Committee Report : JCI- TC164A

Technical Committee on concrete deterioration in natural environments

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Abstract

This technical committee ascertained the state of concrete deterioration, organized and verified the latest environmental evaluation techniques related to the deterioration mechanism, and organized the latest testing methods. The targeted deterioration was rebar corrosion due to carbonation, salt damage, frost damage, and soil degradation, but the group also aggressively examined the state of frost damage in the Kyushu and Chugoku regions in particular, as well as discussing the external degrading forces and initiating new exposure.

Keywords: Natural environments, exposure, real structures, deterioration, frost damage, salt damage, carbonation, soil degradation, environmental evaluation, testing methods

1. Introduction

This technical committee, the “Technical committee of concrete deterioration in natural environments,” was the successor to the “Technical committee of concrete in natural environments” chaired by Dr. Eiji Kamada from 1991 to 1992 and the “Technical committee on concrete performance in natural environments” chaired by Dr. Noboru Saeki from 2003 to 2004, and its purpose was to modify/upgrade the concepts raised by the past two technical committees, as well as the techniques, results, know-how, and discussion they cultivated, for the present times, and leave the study of “concrete in natural environments” to its successors.

Based upon the 12-year cycle on which the previous 1991 and 2003 technical committees were set up, the environments and deterioration targeted by this technical committee were ① deterioration in ordinary environments (carbonation), ② deterioration in salt damage

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environments, ③ deterioration in frost damage environments, and ④ deterioration in corrosive volcanic gas and soil environments. However, the activities on this occasion were focused upon the study of "concrete frost damage in the Kyushu and Chugoku regions" as the key issue. The technical committee initiated a survey on the actual state of frost damage in the Kyushu and Chugoku region, studied the sizes of the external sources of deterioration, and began new exposure tests. Other than these key issues, the group organized information from exposure tests and real structure surveys conducted both within and outside of the group since 2003 with respect to individual problems. **Table 1** shows the members of the technical committee.

Table 1: Committee structure

Chairman: Noboru Yuasa (Nihon University) Secretary: Yukio Hama (Muroran Institute of Technology), Takafumi Sugiyama (Hokkaido University) Tomoyuki Koyama (Kyushu University), Hidehiko Ogata (Tottori University) Yoshitomo Yamada (University of the Ryukyus)
[Frost damage environment WG]◎WG Chief Investigator, ○SWG Chief Investigator ◎Yoshio Hama (Muroran Institute of Technology) ○Tomoyuki Koyama (Kyushu University) ○Hidehiko Ogata (Tottori University) ○Takafumi Sugiyama (Hokkaido University) Hidenori Hamada (Kyushu University), Masumi Inoue (Kitami Institute of Technology), Hidenobu Tokushige (Akita University), Toshinobu Yamaguchi (Kagoshima University), Tamotsu Kuroda (Tottori University), Korekiyo Ito (Tokai University), Takashi Fujii (Okayama University), Toshihiro Otani (Oita University), Masashi Suto (Matsue College), Yasutaka Sagawa (Kyushu University), Akira Nonaka (Kumagaigumi) [Salt damage environment WG] ◎Yoshitomo Yamada (University of the Ryukyus), Jun Tomiyama (University of the Ryukyus) Takahiro Sagawa (Maebashi Institute of Technology), Tatsuhiko Saeki (Niigata University), Shinichi Miyazato (Kanazawa Institute of Technology), Hidenori Hamada (Kyushu University), Toshinobu Yamaguchi (Kagoshima University), Yasutaka Sagawa (Kyushu University), Akira Nonaka (Kumagaigumi) [Carbonation WG] ◎Hitoshi Hamasaki (Shibaura Institute of Technology), Takahiro Sagawa (Maebashi Institute of Technology), Akira Nonaka (Kumagaigumi) [Soil degradation WG] ◎Tomoyuki Koyama (Kyushu University), Korekiyo Ito (Tokai University), Toshihiro Otani (Oita University)

2. Study of frost damage environmental evaluation

Frost damage deterioration has been the subject of study for quite some time. This has included not only studies to elucidate deterioration mechanisms, materials, and mixtures, but also active ongoing studies conducted mainly by research organizations in the cold and snowy regions of

Hokkaido and Tohoku, which involve long-term outdoor exposure tests, and surveys of deterioration in real structures. The results of these studies are reflected in various specifications and guidelines.

The technical committee organized several scientific working groups (SWG) on frost damage environments: the Hokkaido and Tohoku frost damage environment SWG, the Chugoku frost damage environment SWG, and the Kyushu frost damage environment SWG. The Hokkaido and Tohoku frost damage environment SWG re-organized past exposure tests and surveys on the actual state of frost damage deterioration in real structures conducted in the Hokkaido and Tohoku regions. However, the Chugoku and Kyushu regions are generally considered temperate regions, and are not considered frost damage environments. Thus, they have not been subjected to systematic surveys of frost damage deterioration. However, in the interior and mountainous areas of the Chugoku and Kyushu regions, winter snowfall and temperature drops are quite severe, and there is sporadic concrete frost damage; therefore, the Chugoku frost damage environment SWG and Kyushu frost damage environment SWG conducted surveys on the actual state of frost damage in the Chugoku and Kyushu regions

2.1 Frost damage deterioration in the Hokkaido and Tohoku regions

Frost damage in cold regions such as Hokkaido and Tohoku has been recognized as causing fatal damage to concrete structures, and has been the subject of continuous and systematic research.

Exposure tests on frost damage have been actively conducted for a long time, mainly by Hokkaido University, Kitami Institute of Technology, and the PWRI Civil Engineering Research Institute. Well-known examples include exposure tests conducted on campus at Hokkaido University in Sapporo City and Monbetsu City, the Rumoi coastal concrete exposure test site managed by the Civil Engineering Research Institute for Cold Region, the Mimi concrete frost damage experiment site, and long-term exposure and other tests conducted in the tidal zones off the coast of the Sea of Okhotsk by Kitami Institute of Technology; these have been frequently referenced in literature.

In addition, the cold snowy region concrete complex deterioration factors technical committee of the Japan Concrete Institute Hokkaido Branch (Chairman: Professor Takafumi Sugiyama, Hokkaido University) conducted a survey on the state of deterioration in concrete bridges in Hokkaido, and reported that they often found not only frost damage alone, but complex deterioration in the form of frost damage with salt damage, frost damage with ASR, and frost damage with carbonation[1]. This has resulted in a sense that the presumption, evaluation, and assessment of causes of deterioration require deeper findings on complex deterioration involving mainly frost damage, and not simple deterioration on its own. In addition, although the peak construction era for the bridges surveyed was the 1970s, the peak era for frost damage deterioration (including complex deterioration) was apparently the 1960s. The practical effects of disseminating frost damage measures were recognized, and thus there is dramatically less frost damage in structures from newer construction eras.

Furthermore, although deterioration from frost damage alone was often seen in regions with high frost damage risk, damage including complex deterioration with frost damage did not necessarily correspond to frost damage risk.

2.2 Chugoku region environment and survey of frost damage examples

(1) Characteristics of snowfall and snowmelt in the Chugoku Mountains

The Chugoku region forms a backbone range with the Chugoku mountains straddling the San'in and San'yo regions. The southern part of the San'yo region faces the Seto Inland Sea, and is formed mainly by minor islands and plains. The northern part is formed mainly by mountainous terrain and basins. On the contrary, the San'in region faces the Sea of Japan, and thus is characterized by the climate on the Sea of Japan side. The winters are extremely cold in interior and mountain areas, which frequently experience extremely large snowfalls.

The snow in the Chugoku region tends to be heavy and contain much moisture. **Table 2** shows the density of new snowfall determined by rain and snowfall measurements in 22 cities along the

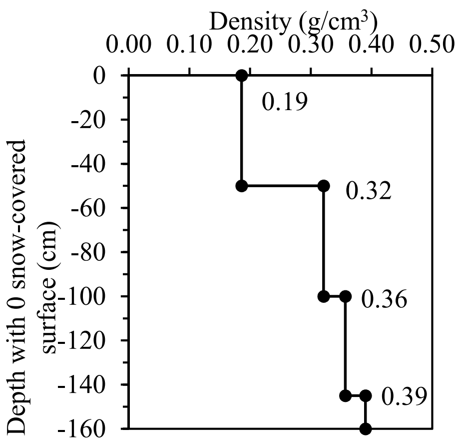


Fig. 1: Snow density in Hiruzen

coast of the Sea of Japan (snowfall within a relatively short 6-to-12-hour period)[2]. The highest snow density was 0.073 g/cm^3 in Tottori, followed by Fukui, Matsui and Niigata. In addition, **Fig. 1** shows the snow density measured at the Field Science Center of the Tottori University Faculty of Agriculture (Hiruzen Forest (35°17'15.5"N, 133°35'13.1"E) in Maniwa City in Okayama Prefecture, which is almost exactly in the middle of the Chugoku mountains. The density was 0.19 g/cm^3 at 50 cm from the surface of the snow, which increased to .32 to 0.39 g/cm^3 owing to compression at deeper points.

Table 2: New snow density in 22 cities on the Sea of Japan coast[1]

City	Snow density (g/cm^3)	City	Snow density (g/cm^3)
Wakkanai	0.058	Wajima	0.073
Rumoi	0.047	Takada	0.064
Sapporo	0.061	Toyama	0.063
Obihiro	0.059	Nagano	0.048
Suttu	0.045	Kanazawa	0.069
Hakodate	0.048	Takayama	0.056
Aomori	0.043	Fukui	0.082
Akita	0.066	Tsuruga	0.073
Sakata	0.071	Tottori	0.073
Yamagata	0.052	Matsue	0.077
Niigata	0.074	Hikone	0.061

Thus, the snow in the Chugoku mountains is characterized as being heavy with high moisture content, but the density increases with snowfall height, and thus the environment is one in which concrete is receives a lot of moisture during snowmelt. Thus, it may be said that the frost damage to concrete structures in the Chugoku region is influenced by the heavy characteristic of the snow.

Fig. 2 shows images from an 11 o'clock fixed point camera taken at an exposure site set up in the Hiruzen Forest from February 11 to 14, 2018. The height from the ground to the stand on which the specimens were placed was approximately 1.2 m.

The images from the fixed point camera show that repeated snowfall and snowmelt occurred within a short period. This indicates that in places exposed to sunlight, except for those close to surfaces where snow is likely to accumulate, the concrete at the height reached by the tallest snowfall is not continuously covered by snow, but is repeatedly wetted by snowmelt water and dried by exposure to the open air. The fact that this repeated drying and wetting occurs not only during non-freeze periods but also during winter periods is characteristic of the Chugoku mountains,

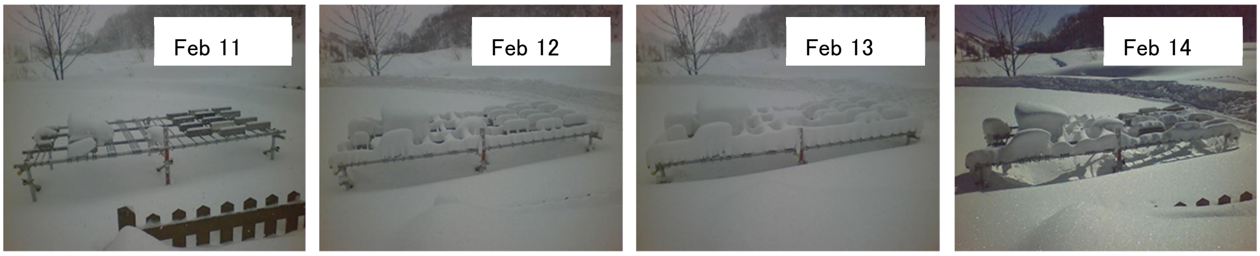


Fig. 2: Hiruzen exposed field fixed point camera images

and thus can also be considered to influence the frost damage to concrete structures in the Chugoku region.

(2) Survey of frost damage examples in the Chugoku region

The survey of frost damage examples in the Chugoku region covered mainly public structures, and involved requests for cooperation mainly from agencies managing those structures. Consequently, the present survey did not target buildings managed by private organizations or individuals. A questionnaire was sent to potential respondents, and then the responses were compiled. The questionnaire items were "Location (longitude, latitude)," "Structure type," "Deformation site," "Deformation site direction," "Year of completion or years of service," "Deformation determined to be frost damage," "Images or deformation development maps," "Water supply source or path to deformation site," "Presumed deterioration mechanism and advancement," "Characteristics of surrounding environment," "Any effects from anti-freezing agents" and "Any detailed surveys (non-destructive testing or core sampling)." The survey period was August 2016 to February 2017. During that time, 77 responses were received for 91 sites. The types and numbers of structures for which responses were received were 62 bridges, 11 roads, two retaining walls, one parking garage, and one dam. The present survey was mainly of public structures with many of the responses concerning bridges. Amongst these, 60 % of all the responses concerned bridge substructures such as the vertical walls of abutments or pier beams. **Fig 3** shows the whereabouts of frost damage in the Chugoku region and frost-damaged structures obtained from the survey. Examples of frost-damaged structures were found even in regions with 0 frost damage risk.

Below, we show some of the results obtained from the present survey.

Fig. 4 shows the verified aggregate results per type of deformation. Scaling was the most

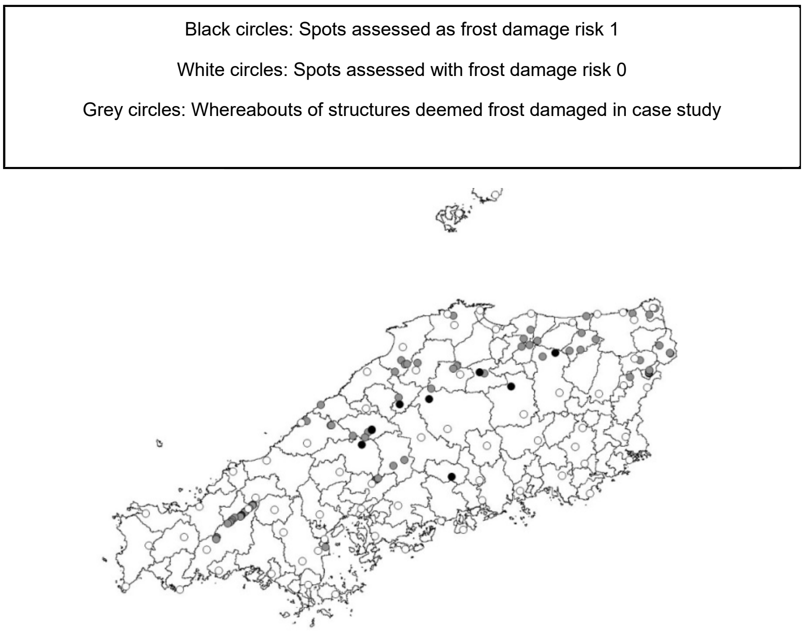


Fig. 3: Locations of frost damage risk and frost damage structures

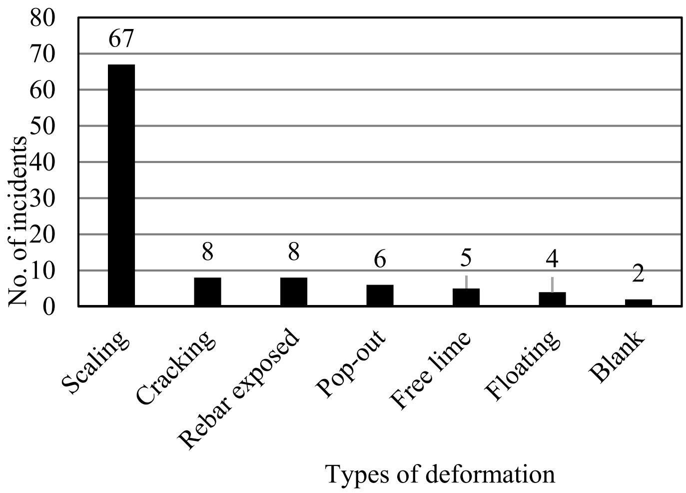


Fig. 4: Aggregate results per type of deformation

frequent verified form of deformation, followed by cracks and rebar exposure.

Fig. 5 shows the results compiled per deformation mechanism. Most deformation occurred as a result of saturation from rainwater or snowfall. Vertical bridge walls were a frequent deformation site in the survey responses, whereas bridge wing walls and retaining wall side walls were less frequent. A few were affected by factors such as slope water from the rear.

Thus, even in the Chugoku region, frost damage occurs in regions prone to receiving rainwater, and drainage systems are particularly important for bridges.

2.3 Examples of frost damage in Kyushu and characteristics thereof

(1) Survey summary

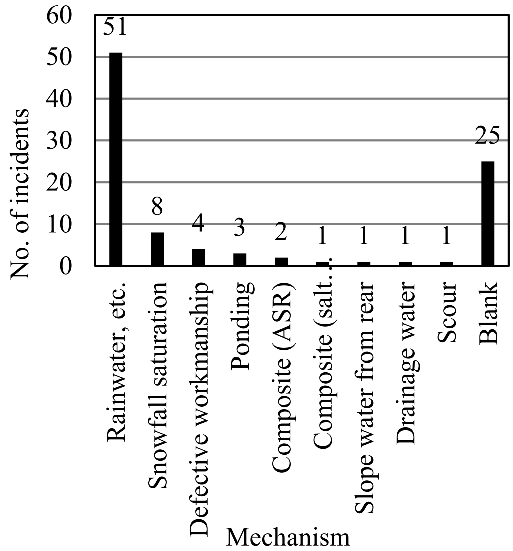


Fig. 5: Aggregate results according to deformation mechanism

Frost damage in cold regions such as Hokkaido and Tohoku is recognized as deterioration that can lead to fatal damage in concrete structures, and has been the subject of research for many years. Because of survey results being properly incorporated into measures for design, materials, and mix proportion, concrete structures have been experiencing less and less frost damage in recent years. On the other hand, frost damage has been considered unlikely in temperate regions, mainly Kyushu. Even in the distribution map of frost damage risk shown in Section 26 of the Japanese Architectural Standard Specification for Reinforced Concrete Work JASS5[3)], “Concrete affected by freezing and thawing action,” the frost damage risk in the areas demarcated by high-elevation mountaintops around Aso and Unzen is risk level 1, “Very mild,” whereas the inland areas are “Frost damage risk regions for plain concrete using poor quality aggregate.” However, there are presently many verified examples of frost damage, even where the risk level is “Very mild” or less, as well as scattered examples of frost damage in places other than the above risk regions. Little knowledge is available on frost damage in temperate regions such as Kyushu, which is thought to be one reason for the lack of appropriate measures. Similarly, because there is little interest in frost damage, the circumstances and characteristics of deterioration have not been well grasped. Against this background, the Kyushu frost damage environment SWG ascertained the overall picture of frost damage to concrete structures in Kyushu, compared frost damage in Kyushu to ordinary frost damage seen in cold regions, and studied their characteristics. This survey targeted concrete structures experiencing deterioration suspected of being frost damage in Kyushu. Mainly a visual survey was conducted on what the working group members were grasping as well as the newly informed structure.

(2) Examination results

Below we present typical examples of structures that experienced deterioration suspected of being frost damage, and describe the similarities and differences between frost damage in Kyushu and ordinary frost damage. Furthermore, there are also examples for which a final assessment of the frost damage could not be reached at this time, and because the notation is quite long, we shall simply refer to “structures experiencing deterioration suspected of being frost damage” as “target structures” or “examples.”

Photograph 1: Scaling in bridge wheel guard

Photograph 2: Scaling and rebar exposure in girder

Photograph 3: Efflorescence on stair side wall

Photograph 4: Pop-Outs in bridge girder

Photograph 5: Peeling-off and reinforcemer exposure at edge of the eaves

Photograph 6: Cracks in the top part of independent column

Photograph 7: Scaling in abutment

Photograph 8: Cracks in parapet

Photograph 9: Example of measures for eaves (Muroran)

Photographs 1 to 8 show examples of target structures. Many of the examples fall within regions with “possible [damage] with poor quality concrete” or regions with frost damage risk level 1 in previous frost damage risk maps, but examples have also been verified in other regions such as mountainous areas on the outskirts of Fukuoka City and the Yakushima mountainside.

Many examples were seen of scaling (**Photograph 1**) and cracks, which are typical deteriorations due to frost damage. Examples were seen in which this deterioration advanced and led to rebar exposure (**Photograph 2**). Otherwise, many examples were seen of efflorescence from cracks. There were cases of oozing from the interior of cracks, and icicle-shaped deposition directly below cracks (**Photograph 3**). These continued to supply moisture to crack sites, indicating that cracks represent a pathway for water to flow, and thus present a further deterioration concern. Furthermore, there were relatively few pop-outs in the present examples (**Photograph 4**).

Deterioration due to frost damage tends to occur around rooftops and near eaves, which are places that ordinarily receive a large amount of snowmelt water. Protruding areas and corners are particularly prone, as they experience large changes in temperature. Similar tendencies are seen in the present survey. Deterioration was often seen on roof slabs at the edge of the eaves (**Photograph 5**), eaves, and on parapets. Furthermore, deterioration also occurred at protrusions at the tops of the outer pillars (**Photograph 6**).

In addition, examples of prominent deterioration were also seen in places where water stagnated, or which were likely to receive water. Deterioration occurred on a north-side abutment of a bridge in a mountainous area of Fukuoka City (**Photograph 7**) that received a large amount of water from the rear. In the photograph, significant deterioration was seen in places directly struck by water drops dripping from overhangs on the top of the abutment.

In buildings, deterioration of framework concrete precedes deterioration of finishes, and examples are often seen in which moisture from such deterioration penetrates and leads to frost damage. There are also examples in which water stagnates on the inside of finished coating film (**Photograph 8**). Falling water penetrates deteriorating waterproof layers, follows cracks in the concrete and boundaries between peeling coating film and concrete, and stops in places that have not yet begun to peel, where it rests inside the coating film. There are of course slight variations in this process. When deterioration in Kyushu and cold regions is observed, it appears that there are no major differences. Next, we compare the overall trends to those of ordinary frost damage, and link them to the climate conditions.

In cold regions with severe winters, the daily maximum temperature is often below the freezing point on days when the daily minimum temperature is below freezing point, and when concrete momentarily freezes, it is unlikely to thaw unless in contact with sunlight. Hence, frost damage is likely on surfaces in contact with sunlight, mainly the south surfaces of buildings. However, in Kyushu, it is rare that daily maximum temperatures are below the freezing point on days when the daily minimum temperature is below freezing point. Consequently, concrete that freezes overnight is predicted to often easily thaw over the course of the day, even in places not touched by sunlight. Owing to this climate property, the deterioration in the present examples would tend to occur in every direction.

In addition, unlike the temperature during severe winters in cold regions, in Kyushu it is quite rare for the temperature to reach 10 °C below freezing. Consequently, frost damage is difficult to occur in plain low places, and easy to occur at high places with over 500 m elevation. However, examples are often seen in places with relatively low elevation of approximately 150–300 m around Hita, which is an interior basin. Because this is an inland area, the temperature tends to drop during the winter and the humidity is relatively high, and therefore concrete tends to remain in a wet state, which is considered an important factor.

The year of completion of most of the target structures was between 1955 and the 1960s, such that the shortest period after construction was approximately 30 years. The annual number of freezes and thaws in Kyushu is approximately ½ to ¼ of that in cold regions. It is thought that, compared to cold regions, where deterioration may occur in as soon as 10 years, in Kyushu it takes longer for deterioration to become evident, even when there is frost damage. This may be related to the fact that deterioration examples are frequent in structures from the above era. However, it is also believed that there are few examples involving relatively new structures because of the recent use of AE agents and reliable air entrainment in temperate regions, mainly for the purpose of improving workability. Furthermore, it seems that the relatively mild degree of deterioration due to frost damage in Kyushu compared to cold regions is the reason for the numerous existing examples.

In addition, frost damage in Kyushu is characterized by concrete eaves (**Photograph 9**), which are not seen much in Hokkaido (although the example is from Muroran), and a lack of consideration in design for such factors as pooling water.

Another characteristic of Kyushu is the prevalent effect of acidic gas in regions located close to volcanos or hot spring areas, such as Unzen, Aso, Kirishima, and Ebino, and there are many examples in which complex deterioration from frost damage and chemical deterioration are suspected. Similarly, the use of anti-freezing agents around certain civil engineering structures may have an effect, leading to the supposition of complex deterioration with salt damage.

2.4 Study of regional frost damage environment indexes

The Hasegawa frost damage risk distribution map is a well-known reference for the risk level of regional external factors (climatic environment conditions) for frost damage. It is mentioned in publications such as JASS5 of the Architectural Institute of Japan (AIJ)[3)] and Concrete Diagnostic Techniques[4)], and is presently used as a valuable reference.

The Hasegawa frost damage risk distribution map is characterized by using air temperature as the main climatic data, and calculating the frost damage risk value by weighing it against the moisture supplied by snowmelt water[5)]. It uses isolines to depict the frost damage risk level graded on six levels of frost damage risk. The climatic data used at the time was from 1965 to 1970, and the frost damage risk calculation locations were 140 climate monitoring stations across the country. However, it is difficult to make a detailed determination of frost damage risk in those locations.

In recent years much statistical climatic data, such as AMeDAS data, has become easily obtainable, and Narita, et al. prepared a frost damage risk map based upon on-site survey data from 176 locations focusing on mesh climatic data in order to make a detailed calculation of the risk level per location[6)]. Mesh climatic data are climatic data using calculations to estimate mean values per square kilometer from a monitoring site for the past 30 years, and compared to other statistical climatic data, enables more detailed calculation of indexes for a location. The 2000 mesh climatic data used by Narita, et al. were prepared using mean values for climatic data such as the air temperature and deepest snowfall for a statistical period from 1971 to 2000, and were updated with the latest data up to 2010.

Furthermore, in terms of recent research, Hama, et al. considered the effect of summer drying on coarsening concrete pore structures and reducing the potential freeze-thaw resistance[7)8)] in evaluating the climatic environment conditions, used it as an index in combination with the ASTM-equivalent cycle count[9)] to show environmental conditions for freezing and thawing, proposed a frost damage-climate index (FD-CI), and used the latest 2010 mesh climatic data for mapping (**Fig. 6**)[10)]. According to this figure, we find that the inland and mountainous areas of the Chugoku and

Kyushu regions, which were the focus of this WG, were frost damage environments similar to Hokkaido.

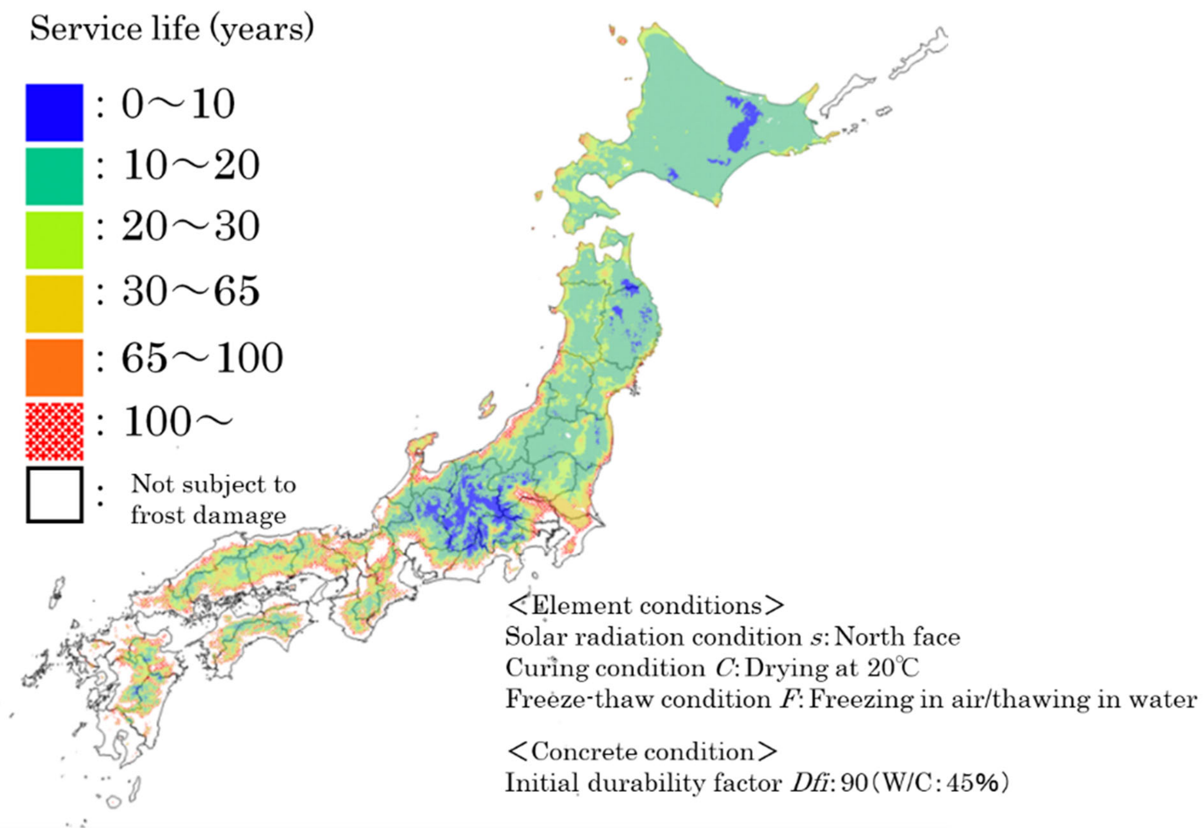


Fig. 6: Calculation results of service life by FD-CI

3. Study of salt damage environment evaluation

The salt damage environment WG of this technical committee compiled studies of salt damage environment evaluation released over the past 10 years by the Japan Concrete Institute, Japan Society of Civil Engineers (JSCE), and Architectural Institute of Japan, and further compiled information on methods to measure and evaluate airborne ~~salt~~ chloride ion, which is an external source of salt damage deterioration, information on exposure sites and tests, as well as information on the latest techniques for measuring and analyzing chloride ion.

Here, we present a summary of existing airborne ~~salt~~ chloride ion measuring methods, methods of measuring airborne salt with thin-plate mortar specimens, which have increasingly come into use in recent years, and examples of evaluating airborne salt environments. Furthermore, in this section, we summarize “Simple test methods for chloride ion content in hardened concrete” (NDIS

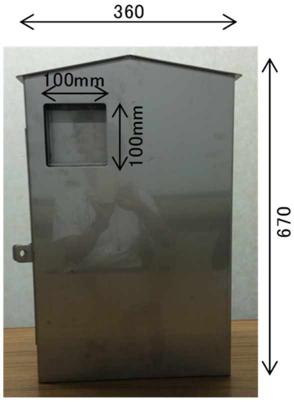
3433) enacted in 2017 by the Japanese Society for Non-Destructive Inspection.

3.1 Examples of evaluating airborne chloride ion environments with various airborne chloride ion collecting methods and thin-plate mortar specimens, and the issues thereof

(1) Various airborne chloride ion collecting methods

A typical example of a method for measuring airborne choride ion content from the ocean is to use a PWRI-type collector[11]. **Photograph 10** shows an example of a collector. As shown in the figure, in this measuring method, chloride adhering to a 10 cm × 10 cm stainless-steel plate is stored in a tank. The airborne choride ion content is measured by measuring the salinity. The measurement intervals are often approximately one month. The measured airborne choride ion content is recorded in units of mg/dm/day (mdd). In addition, collectors may operate in multiple directions. An upgraded collector has been used that can measure the airborne choride ion content in four directions[12].

The above PWRI-type airborne choride ion collector is a large-type model, which means that its weight imposes restrictions upon where it can be installed. One way of overcoming this is the dry gauze method, which is a technique in which airborne choride ion is collected with



Photograph 10: PWRI-type collector

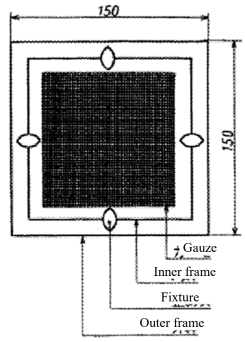
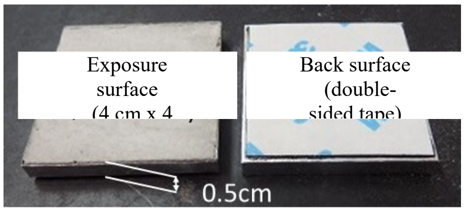


Fig. 7: Dry gauze

Photograph 11: Eight-direction dry gauze collector



Photograph 12: Thin mortar test pieces

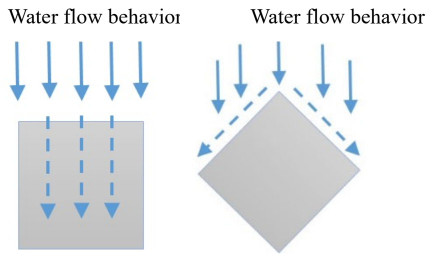


Fig. 8: Effect of differences in attachment on water flow

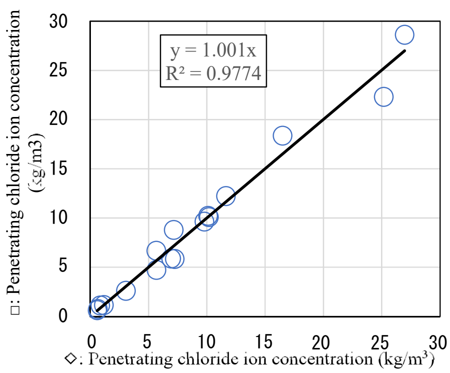


Fig. 9: Differences due to differences in mounting

dried gauze[13]. A summary of this is shown in **Fig.7**.

In this method, chloride adhering to gauze is dissolved with refined water or a similar solvent, and then the airborne choride ion content is evaluated by measuring the salinity of the solution. The chloride collection area is the same as with the PWRI-type collector, and the airborne choride ion content units by the dry gauze method are also the same as with the PWRI-type collector. Furthermore, the dry gauze method involves a structure that allows the wind to pass through, and thus it is difficult to ascertain how much airborne choride ion has adhered and from which direction. Therefore, a collector is proposed with eight airborne choride ion collecting surfaces and a structure that does not allow wind to pass through gauze[14] (see **Photograph 11**).

Fine salt particles drifting in the air might not adhere to the surface of a stainless-steel plate in a PWRI-type airborne choride ion collector. However, it is predicted that with the dry gauze method, in contrast to the PWRI-type collector, chloride with large particles, as in sea spray, cannot be caught. In addition, rainfall and snowfall adheres to the collecting surfaces of both, and thus it may not be possible to prevent this effect.

Furthermore, when we consider that chloride penetrates concrete structures, the chloride adhering to the surface of a structure does not all penetrate the interior of the structure. Some of the chloride penetrates owing to washout or adsorption into the porous concrete body. Hence, using a material close to concrete in or der to evaluate the salinity flying toward and penetrating structures may lead to properly ascertaining the airborne choride ion content. Based on such thinking, Saeki, et al.[15] propose an airborne choride ion measuring technique using thin-disk mortar specimens of diameter 100 mm and thickness 10 mm.

In recent years, thin-plate mortar specimens even smaller than thin-disk mortar specimens[16] (height 40 mm, length 40 mm, thickness 5 mm) have become available and have been increasingly used (see **Photograph 12**).

(2) Example of evaluating airborne choride ion environment with thin-plate mortar specimens

A quantitative evaluation of external sources of deterioration is required for the construction and rational operation and maintenance of durable structures. Here, we show examples of measuring airborne choride ion with thin-plate mortar specimens, which have been increasingly used in recent years[16].

It is assumed that thin-plate mortar specimens, depending upon how they are mounted, will be affected by the flow of rainwater adhering to structures (see **Fig. 8**). No effects due to differences in mounting were found as shown in **Fig. 9**, based upon the results of verifying differences in salt collection due to differences in mounting on four exposure test sites and 10 bridges in Okinawa Prefecture[17)].

In addition, thin-plate mortar specimens and PWRI-type specimens (four directions) were compared at the Irabu Bridge exposure site on Miyakojima Island in Okinawa Prefecture. **Fig. 10** shows the results. Based on the results, although there are only four data points, both methods showed a good correlation[17)].

The coastal area on the Japan Sea side, including Niigata Prefecture, is known to be a severe salt damage environment similar to Okinawa Prefecture. In Reference [18)], the airborne choride ion environment from the sea is evaluated as an external source of salt damage deterioration with thin-plate mortar specimens. Here, an evaluation was performed by correcting for the distance from the coast, and accounting for coastal conditions in each exposure location. The type of coast (sandy beach, rocky shore), the presence of wave dissipation structures (wave dissipating blocks, breakwaters), elevation, wind direction, and wave energy were considered for the correction.

The corrected distance calculation formula is as in formula (1).

$$x = (x_0 + 25z)\frac{1}{\cos\theta} \cdot \frac{39.6}{W_0} \quad (1)$$

Here, x: Distance after correction (m)

x_0: Distance from actual coast (m)

θ: Angle formed by most frequent wind direction and shoreline right angle direction

z: Elevation (m)

W_0: Target location wave energy (kW/m)

Fig. 11 shows the relationship of the above corrected distance with the surface chloride ion oncentration. Here, the surface chloride ion concentration assumes concrete with a water-cement ratio of 50% using ordinary Portland cement, and a unit cement content of 350 kg/m^3, and is converted from the amount of chloride penetration of a thin-plate mortar specimen.

From **Fig. 11**, it is possible to verify that surface chloride ion concentration can be estimated with high accuracy by distance correction accounting for coastal conditions. Furthermore, although coastal conditions are visually classified according to “rocky shore,” “sandy beach,” and the presence of wave dissipation structures, no definite effects of these factors were found within the scope of the survey in the present study.

The chloride ion concentration on concrete surfaces provides the boundary condition required to analyze the chloride penetration of reinforced concrete buildings in salt damage environments. The usefulness of formula (1) needs to be verified in many regions.

(3) Issues with evaluating airborne choride ion environments

The locations encompassed by the broken line in **Fig. 11** is a special environment with obstacles such as windbreaks. The evaluation of their effects is a pending issue for the future. In addition, formula (1) uses the assumptions in the "Maintenance" section of the 2007 Standard Specifications for Concrete Structures, in which elevation increasing 1 m corresponds to distance from the coast increasing 25 m. This assumption is believed to be correct when there is no local updraft or obstacles near the surface of the ground. However, when there is a local updraft from coastal structure or buildings, or obstacles due to clusters of buildings, then the airborne choride ion content may increase higher above the ground rather than close to the ground, an example of which is shown in **Fig. 12**.

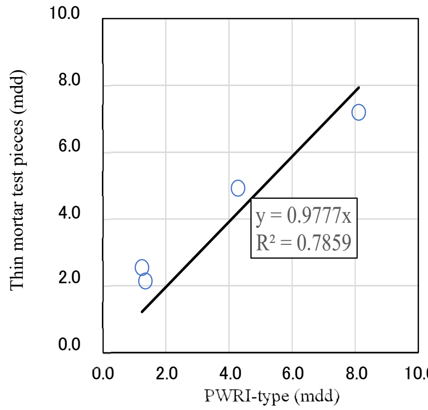


Fig.10: Comparison of PWRI-type and thin mortar

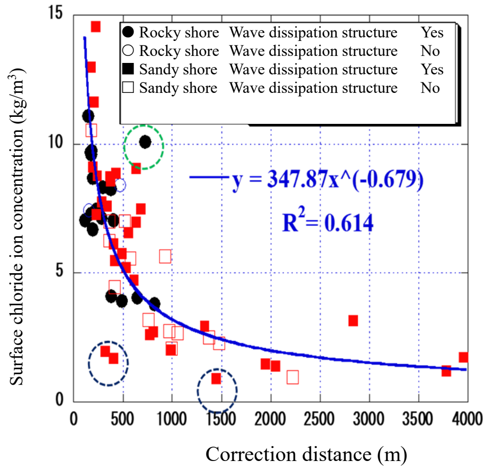


Fig. 11: Relationship of correction distance and surface chloride ion concentration

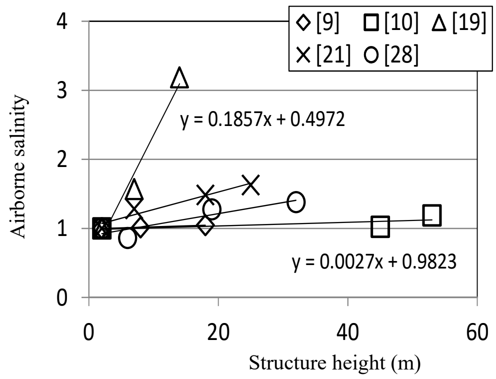


Fig. 12: Comparison of structure height and airborne salt amount

Fig. 12 shows the results[19] of measuring the airborne choride ion content by mounting multiple thin-plate mortar specimens in the height direction of a structure at five locations on the grounds of a thermal power plant near the coast. Here, the percentage of increasing airborne choride ion content on the vertical axis assumes the airborne choride ion content at a structural height of 2 m at each monitoring location to be a reference value, and the airborne choride ion content at each structural height is divided by this

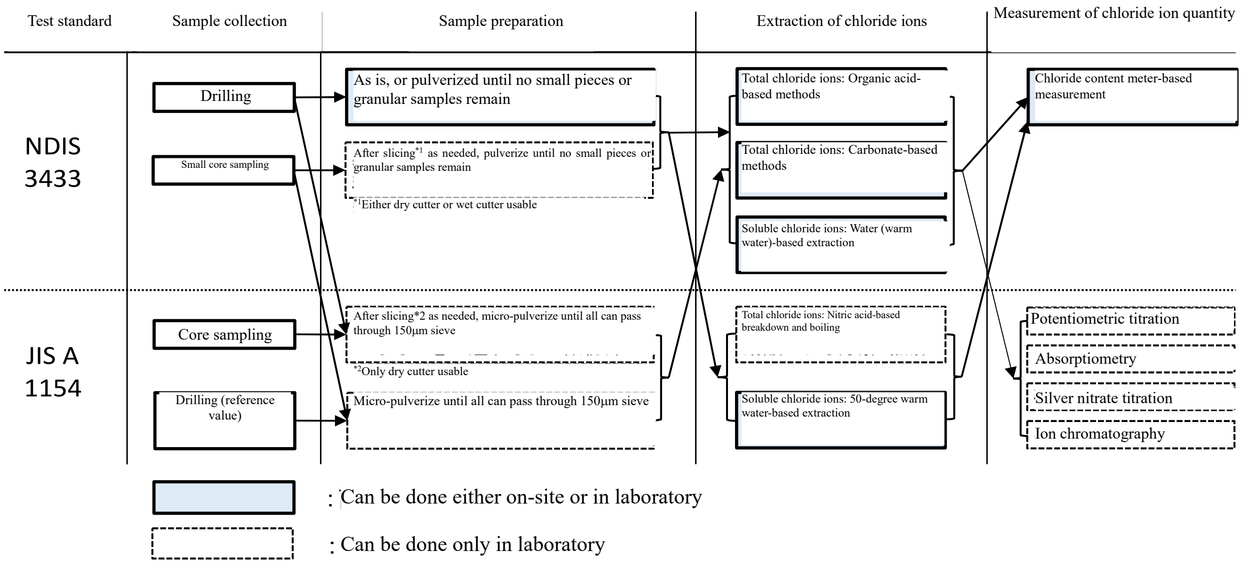


Fig. 13: Comparison of NDIS and JIS test methods

reference value. From the figure, in thermal power plants with structures packed tightly together near the coast, if the structures are higher rather than closer to the ground, then cases in which airborne choride ion content increases, and a tendency for the airborne choride ion content to be largely constant regardless of height, are found. It is thought that numerical analysis[20)] should be used to evaluate the local effects of such structures.

3.2 Simple test methods for chloride ion content

In the 2003 JIS A 1154 (testing methods for chloride ions contained in hardened concrete), core samplings three times or larger than the largest size of rough aggregate was the standard. Reduced damage to structures and accelerated testing was desired from a need to prepare analytical samples and conduct test chamber analysis.

Against this background, in 2017, The Japanese Society for Non-Destructive Inspection further enacted NDIS 3433 (Simple test methods for chloride ion content in hardened concrete) (hereinafter, NDIS). Here, we present a summary of NDIS.

Fig.13 shows a comparison of NDIS and JIS testing methods. In NDIS, drilling or small core sampling is the standard for sample collection. The weight of samples required for analysis may also be small.

Sample preparation in JIS is by micropulverizing until all the particles can pass through a 150 μm sieve, but this is time-consuming. In NDIS, if preparation is by drilling, then it is done until no particles remain. This has been experimentally verified to have no effect on the test results[21)]. In addition, core cutting may be performed using a wet cutter, which simplifies the testing.

Chloride ion extraction in JIS involves filtering a solution that has been boiled and dissolved using acetic acid, whereas in NDIS, a method is adopted in which all the chloride ions are extracted using an organic acid or carbonate, which may be completed within approximately 20 minutes. In addition, in NDIS, a simple meter is used to measure the chloride ion content, such as those used in fresh concrete salinity measurements, including Mohr's method (detection paper, detector tube), coulometric titration, or ion electrometry. The method may even be employed at survey sites.

If this series of methods is combined into a rushed procedure, then test results may be obtained within approximately 1 to 2 h after starting sample collection at a survey site. This is effective for obtaining onsite test results for outdoor structural surveys and exposure tests, and setting upon survey plans and sample collection plans. In addition, although test accuracy is a problem with such simple test methods, it has been verified that test results of consistent accuracy (JIS method ±10%, for example) can be obtained even when applying the series of methods proposed by NDIS.

4. Soil degradation

Chemical deterioration is given as a deterioration factor that hinders the durability of reinforced concrete buildings. In Kyushu, there are many volcanos that are presently active, such as Mt. Aso, Mt. Kirishima, and Mt. Sakurajima, and which have a wide distribution of hot spring zones around them such as Yufuin, Beppu, and Kirishima. In addition to old coal fields, there are scattered sightings of sulfate soil. This SWG conducted a survey of deterioration in concrete attributable to chemical factors. This consisted mainly of deterioration due to the soil, and focused primarily on the literature and past research of group members.

(1) Strong acid environments

As described above, there is a wide distribution of strong acidic soil in volcano and hot spring zones in Kyushu. Civil engineering structures that come into contact with these zones, such as the Oita Expressway that traverses Kyushu, had careful surveys and experiments conducted prior to any work[23]. The hot springs in Tsukahara and Myoban are strongly acidic, approximately pH 1 to 2 and pH 2 to 3 respectively, and the surrounding soil is also strongly acidic. In general, it has been shown that measures for the densification of concrete in strong acidic environments, such as lowering the water-cement ratio, have tended to have the opposite effect[24][25]. In the same work

Photograph 13: Exposure experiment in Kirishima volcanic zone (underground laying in back soil)

project, measures were undertaken such as increasing the concrete thickness, adding corrosion-resistant lining to surfaces, and providing alkaline soil treatment[26]. In recent years, bridges in the Kirishima volcanic zone have been built with concrete using shirasu as fine aggregate for a strong acid measure, which has proven effective[27].

(2) Weak acid environments

In construction, it is rare for concrete structures built on sulfuric acid soil such as hot spring zones to be directly exposed to strongly acidic sulfuric ground. Often, they come into contact with sulfuric acid soil with a relatively low concentration of approximately pH 4 to 5. However, in weak acid environments, it takes several years to decades for deterioration to advance, and thus there are few examples of research. However, as found among the members of this group, because the reaction process and products in concrete deterioration in strong acidic environments and deterioration in weak acid environments are often different[28], it is not appropriate to predict and evaluate deterioration in weak acid environments from results obtained in strong acidic environments. In other words, accelerated tests are not appropriate. Consequently, considerable time is required for experiments, but exposure experiments lasting over 10 years have been conducted in the Kirishima volcanic zone[29] (**Photograph 13**). From these results, it is clear that it is possible to deal with weakly acidic sulfuric acid soil by densifying concrete through the use of low water-cement ratios and admixtures.

(3) Sulfate soil

In residential areas built using slag near old coal fields, examples are seen of concrete floor post footings and continuous footings deteriorating under floors, as in research by technical committee members. Sulfate ions in the ground concentrate under floors as sulfates, and as a result of ettringite generation and sodium sulfate crystal pressure, there are common points of concrete deterioration. Therefore, the sulfate ions contained in the ground clearly influence sulfates and concrete deterioration[30)]. Deterioration was mild in examples of mat foundations that did not expose soil under floors. In addition, experiments by group members demonstrated that it is possible to reduce deterioration through densification of concrete and properly using admixtures[31)].

5. Conclusion

This technical committee attempted to share a cooperative framework for personnel training (development of successors), know-how, and concrete engineering, which is indispensable for long-term exposure tests. We consider the achievements of the technical committee to be as follows.

(1) Studied the actual state of frost damage and the size of external sources of deterioration in the Kyushu and Chugoku regions.

(2) Initiated the collecting of test data by commencing exposure to frost damage in the Kyushu and Chugoku regions.

(3) Ascertained trends over the past 10 years in research and test techniques for carbonation, salt damage, and soil degradation.

(4) Discussed the state of exposure tests, standardized exposure tests, shared and sorted information, including handling of know-how and data, and revised the "Manual for long-term exposure tests of concrete" proposed by the technical committee in 2003.

(5) Developed next-generation leadership for exposure tests in the concrete field and constructed a test cooperation network.

In the 2003–2004 study report, Chairman Noboru Sakei wrote in the closing of his foreword, "Since studies based on exposure tests will take a long time, I hope that the collection and effective use of data is passed onto the next technical committee." All the members of the technical committee would like to take this to heart, and pass on the sentiment to the next generation.

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