0.7 N/mm^2 is generated by the preceding lift, which serves as a restraining body; and the apparent chemical prestress increases while the preceding lift is in the expansion phase, but when the following lift expands, the tensile stress of the intermediate lift rapidly increases, causing concern (**Fig. 13**).

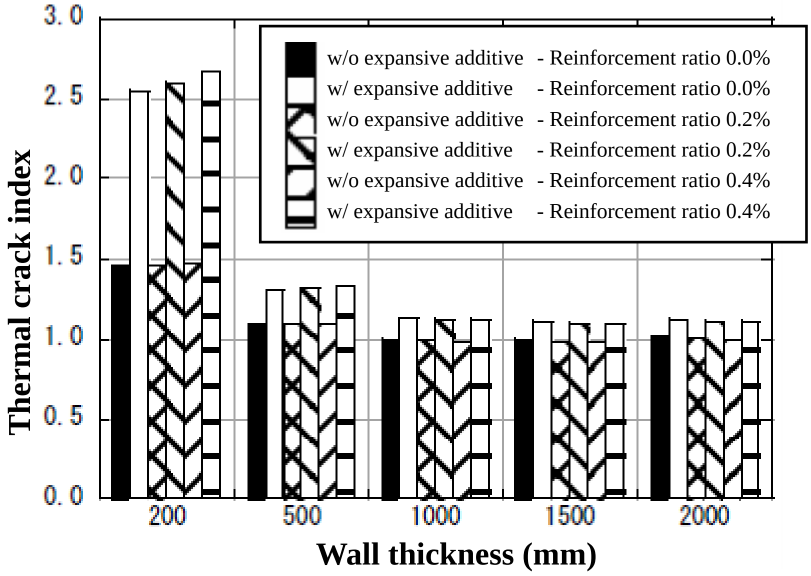

Fig. 12: Comparison of thermal crack indexes

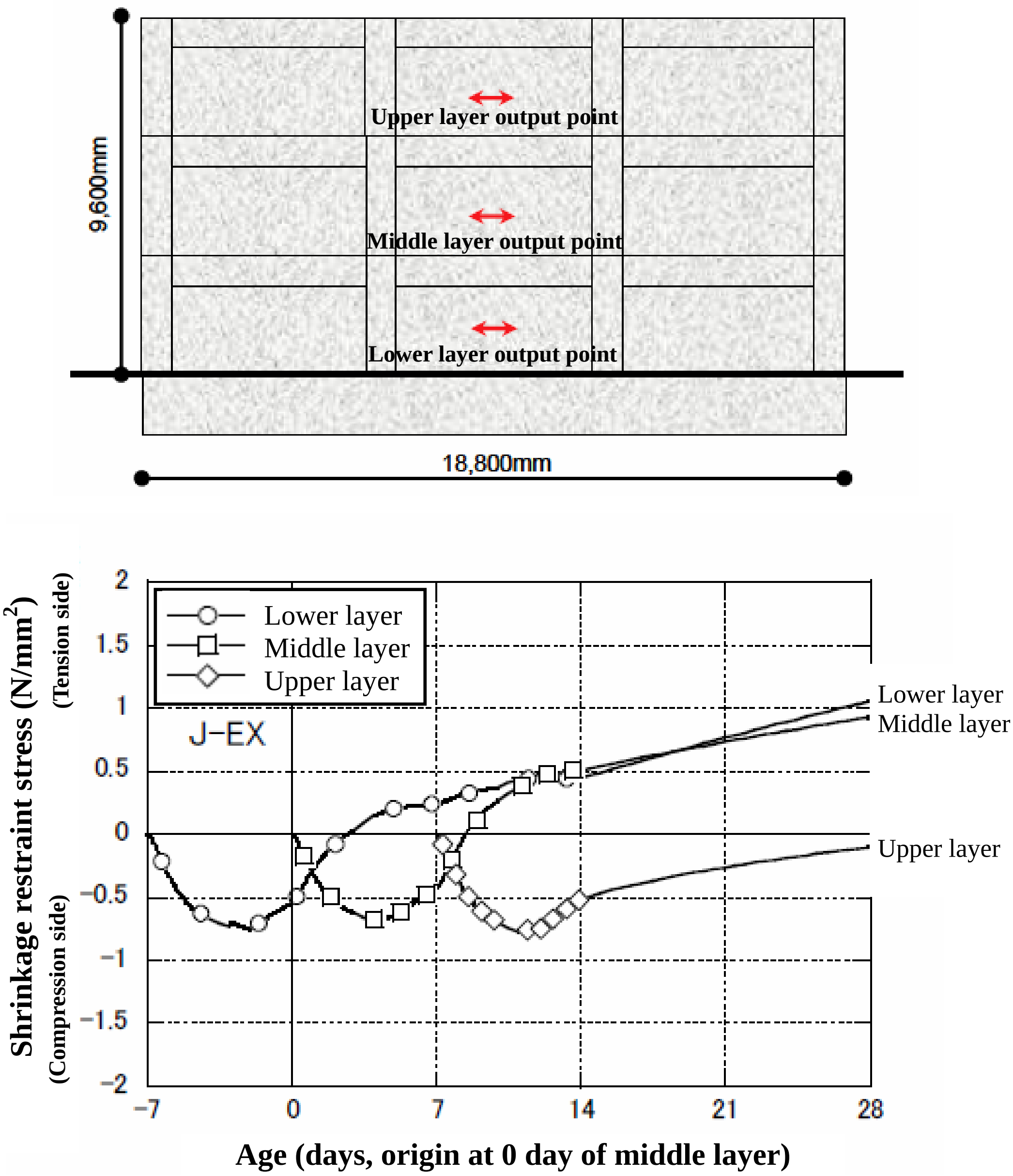

Fig. 13: Analysis model and stress history at focus point in each layer

3.7 Anticipated results

WG2 focused on the performance evaluation of expansive concrete on the member/structure level. It began with understanding of the current state and went on to investigate from various aspects the direction in which future study should proceed, obtaining many useful findings. It is expected that these achievements will be widely utilized by being applied to design practice and incorporated in institutional standards and guidelines.

4. Crack control systems

4.1 Direction of investigation

WG3 surveyed the necessity and significance of controlling cracks in reinforced concrete structures, which provide the strongest motive for using an expansive additive, including instances of attempts for crack control in industry, government, and academia. The working group demonstrated the current situation in which cracking is regarded as an assessment index to the assurance of the quality (durability) of a reinforced concrete structure both in design and execution. It also intended to investigate a mechanism of rationally achieving crack control not only technically but also including the aspect of social management, primarily regarding the civil engineering field. The final goal of the group was to propose a future system of order placing for public works construction and the direction of revising standards. The results of these activities in both civil engineering and architectural fields are summarized as follows:

4.2 Crack control in the civil engineering field

(1) Significance and necessity of crack control in civil engineering

Awareness of cracking has been increasing in the civil engineering field as well since the enforcement of the Housing Quality Assurance Act in 2001. Though ordinary cracks scarcely affect the bearing capacity of structures, cracks should preferably be eliminated from an aesthetic aspect. From the aspect of durability, deleterious cracks must be eliminated. This may be commonly understood among engineers, but is not necessarily shared among those who are involved in the construction of a structure – the owner, designers, contractors, workers, material suppliers, and inspectors - as well as citizens. In case of deleterious cracking, demerit marks are given in the construction rating by the current system. However, this causes various kinds of friction, as the causes of cracking have not yet been fully elucidated. Also, despite the number of crack-suppressing technologies proposed, it has generally been difficult to include these technologies in the order placing system based on evidence, as their effect in actual structures has not been evidently proven. In these circumstances, an example of a crack-suppressing system formulated by the Yamaguchi prefectural government using a database as a core is worthy of attention.

(2) Crack-suppressing system in Yamaguchi Prefecture

In the face of petitions from contractors who suffer through cracks in concrete, the Yamaguchi prefectural government launched an attempt to apply various crack-suppressing measures to actual structures on the Yamaguchi-Ube Prefectural Highway in 2005. This was an experiment on structures in actual use. Though the tests began in a groping manner, they led to remarkable results immediately after the trial placement thanks to the cooperation among industry, government, and academia. For instance, those referred to as construction-induced cracks were drastically reduced. Particularly, non-through axial cracks in the top slabs of box culverts were eliminated. On the other hand, parapet walls and the vertical walls of abutments were found to be prone to cracking even when made with careful concreting. To cope with this, the necessity for crack-suppressing measures from the design stage was recognized by parties concerned. This was the centerpiece of the experiment.

A crack-suppressing system shown in **Fig. 14** was implemented in fiscal 2006. Contractors are required to submit a placement control record shown in **Fig. 15** for each concreting lift. Each placement control record contains the structural specifications, adopted crack-suppressing measures such as increased crack-control reinforcement and the use of an expansive additive, information on concrete, conditions during placing, concrete temperature history after placing, and information on cracks generated.

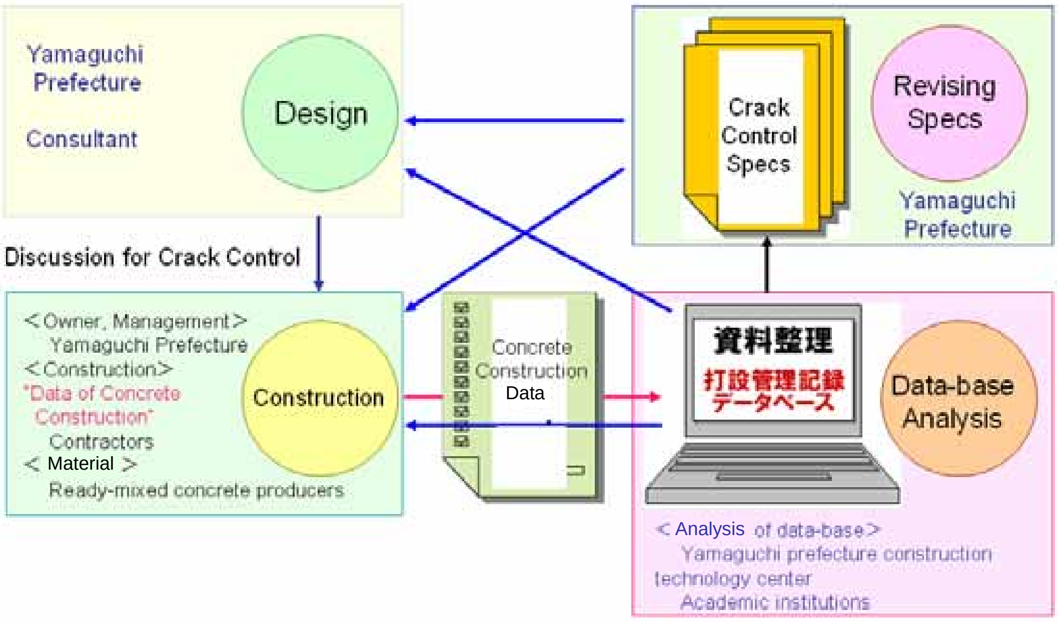

Fig. 14: Flow of crack control system by Yamaguchi prefectural government

Concrete placement control record

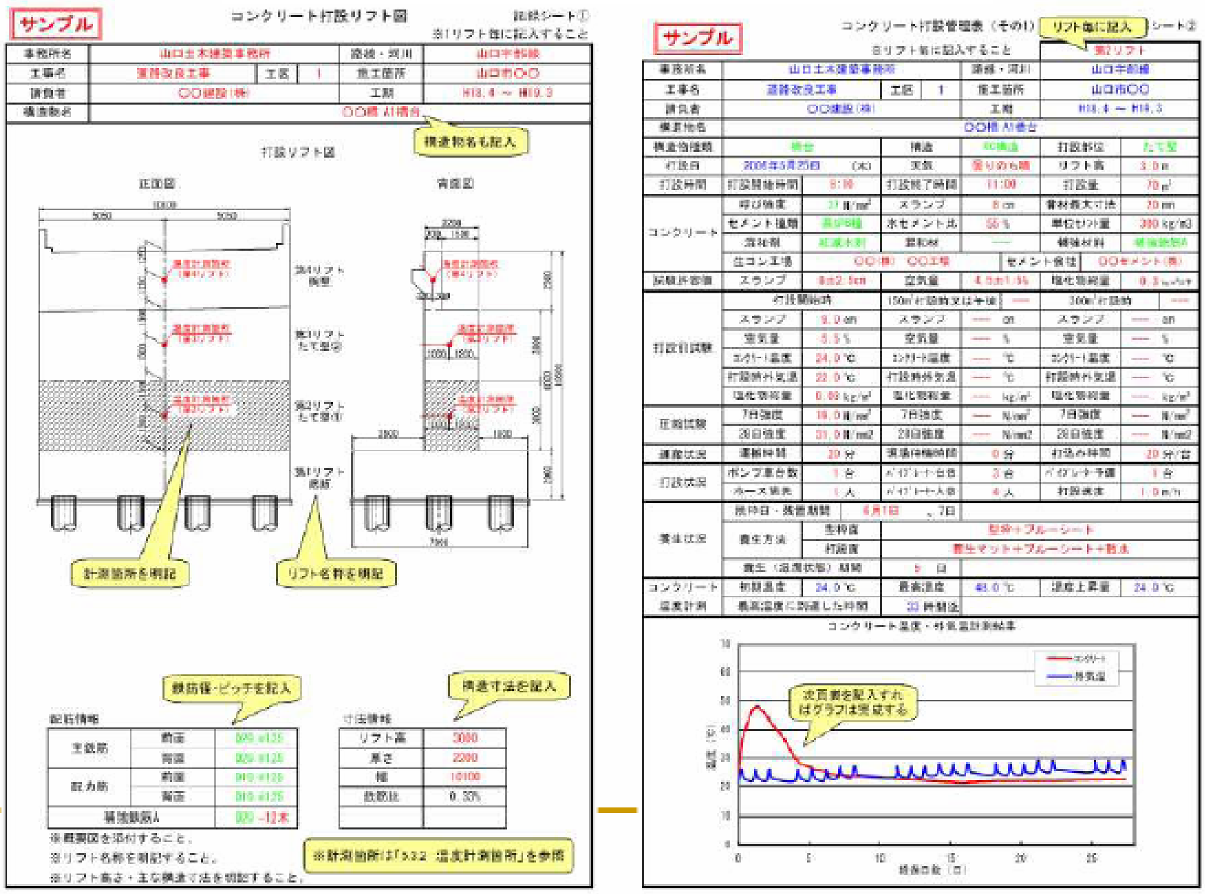

Fig. 15: Placement control record

The placement control records are disclosed as a database on internet webpages operated by the Yamaguchi prefectural government, based on which data on crack-suppressing measures are summarized. New structures are designed based on these data. A checklist consisting of 29 items referred to as a “check sheet for grasping the concreting conditions” for placement supervisors (**Fig. 16**) is also used on a daily basis as part of concreting practice. “Meeting the basic requirements of concreting” is thus recognized as a key to success of this system. It is of great significance that a record of concreting that meets the basic requirements is acquired each time into the database. It follows that the effect of crack-suppressing measures can be verified after each project.

The Technical Committee on Improvement of Quality of Concrete Structures Based on Database (Chairman: Prof. Takahiro Tamura of Tokuyama National College of Technology, Secretary General: Associate Prof. Akira Hosoda, Yokohama National University), which was organized in 2011 as a JCI committee, is going to deepen the discussion into elucidation of the quantitative effects of Yamaguchi Prefecture’s crack-suppression system.

It is expected that Yamaguchi Prefecture's crack-suppression system will continue to provide information useful for quality assurance of structures. The present committee's report also includes findings for improving the comprehensive evaluation method, findings related to the improvement of crack-suppressing design techniques, enhancement of crack-suppressing measures, and crack inspection.

Check Sheet for Concrete Construction

事務所名	山口土木建築事務所				工事名	○○県道 道路改良工事		工区	1
構造物名	○○橋　A1橋台				部位	たて壁		リフト	2
請負者	○○建設（株）				確認者	○○技師			
配合	27-8-20BB				確認日時	2006/5/25(木)　7:30～12:00			
打込み開始時刻	予定	8:00	実績	9:10	打設開始時気温	22.0°C	天候	曇のち晴	
打込み終了時刻	予定	12:00	実績	13:30	打設量(m3)	100	リフト高(m)	3.0	

施工段階	チェック項目	記述	確認
準備	運搬装置・打込み装置は汚れていないか。	－	○
	型枠面は湿らせているか。	－	○
	型枠内部に、木屑や結束線等の異物はないか。	－	※1
	かぶり内に結束線はないか。	－	○
	既コンクリート表面のレイタンス等は取り除き、ぬらしているか。	－	○
	コンクリート打設作業人員に余裕を持たせているか。	5人	○
	バイブレータの予備を準備しているか。	4台中1台	○
	発電機のトラブルがないよう、事前にチェックをしたか。	－	○
運搬	練混ぜはじめてから打ち終わるまでの時間は適切か。	50分	○
打込み	ポンプや潤滑性を確保するため、先送りモルタルの圧送等の処置を施したか。	－	○
	鉄筋や型枠は乱れていないか。	－	○
	垂直かつ打込み位置近くに打設し、横移動させていないか。	－	○
	一区画内のコンクリートは、打込みが完了するまで連続して打ち込んでいるか。	－	○
	コンクリートの表面が水平になるように打込んでいるか。	－	○
	一層の高さは、40～50cm以下か。	50cm	○
	2層以上に分けて打ち込む場合は、上層のコンクリートの打込みは、下層のコンリートが固まり始める前に行っているか。	－	○
	ポンプ配管等の吐出口から打込み面までの高さは、1.5m以下としているか。	約1.8m	※2
	表面にブリーティング水がある場合には、これを取り除いてからコンクリートを打ち込んでいるか。	－	○
締固め	バイブレーターを下層のコンクリートに10cm程度挿入しているか。	－	○
	バイブレーターは鉛直に挿入し、挿入間隔は50cm以下か。	－	○
	締め固め作業中に、振動機を鉄筋等に接触させていないか。	－	○
	バイブレーターでコンクリートを横移動させていないか。	－	○
	バイブレータは、穴が残らないように徐々に引き抜いているか。	－	○
養生	硬化を始めるまでに乾燥するおそれがある場合は、シートなどで日よけや風よけを設けているか。	－	○
	コンクリートの露出面を湿潤状態に保っているか。	－	○
	湿潤状態を保つ期間は適切か。	10日間	○
	型枠および支保工の取外しは、コンクリートが必要な強度に達した後であるか。	－	○
要改善事項等	※1　型枠内部に結束線（3本）が落ちていたため、打設前に取り除かせた。 ※2　排出口から打込み面までの高さが、明らかに1.5m以上であるため、口答で改善指示した。 上記※1、※2についての改善と、次回打設時も施工状況把握を行うことを、工事打合せ簿にて指示する。		

養生については、後日記入をする。

Fig. 16: Check sheet for grasping the concreting conditions

(3) Crack suppression related to surface quality

Since "meeting the basic requirements of concreting" was a key element of Yamaguchi Prefecture's crack-suppression system, the surface qualities of structures were deemed to be simultaneously enhanced. Thus the surface qualities of structures built under the system principles were examined[15)]. While no marked difference was observed in the standard rebound of a test hammer on concrete placed after implementing this crack-suppressing system, the air permeability by the Torrent method significantly decreased, demonstrating enhanced surface concrete qualities (**Fig. 17**). Structures for which crack-suppressing measures were taken were therefore found to achieve better surface qualities, clarifying the significance of suppressing cracks.

A survey of other structures also revealed that those made using expansive concrete tend to have higher surface qualities. This presumably results from inhibition of defects including microcracks and careful concreting in expectation of the effect of an expansive additive. A greater amount of data will be acquired in the future to further demonstrate the effect.

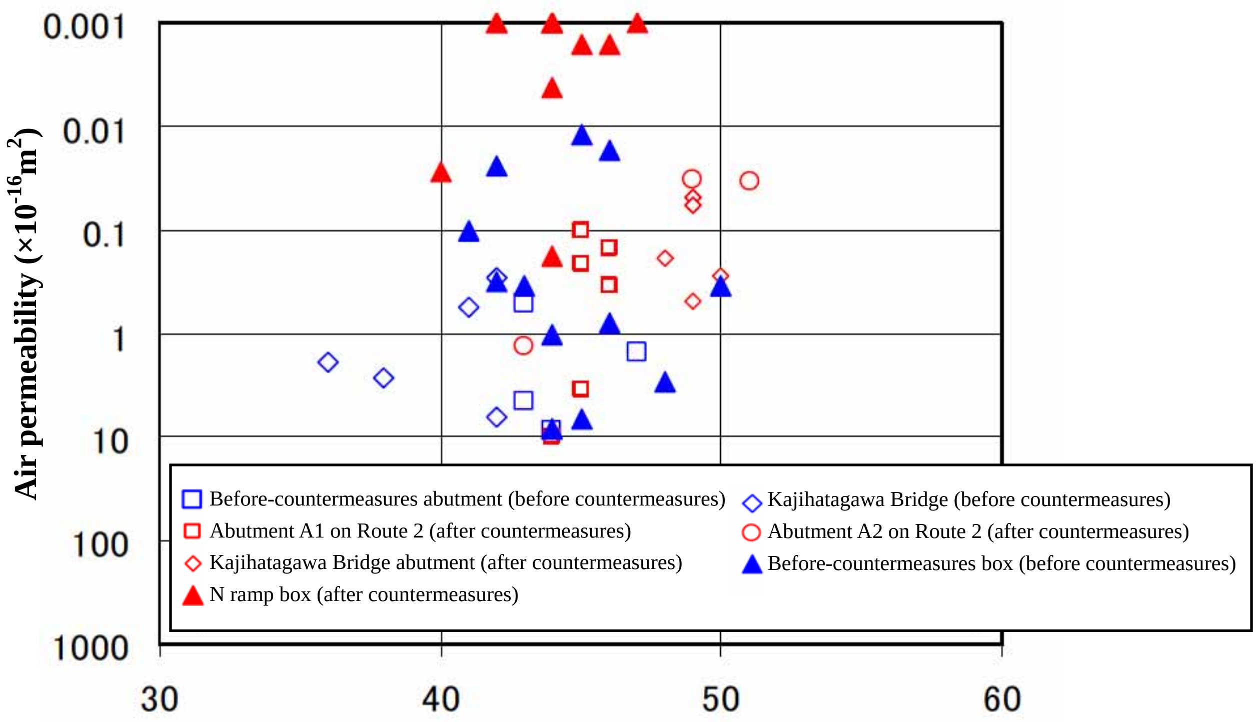

Fig. 17: Surface qualities of structures in Yamaguchi Prefecture

(4) Problem of shrinkage and cracking in civil engineering

In the wake of the cracking problem at the Tarui viaduct induced by excessive shrinkage, JSCE has been holding active discussions on the treatment of concrete shrinkage at the design stage. When designing railway girders, for instance, keeping the design crack width below the limit crack width is the primary factor for determining the cross section and rebar arrangement. Therefore, an excessive shrinkage allowed for in the design can make the resulting structure uneconomical. The use of expansive concrete enables the design of an economical structure. This way of thinking was summarized in the report.

4.3 Crack control in architecture

(1) Significance and necessity of crack control in architecture

The problem of crack-related defects has become increasingly apparent in the architectural field. A defective state of a building means a state in which the quality and performance of the building to be handed over deviate from the initially agreed values (Agreement), with its values and functions being impaired. Particularly regarding residential buildings, cracking has tended to attract attention of promoters and purchasers since the enforcement of the Housing Quality Assurance Act. This can be attributed to the fact that a technical standard was announced for the first time in relation to this law regarding the relationship between cracking and the possibility of defects in areas critical to the structural capacity of the building (Notification No. 1653 of the Ministry of Construction).

Under the Housing Quality Assurance Act, the purchaser can apply to an authorized institution for housing dispute settlement when the housing supplier undertakes the construction of a house having performances described in the housing performance assessment report but is deemed to have deviated from the agreement. According to the Housing Reform/Dispute Settlement Support Center, which backs dispute settlement, water ingress (rainwater leakage) and cracking account for the largest part of the total number of complaints among relevant defective events as shown in **Fig. 18**[16)]. This also suggests that cracking poses a serious social problem in the house building industry. However, the occurrence of cracking as such scarcely causes grave failure that jeopardizes the function of the entire building. It is rather likely that cracks provoke complaints because they are regarded as an assessment index to the quality of construction, easy to find, and easy to express in numerals.

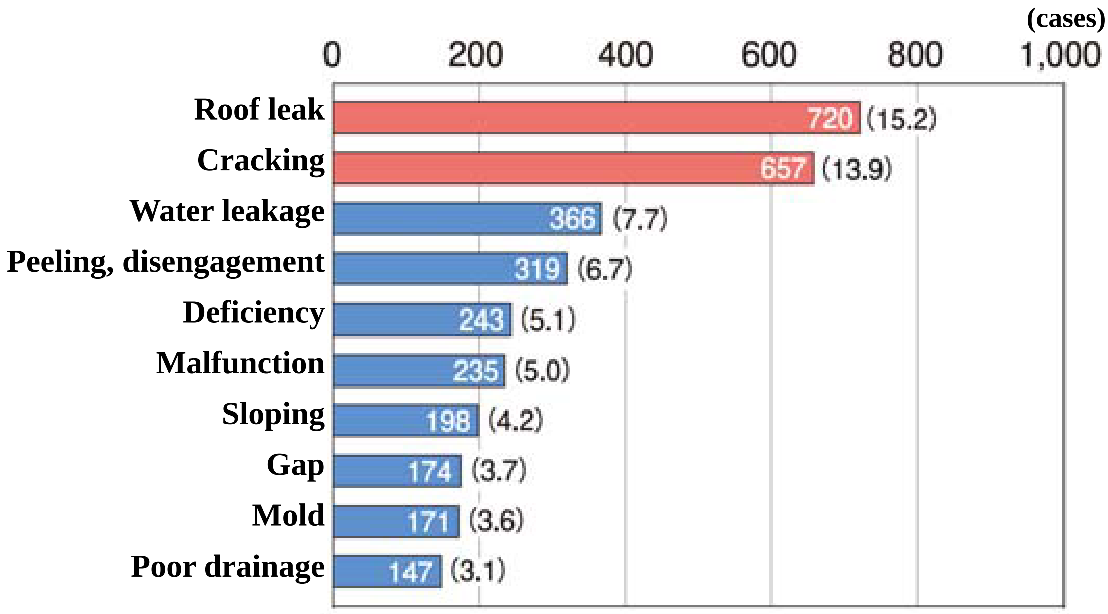

Fig. 18: Types of complaints about buildings[16)]

(2) Role of expansive additives for crack control of buildings – regarding shrinkage cracks

This section quantitatively describes the effect of expansive additives on the shrinkage crack control of buildings, in regard to floor members. The effect of an expansive additive for a floor slab is expressed by an analyzed stress-strength ratio, which is the ratio of shrinkage restraint stress generated in the floor slab restrained by beams to the cracking strength of concrete. Analysis was conducted on floor slabs of the three buildings given in **Table 2**, in which only B-1 and B-2 are made of concrete containing an expansive additive.

A crack survey was also conducted on the floor slabs shown in **Table 2** after construction. The length and maximum width of cracks generated were measured, and the results were organized in terms of crack density, which is defined as a value determined by dividing the product of crack width and length by the survey area.

Figure 19 shows the effect of an expansive additive by the results of the survey and analysis. This figure reveals that most floor members are inevitably prone to many cracks. In contrast, the inclusion of an expansive additive reduces the stress-strength ratio, suggesting the possibility of significantly reducing cracks.

Accordingly, floor members of buildings were generally found prone to cracking. Though measures to control cracking for floor slabs are limited, expansive additives can be regarded as a promising choice.

Table 2: Buildings subjected to shrinkage crack analysis and provided with measures against cracking

	Building under analysis				Concrete condition			
	Building		Structural condition	Floor	Nom. str.	W/B (N/mm^2)	W (kg/m^3)	Drying shrink. (μ)
A-1	A	Multi-storied parking lot	Flat deck slab Slab: 160 mm × 6,000 mm D13 double rebars at 150 mm spacing Steel beams: Two 700-300-200-24 beams	2F	24	53.0	171	545
A-2				3F	24	53.0	171	545
A-3				4F	24	53.0	171	545
A-4				5F	24	53.0	171	545
B-1*	B	Production facility	Flat deck slab Slab: 150 mm × 13,250 mm D10 double rebars at 200 mm spacing Steel beams: Three 596-199-10-15 beams and two 800-358-16-28 beams	2F	27	53.8	180	807
B-2*				3F	27	53.8	180	807
B-3				4F	27	53.8	177	807
B-4				5F	27	53.8	177	807
C-1	C	Commercial facility	Corrugated deck slab Slab: 80 mm × 8,050 mm D13 rebars at 150 mm spacing ϕ6 rebars at 150 mm spacing Steel beams: One 588-300-12-20 beam and two 600-300-12-22 beams	3F Zone 1	27	54.1	176	749
C-2				3F Zone 2	27	54.1	176	749
C-3				4F Zone 1	27	54.1	176	749
C-4				4F Zone 2	27	54.1	176	749

*Both an expansive additive and a shrinkage-reducing admixture were used for B-1 and B-2.
The effect of the shrinkage-reducing admixture was incorporated by multiplying the above drying shrinkage characteristic values by 0.7.

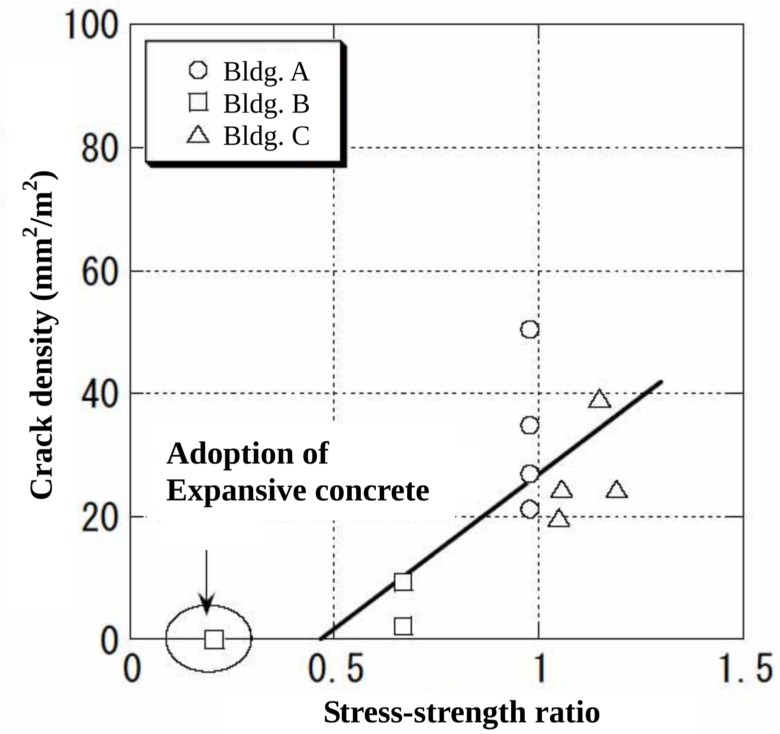

Fig. 19: Effect of expansive additives

5. Summary

In the recent state of the strong demand in society for high quality structures and buildings with cracking controlled to a high degree, expansive additives are expected to play a significant role. This committee has completed a report recapitulating the development of studies from the material aspect on expansive concrete, development and history of studies on the methods of evaluating crack-suppressing effects, and proposals for desirable crack suppression in architectural and civil engineering fields. The committee members hope that the proposed simple test method for an expansion coefficient and method of evaluating a crack-suppressing effect will be enhanced through practical use and fed back to promote studies into higher stages. Cracking is a complicated problem representing problems of the entire system of construction. Active discussion on crack suppression as a system is therefore anticipated by referring to such systems as Yamaguchi Prefecture's crack suppression system so that related techniques and institutions would keep on developing.

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