Conservation and Restoration of Concrete Structures









Independent Administrative Institution
National Institutes for Cultural Heritage
Tokyo National Research Institute for Cultural Properties

Foreword

The Tokyo National Research Institute for Cultural Properties is presently involved in research of various tangible cultural properties including methods for their preservation and restoration. Particularly regarding fundamental studies with the aim of protection of diverse cultural heritage properties from Japan's Modernization period following the Meiji Restoration in 1868, a project titled “Research on Conservation and Restoration of Modern Cultural Heritage Properties” was established in 2001 when the institute became an independent administrative institution. Since then, an annual theme has been set and study meetings have been held, inviting guests from Japan and abroad, to share information so that further advancements in our studies could be made.

In the meantime, in 2006, so as to convey our strong focus on preservation and restoration of cultural heritage properties from the Modern era, the name of the section in charge was changed from Technical Application Section to Modern Cultural Heritage Section, and the organization has been reinforced.

Topics that have been dealt with pertaining to modern cultural properties are vessels, aircraft, large-scale structures, steel structures, and concrete structures. Additionally, we have focused on media for recording audio and video including vinyl records, film, and tape. Preservation issues that were focused on regarding works that employ such materials as oil paint, Western paper, or modern textiles have been published as a series of reports titled“Conservation of Industrial Heritage."

Although the basic principles regarding protection of Modern heritage as cultural properties have already been provided by Japan's Agency of Cultural Affairs in 1996 in a report titled “Preservation and Adaptive Use of Modern Cultural Heritage,” twenty years have passed since its publication. Since then, preservation of cultural heritage properties has come to include cases in which working properties need to be protected with their original functions intact or while requiring enhancement, rather than as mere monuments. They also may involve changes in use or planning for adaptive use. Today, various flexible measures need to be derived for each property according to their characteristics. Therefore in 2015, a study meeting with the theme of principles for preservation and restoration was held, to summarize the outcome of the past projects, which was published as “Principles for Conservation and Restoration of Modern Cultural Heritage Properties.” Nevertheless, it cannot be denied we are still only at the beginning of our studies on modern cultural heritage properties.

From fiscal year 2016, as the fourth mid-term (a five year period from 2016-2021) in the schedule planned by the institute was about to begin, the Modern Cultural Heritage Section in order to further promote the deepening of our research into a wider field, focused on brick structures. As a result of their comparatively successive national cultural properties designation, brick masonry structures have been restored and much experience has been gained over the years. The outcome was compiled into a report titled “Conservation and Restoration of Brick Masonry Structures” and “Conservation and Restoration of Steel Structures.” This fiscal year, we decided to concentrate on concrete structures, focusing on deterioration of the concrete material, issues regarding structures such as carbonation of concrete, seismic reinforcement, as well as restoration of exterior. Presented in this report are papers gathered from leading specialists who are well informed on cases in Japan as well as foreign countries together with case studies documented by the Modern Cultural Heritage Section over the past year.

I would like to thank all of those who took part in this research and seminar and hope that full use of this report would be made in the actual practices of preservation and restoration of concrete structures.

Our institute intends to proceed with studies on theory and methods for protection of modern cultural properties through involvement in actual cases of restoration. We would like to ask you for your continued support and cooperation.

Saito Takamasa
Director General
Tokyo National Research Institute for Cultural Properties

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Introduction

Introduction

Kitagawa Daijiro *

Head of Modern Cultural Heritage Section
Center for Conservation Science
Tokyo National Research Institute for Cultural Properties

* Currently, Senior Conservator of Cultural Properties, Agency for Cultural Affairs

1. Cultural Property Designation

Among nationally designated Important Cultural Properties (structures), the ratio of concrete structures is merely 3.6% (**table 1**). Although this is extremely small compared to wood-frame structures, when limited to designated structures other than those of wood-frame, they comprise the largest category.

The first reinforced concrete structure to be nationally designated as an Important Cultural Property was the Yamamura Family Residence (Hyogo Prefecture) in 1974. There were no designations of concrete structures to follow for a while until the 1990s, when nationwide surveys were begun on heritage properties from Japan's modernization period. This brought chances for designation as Important Cultural Properties of not only architecture, but also various structural types including dams and bridges. In fact, the number of designated concrete structures after the start of designation of "modernization period properties" has increased to approximately 10% of all Important Cultural Properties and continues to be on the rise.

The presently designated Important Cultural Property structures categorized into architecture and those related to civil engineering or industries are listed in **tables 2** and **3**. Regarding architecture (**table 2**), all are either reinforced concrete or steel-framed reinforced concrete structures, except for Ijokaku [Sun Yat-sen Memorial Hall] (Hyogo Prefecture) which is a concrete block masonry structure. Regarding construction period, they are from the Taisho period (1912-1926) on, when developments were made in reinforced concrete technology and concrete structures became more common. Particularly regarding steel-framed reinforced concrete structures, they can be seen among commercial and office buildings from the start of the Showa period (1926-1989) and later years. Overall, many of the concrete structures are large in scale and located in urban areas for use by the general public. Therefore, in planning their restoration, focus is often placed on the assurance of safety.

On the other hand, regarding civil engineering structures and industrial heritage properties (**table 3**), the ratio of non-reinforced and reinforced concrete structures is about the same and compared to architectural works, many are from the Meiji period (1868-1912). Also, among the types

table 1 Percentage of buildings nationally designated as Important Cultural Properties by type of building material (as of June of 2018): Buildings of supplementary designation are not included. The table is based on data provided by the Agency for Cultural Affairs.

wood	earthen-walled	stone	concrete	brick	steel	copper	earth
77.0%	8.2%	6.6%	3.6%	3.4%	0.7%	0.4%	under 0.1%

table 2 List of buildings nationally designated as Important Cultural Properties (as of June of 2019) The table is based on data provided by the Agency for Cultural Affairs.

Location		Name of Property		Year of Construction	Structure
Hokkaido	Hakodate City	Otani-ha Branch Hongan-ji Temple Hakodate Branch Temple	Worship Hall	1915	RC
			Belfry	early Taisho era	RC
			Main Gate	early Taisho era	RC
Akita	Daisen City	Former Ikeda Family Residence Western-style Residence		1922	RC
Saitama	Kawajima Town	Former Tōyama Family Residence	Earthen Storehouse	1934	RC
Tokyo	Chiyoda Ward	Meiji Life Insurance Company Main Building		1934	SRC
	Chuo Ward	Mitsui Main Building		1935	SRC
		Tsukiji Hongwan-ji Worship Hall		1934	SRC
		Mitsukoshi Nihonbashi Department Store		1927	SRC
	Chiyoda Ward	Takashimaya Tokyo Department Store		1933•1954	SRC
	Minato Ward	Former Residence of Prince Asaka (Tokyo Metropolitan Teien Art Museum)	Main Building	1933	RC
			Storehouse	1933	RC
			Garage	1933	RC
			Main Gate	1933	RC

Location		Name of Property		Year of Construction	Structure
Tokyo	Taito Ward	The National Museum of Western Art Main Building		1959	RC
		Former Tokyo National Museum of Nature and Science Main Building		1931	SRC
		Former Imperial Museum Main Building		1937	SRC
	Shinjuku Ward	Waseda University Okuma Memorial Hall		1927	SRC
		Meiji Memorial Picture Gallery		1926	RC
	Shibuya Ward	Former Asakura Family Residence	Earthen Storehouse	ca. 1919	RC
		Meiji Jingu Homotsuden Treasure Museum	Middle Storehouse	1921	RC
	Shibuya Ward	Meiji Jingu Homotsuden Treasure Museum	East and West Storehouses (2 structures)	1921	RC
			East and West Corridors (2 structures)	1921	RC
			East and West Bridge Corridors (2 structures)	1921	RC
			North Corridor	1921	RC
			Car Portico	1921	RC
			Office	1921	RC
			Main Gate	1921	RC
	Meguro Ward	Former Maeda Family Main Residence	Western-style Residence	1929	RC
			Western-style Residence Connecting Corridor	1930	RC
			Guard House	1929	RC
			Main Gate and Wall	1929	RC
		Sonkeikaku Library	Reading Hall	1928	RC
			Book Vault	1928	RC
			Treasure House	1928	RC
			Gate and Wall	1928	RC
Nagano	Ueda City	Former Tokidakan Silk Mill Facilities	Five-storied Reinforced Concrete Cocoon Warehouse	1926	RC
	Suwa City	Katakurakan	Bath House	1928	RC
Shizuoka	Atami City	Former Hyuga Family Atami Vacation Residence Basement		1936	RC
Aichi	Nagoya City	Aichi Prefectural Hall		1938	SRC
		Nagoya City Hall		1933	SRC
Kyoto	Kyoto City	Former Kyoto Central Telephone Exchange Nishijin Branch		1921	RC
	Uji City	Shoden Sanso Villa	Treasure Storehouse	1934	RC
Osaka	Osaka City	Cotton Trade Hall		1931	SRC
Hyogo	Kobe City	Former Murayama Family Residence	Clothing Storehouse	Taisho era	RC
			Art Storehouse	Taisho era	RC
		Ijokaku (Sun Yat-sen Memorial Hall)		1915	wood-frame CB
	Nishinomiya City	Kobe College	Administration Building (including Auditorium and Searle Chapel)	1933	RC
			Library	1933	RC
			Literature Building	1933	RC
			Science Building	1933	RC
			Music Building	1933	RC
			Gymnasium	1933	RC
			Hokokan (High School Building)	1933	RC
			Social Center	1935	RC
			Boiler House	1933	RC
			Main Gate and Guard House	1933	RC
	Ashiya City	Former Yamamura Family		1924	RC
Hiroshima	Hiroshima City	Hiroshima Peace Memorial Museum		1955	RC
		Hiroshima Memorial Cathedral for World		1954	RC
Yamaguchi	Yamaguchi City	Arichika Family Residence	Main Gate	ca. 1924	C
	Ube City	Ube City Watanabe Memorial Hall		1937	SRC
	Hofu City	Former Mouri Family Main Residence	Storehouse with Kitchen	1916	RC
			Office Storehouse	1916	RC
			Stone Bridge	1916	RC
			Main Gate	1916	RC
Tokushima	Tokushima City	Mikawa Family Residence		ca. 1928	RC
Aichi	Matsuyama City	Bansuiso (Former Hisamatsu Family Villa)	Main Building	1922	RC
Okinawa	Ogimi Village	Former Ogimi Village Hall		1925	RC

of non-reinforced concrete structures, there is rubble-filled concrete with limited use of cement and increased ratio of aggregate. This was used in enormous structures requiring large amounts of cement such as dams. Also, not included in the table are structures of man-made stone using a cement substitute (lime and powdered granite) as seen in the Yokkaichi Old Port Breakwater (Mie Prefecture). It needs to be noted that compared to architecture, their locations (proximity to the sea, river, or mountain) and exterior forces to be considered (waves, mudslides, or water pressure) are varied. Also, many are operating infrastructure facilities. Therefore, it is difficult to generalize the methods to be employed for restoration, repairs, and seismic reinforcement.

2. Cultural Property Restoration Focusing on Structural Characteristics

Structures made of concrete (excluding concrete blocks and precast concrete) differ from those of brick or steel in that they are monolithic and not composed of standardized elements. (Structures of brick and steel had been chosen respectively as research themes starting in 2016 by the Modern Cultural Heritage Section at Tokyo National Research Institute for Cultural Properties.) This is also the difference between wood-frame structures, making it difficult to apply traditional methods involving dismantlement for restoration and repairs.

On the other hand, concrete is one of the materials for

table 3 List of civil engineering structures nationally designated as Important Cultural Properties (as of June of 2019) The table is based on data provided by the Agency for Cultural Affairs.

Location		Name of Property		Year of Construction	Structure
Akita	Akita City	Fujikura Reservoir Waterworks Facilities	Dam	1911	C
			Floodway	1911	C
Gunma	Annaka City	Former Usui Pass Railway Facility	Kumanotaira Substation Main Building	1937	RC
	Katashina Village	Marunuma Dam		1931	RC
Ibaraki	Takahagi City	Ishioka First Power Plant Facilities	Intake Weir	Taisho era	C
			Settling Basin	1911	RC
			First Aqueduct	1911	RC
			Second Aqueduct	1911	RC
			Pressure Controlling Cistern	1911	RC
			Main Building Dynamo Hall	1911	RC
			Main Building Former Transformer Hall	1911	RC
			Main Building Substation Hall	1916	RC
Tokyo	Arakawa Ward	Former Mikawajima Sewage Treatment Plant Pump Facilities	East and West Sluice Gate Chambers	1921	RC
			East and West Grit Chambers and Screen Rooms	1921	C
			Screen Room Shed	1921	RC
			Water Meter Chamber and Pump Chamber Culvert	1921, 1923	RC
			Pump Chamber	1921	RC
Kanagawa	Hakone Town	National Highway Number One Hakone-Yumoto Roadway Facilities	Kanrei-Domon Tunnel	1931	RC
			Chitose-bashi Bridge	1930	RC
			Asahi-bashi Bridge	1933	RC
Niigata	Niigata City	Bandai-bashi Bridge		1929	RC
	Sado City	Former Sado Mine Mining Facilities	Odate Vertical Shaft Winch House	1940	RC
Toyama	Toyama City	Joganji-gawa River Erosion Control Facilities	Shiraiwa Dam	ca. 1939	C
			Hongu Dam	1936	C
			Dorodani Dam	1931-32	C
		Fugan Canal Lock Gate Facilities (Nakajima Lock Gate)	Lock Gate	1934	C
Yamanashi	Otsuki City	Yatsusawa Power Plant Facilities	First Tunnel	1912	C
			Second Tunnel	1912	C
			First Aqueduct	1912	RC
			Third Tunnel	1912	C
			Fourth Tunnel	1912	C
			Fifth Tunnel	1912	C
			Sixth, Seventh, Eighth, Ninth, Tenth, and Eleventh Tunnels	1912	C
			Twelfth, Thirteenth, Fourteenth, Fifteenth, Sixteenth, Seventeenth, and Eighteenth Tunnels	1912	C
Nagano	Nagiso Town	Yomikaki Power Plant Facilities	Power Plant	1923	RC
			Kakizore Aqueduct	1923	RC
			Momosuke-bashi Bridge	1922	RC

which contemporary construction methods continue to be avidly developed. In recent years, technological innovations are being made not only for new construction, but also for maintenance and repairs. Because the number of cases of restoration of historic concrete structures is still few and restoration techniques have not yet been fully developed, it is perhaps realistic to rely on contemporary construction technology in restoration of concrete structures. In this world of concrete without “traditional construction techniques,” new methodologies different from those for traditional cultural properties need to be sought after.

Of course, although the approach might be different, the restoration principles for traditional cultural properties including reversibility, minimum intervention, harmonization of appearance, and application of reliable technical experience are the basics to be followed. However, from observing past restoration experiences of concrete structures, it appears that there are other rules to be regarded.

For example, when taking into account characteristics of a concrete structure as a monolith, designing a new additional member for seismic reinforcement is difficult as compared to wood-frame structures, in which each building member can be handled individually. Therefore, there are cases in which the balance between structural significance and function is pursued and an irreversible reinforcement method, involving increased wall thickness or insertion of pre-stressed con-

Location		Name of Property		Year of Construction	Structure
Aichi	Inuyama City	Former Shinagawa Lighthouse		19649 (1872)	RC
Kyoto	Kyoto City	Umekoji Locomotive House		1914	RC
	Maizuru City	Maizuru Former Navy Base Waterworks Facilities	Katsura Intake Weir	1900	C
			Katsura Measuring Weir	1900	C
			Former Kishitani River Upper Stream Mainstream Intake Weir	1905	C
			Former Kishitani River Upper Stream Subsidiary Stream Intake Weir	1905	C
Osaka	Osaka City	Oe-bashi Bridge and Yodoya-bashi Bridge	Oe-bashi Bridge	1935	RC
			Yodoya-bashi Bridge	1935	RC
Hyogo	Kobe City	Nunobiki Reservoir Waterworks Facilities	Diversion Dam	1907	C
			Diversion Dam Bridge	1907	RC
			Closed Dam	1908	C
			Gohonmatsu Dam	1900	C
			Tanigawa-bashi Bridge	early Taisho era	RC
			Mendaki Intake Weir	1900	C
Okayama	Kurashiki City	Takahashi-gawa River East and West Water Intake and Service Facilities	Sakazu Intake Sluice	1920	RC
			South Service Sluice	1923	RC
			North Service Sluice	1922	RC
Hiroshima	Kure City	Honjo Reservoir Dam Waterworks Facilities	Dam	1916	C
			First Measuring Pool	1916	C
Tottori	Tottori City	Mitani Old Fountainhead Water Facilities	貯 Reservoir Dam	1922	C
			Mitani-gawa River Upper Stream Measur ing Weir	1915	C
			Toridani Measuring Weir	1915	C
			First Filter Basin	1915	C
			Second Filter Basin	1915	C
			Third Filter Basin	1915	C
			Fourth Filter Basin	1915	C
			Fifth Filter Basin	before 1928	C
			Junction Well	1915	C
			Water Meter Chamber	early Showa era	RC
Kagawa	Kanonji City	Honen-ike Dam		1929	C
Kochi	Kitagawa Village	Former Yanase Shinrin Railways	Futamata-bashi Bridge	1940	C
			Horigawo-bashi Bridge	1941	RC
Fukuoka	Shime Village	Former Shime Coal Mine Shaft Tower		1943	RC
Nagasaki	Nagasaki City	Hongochi Reservoir Waterworks Facilities	Lower Dam	1903	C
	Sasebo City	Sasebo Radio Transmission (Hario Transmitting Station) Facilities	Radio Towers	1922	RC
			Telegraph Room	1922	RC
			Oil Storage	1922	RC
Oita	Takeda City	Hakusui Reservoir Dam Farm Irrigation Facilities	Main Dam	1938	C
			Subsidiary Dam	1938	C

crete steel bars, is chosen. Here, it is minimum intervention or harmonization of the exterior appearance that has been prioritized, rather than reversibility. The importance of minimum intervention in repairing concrete structures has been pointed out by Professor Eugen Brühwiler of Swiss Federal Institute of Technology Lausanne (Switzerland), in an interview undertaken in the course of publication of this report.[1]

Also, there are times when it becomes difficult to comprehensively follow the two principles of minimum intervention and harmonization of the exterior appearance. For example, when a deteriorated portion of a concrete structure is to be carved off and filled with fresh concrete, the section to be processed should be limited to a minimum. However, rarely is a clear standard set for the area or form to be carved off, which actually differs by object. Also, with a new concrete finish, it might be possible to replicate the coloring and surface texture of formwork, but it would be difficult to perfectly match this finish with the extant structure. The colors might appear to be perfect when completed, but as time passes, there are cases where differences in the original and new finishes become apparent. Therefore, at Saint Clement's Church (Bettlach [Switzerland], completed in 1966) with the idea of minimum intervention in mind, the damaged areas to be repaired were intentionally carved off in geometric shapes outlined by simple lines, to match the architectural design based on geometry (**photo 1**). This can be referred to as an attempt in balancing both minimum intervention and harmonization of the exterior appearance.

3. Outline of this Report

With an understanding of the aforementioned social background regarding cultural property designation and characteristics of concrete structure restoration, it was decided to focus on a wide range of topics from construction materials to seismic reinforcement in this report. From the aspect of materials, Professor Kei-ichi Imamoto of Tokyo University of Science has pointed out "Current issues related to the conservation and restoration technology used for historically important concrete constructions." In this paper, an overall view of restoration methods for concrete structures has been given, followed by an explanation of the innovative attempts taken in the restoration of The National Museum of Western Art Main Building.

The following chapter, "Restoration of Mitani Old Fountainhead Water Facilities and Early Reinforced Concrete Structures in Japan," was written by Senior Fellow Mr. Hasegawa Naoji of The National Institute for Land and Infrastructure Management (NILIM) in which restoration details of a severely deteriorated concrete structure were focused on. A technological history of reinforced concrete has also been compiled.

Also regarding seismic reinforcement is a paper by Mr. Nishioka Satoshi, a Specialist for Cultural Properties, at the Agency of Cultural Affairs titled "Issues in Anti-Seismic Technology for Historic Concrete Structures." This deals with topics that are directly applicable to restoration practices, including guidelines for seismic reinforcement, reinforcement designs, and an introduction of notable cases of seismic reinforcement in recent years.

Lastly, Mr. Ishida Shin-ya, an associate fellow at the Tokyo National Research Institute for Cultural Properties, wrote a chapter introducing various restoration projects of concrete structures in Japan.

As with our previous reports on preservation and restoration of brick masonry structures (2017 [English edition 2019]) and steel structures (2018 [English edition 2020]), this report is aimed at practitioners and comprised mainly of

photo 1　Saint Clement's Church（photo taken by: Kitagawa Daijiro）

analyses of case studies rather than theoretical studies. Perhaps “Conservation and Restoration of Concrete Structures” (Tokyo National Research Institute for Cultural Properties, 2010 [English edition 2012]) which was compiled ten years ago focusing on the cutting-edge technology at that time, would be of reference in understanding restoration of concrete structures.[2]

Footnotes

1. BRUHWILER E., Les pont en béton armé de Robert Maillart : intervenir pour pérenniser, Cahiers du TSAM, pp. 126-141.
2. https://www.tobunken.go.jp/image-gallery/conservation/index.html

Summary of a 1st Study Meeting on Preservation and Restoration of Concrete Structures

Date：June 17, 2018, 16:00 ～ 18:00

Place：Tokyo National Research Institute for Cultural Properties

Participants：Imamoto Keiichi (Tokyo University of Science), Onoda Shigeru (Railway Technical Resarch Institute), Suzuki Kei (Nihon University), Hasegawa Naoji (National Institute for Land and Infrastructure Management), Honma Nobuyuki (Bureau of Construction, Tokyo Metropolitan Government), Mukai Tomohisa (Building Research Institute), Igawa Hirofumi / Nishioka Satoshi (Agency for Cultural Properties), Kitagawa Daijiro / Ishida Shin-ya / Toriumi Hidemi / Nakayama Shunsuke / Nishi Kazuhiko (Tokyo National Research Institute for Cultural Properties)

Kitagawa: The investigation on the conservation and rehabilitation of concrete buildings was conducted in the third year of the five-year plan of the Modern Culture Heritage Section, whereas the brick buildings were conducted in the first year, and iron structures in the second year. Buildings designated and registered as buildings or structures designated as historical sites were considered as subjects. The following scope of service were considered in the survey: conservation and repair properties in Japan, overseas rehabilitated properties of structures designed by Robert Maillart of Switzerland and Pier Luigi Nervi of Italy, etc. Additionally, several relevant materials were prepared.

- Japan Society of Civil Engineers: Guidelines for Reinforcement of Concrete Structures (Draft) [（社）土木学会：コンクリート構造物の補強指針（案）], 1999.
- Taiheiyo Cement Group: All About Survey, Diagnosis, and Repair of Concrete Structures[太平洋セメントグループ：コンクリート構造物の調査・診断・補修すべて], 2005.
- Japan Concrete Institute: 100 Years of Japanese Concrete[（社）日本コンクリート工学協会：日本のコンクリート 100 年], 2006.
- Japan Concrete Institute: Report of Research Committee for Diagnosis and Rehabilitation of Historical Structures in the Architectural and Civil Engineering Sectors[（社）日本コンクリート工学協会：建築・土木分野における歴史的構造物の診断・修復研究委員会報告書], 2007.

Additionally, guidelines were published by the Architectural Institute of Japan in the 1990s.

Imamoto: The Architectural Institute of Japan published the "Durability Survey, Diagnosis, and Repair Guidelines for Reinforced Concrete (RC) Buildings (draft) and Commentary[鉄筋コンクリート造建築物の耐久性調査・診断および補修指針（案）・同解説]" in 1997 in 2 volumes, and a part pertaining to the durability design in 2016. Additionally, formulation of sections pertaining to survey, diagnosis, repair, and renovation (specifications) is proceeding at present. Moreover, not only concrete but also waterproofing and external walls are planned to be included.

Kitagawa: Is there any difference in the content published by the Japan Society of Civil Engineers and the Architectural Institute of Japan?

Imamoto: There is a big difference in the content of waterproofing and finishing materials. However, they seem to be similar in the concrete investigation and diagnosis sections. Additionally, the lineups of repairs and reinforcements differ.

Measures Against Neutralization

Igawa: The repair of the Former Shime Coal Mine Shaft Tower (hereinafter referred to as the Shime Shaft Tower) started last year. Presently, there is almost no covering thickness of the concrete, so the reinforcing bars are corroded and exploded. Though it will likely be restored to a sound condition, how the finish of the cover part should be treated, etc., has become a problem.

Nishioka: What do you think about deterioration? Should Neutral degradation be considered as degradation? Even in the guidance of the Agency for Cultural Affairs (ACA), it is considered that the deterioration of concrete is not neutralization = deterioration, but rather rainwater and air penetrating into the concrete and corroding the reinforcing bars.

Imamoto: We share a similar approach even among the members of the Architectural Institute. The Architectural Institute has conducted approximately 20 to 30 investigations to date on concrete buildings older than 50 years. Among the investigated properties, the reinforcing bars were not corroded in some structures even when the concrete was neutralized while corrosion had progressed in others. Uncorroded properties were more frequent in previous investigations. The investigation members say that the difference is whether there is adequate concrete cover thickness or not. Along with this investigation, a panel discussion "Reconsideration of limit states" was conducted by the material construction committee at the general meeting of the Architectural Institute last year. The panel discussed whether the neutralization of concrete is an indicator for deciding the limits of concrete. As far as 50–80 year-old buildings that were investigated, no corrosion of reinforcing bars was found even when neutralized, provided that the buildings had sufficient cover. Additionally, it is unlikely that corrosion will proceed rapidly in the future. Agreement on this point was obtained from many of the attended instructors. Heading into the 2020s, we are preparing for a major revision of the RC Work Standard Specifications that reflects this concept. Particularly, the guidelines prepared by the ACA will be used as a reference because they also include items related to the action of water.

Kitagawa: When did the ACA provide guidance on concrete?

Nishioka: March 2017. Specifically, it was the "Guide to Seismic Diagnosis and Seismic Reinforcement of Important Cultural Properties (Buildings) [重要文化財（建造物）耐震診断・耐震補強の手引き（改訂版）]". Diagnostic methods for brick structures, deterioration of concrete structures, countermeasures for ceiling collapse, etc., were added in this revised edition. This guide is also available on our website.

Imamoto: For buildings, the response to water becomes important as it constitutes the outdoor environment. Neutralization is merely a starting line for corrosion.

When the cover is thick, the internal humidity fluctuation is very minimal. When the cover thickness was 3–4 cm, most of the variations in dry and wet conditions occurred in the surface layer. Conversely, if the covering thickness is thin, the effect of dryness and wetness will reach the reinforcing bars, resulting in corrosion. Considering only the deterioration of concrete, it is considered that protecting the concrete using a material with high moisture permeability resistance may suppress humidity fluctuations. Therefore, it may be possible to preserve buildings with thin cover.

Kitagawa: Does the Shime Shaft Tower reflect this idea in terms of covering thickness?

Hasegawa: The investigation work was performed at the Shime Shaft Tower until two years ago. Apart from the cover problem, the reinforcement had already exploded, the concrete had peeled off, and the reinforcing bars were exposed. It was found that the original covering surface was not sufficiently rehabilitated because the covering thickness was thin even after the original covering surface had been restored. Therefore, it is necessary to further add 6 cm of coverage thickness. As to whether this practice is good for the conservation and restoration work of a cultural property is controversial, to preserve the Shime Shaft Tower, an additional 6 cm covering thickness must be added, otherwise the same deterioration will recur.

If we are talking about concrete buildings that are cultural properties, I think it is important to discuss what should be preserved. It was possible to check the formwork traces at that time for the Shime Shaft Tower, and I intuitively think these formwork traces are important. However, these formwork traces will be lost by adding the additional 6 cm covering thickness. Therefore, it is necessary to examine the construction to reproduce the wooden grain of formworks using the same techniques of that time. However, technological and cost aspects are a major problem. In cases where reproduction by formwork is difficult, there is a technique for drawing wood grains. However, it will be conceived that finishing without wood grains is a limitation of the present technology if a plaster finish is desired.

The restoration work of the Hiroshima Memorial Cathedral for World Peace was performed using actual cedar board formworks although it was extremely partial. Because of the high cost, it would be difficult to implement on the entire surface of the Shime Shaft Tower.

Kitagawa: Is there any basis for the 6 cm of cover thickness to be added?

Hasegawa: In the Building Standards Act, pillars and beams have a coating thickness of 3 cm, whereas foundations are 6 cm thick. However, as the cross section of the Shime Shaft Tower is quite large, it is considered as a foundation, and there is a possibility that the tower was considered as a foundation.

We have been discussing about formworks, but considering other things to be upheld, it may be necessary to consider how to preserve the neutralized concrete and corroded reinforcement.

Remediation Method Selection

Kitagawa: Is there an option to retain corroded reinforcing bars in cultural property buildings?

Hasegawa: Not at present. How is the debate actually progressing on Hashima (Gunkanjima)?

Imamoto: Under the leadership of the Japan Concrete Institute, a joint test of approximately 200 exposed specimens is being conducted on Hashima Island regarding repair methods that include the intent to maintain a sense of ruin. In fact, there are some parts of the Shime Shaft Tower in which the reinforcement is sound, and it is thought that the optimization of the repair can be attempted by examining the cover thickness based on existing knowledge.

Kitagawa: Corrosion shows the passage of time, and there are some discussions evaluating this as the accumulation of time.

Hasegawa: There are similar discussions about the Genbaku Dome (Hiroshima Peace Memorial), When the corroded reinforcing bars of the Genbaku Dome (Hiroshima Peace Memorial), etc. had to be preserved, there was a memorable discussion on the possibility of conservation methods similar to those of archaeological materials, such as iron swords preserved in the rusted condition.

Igawa: The repair work of the Hiroshima Memorial Cathedral for World Peace was executed in 1984. Nevertheless, the wall surface repair locations seem like a patchwork presently. The designer, Murano Togo, decided that there would be no particular problems, including wall construction, because it would allow repair irregularities caused by the maintenance and management of the building.

Hasegawa: Regarding the occurrence of irregularities due to repairs, personally, I think it is better not to apply an extra patina, etc.

Igawa: It is believed that irregularities due to surface repairs gradually match with other areas as it changes over time.

Honma: In the Tokyo metropolitan area, long-life construction work is being performed on historical bridges, such as the Hijiri-bashi Bridge, Eitai-bashi Bridge, Kiyosu-bashi Bridge, and Kachidoki-bashi Bridge. Regarding the state of deterioration, as was the case of Shime Shaft Tower and others, concrete flaking occurred where the covering was thin and some of the reinforcement was corroded. Even if a structure had advanced neutralization, reinforcement corrosion was not found if the cover thickness was sufficient. However, locations with poor drainage are vulnerable to degradation. Although members should be sound and dry, in cases where the cover was thin and suffered damage, water was prone to infiltrate, resulting in peeling of concrete and corrosion of reinforcement. This is particularly observed in girder edges and overhanging floor slabs.

In the case of bridges, as they are in service, if the reinforcement is corroded, the structural safety shall be checked by examining the reduction in thickness of the reinforcement. Reinforcement and repair will be implemented according to the content of deterioration and damage. Materials to be used for repair are selected to be similar to the color of existing materials, and consideration is given to not seem out of place, etc.

Kitagawa: Are there any differences in maintenance and repair, etc. of historical bridges and other bridges?

Honma: There are no particular differences.

Kitagawa: What kind of repair should be executed when corrosion has advanced in places where the cover thickness is thin?

Honma: We determine the corrosion range by measuring the thickness reduction of the corroded reinforcement. The concrete in the corroded area is scraped off, and cross-sectional restoration is performed using polymer cement, etc. When repairing, the concrete returns to the pre-repair cover thickness. If necessary, reinforcement is provided with additional reinforcing bars or carbon fiber, etc.

Kitagawa: Are there problems associated with the use of polymer cement that is not being particularly pointed out? It seems to be commonly used in the conservation and repair work of cultural property buildings.

Imamoto: There may be problems depending on the point of use. As polymer cement mortars contain organic polymers, some of them cannot clear the fire resistance tests depending on the content of the polymer. In the case of buildings, additional consideration is required for the use of polymer cements because the concrete construction itself is a fireproof structure.

Nishioka: Are there any aging changes, such as color change, for polymer cement mortars?

Imamoto: I have never heard of changes in color, etc.

Nishioka: Change of color has not been manifested. However, it may appear in the case of the Hiroshima Memorial Cathedral for World Peace.

Igawa: Polymer cement mortar might have been used in the repairs performed in 1984, and these look darker compared to the parts considered to be the original wall surface.

Hasegawa: During the 1984 repairs, it was not designated as a cultural property, so polymer cement mortar would have been used without special care.

Suzuki: On a bridge in Switzerland, the repair work was performed by sticking the material of an imaging film made by BASF (Germany) to the surface of the bridge. However, there was a problem; the attached material turned white. We are currently investigating the details.

About the Value of Buildings and Restoration Methods

Hasegawa: While restoring concrete, it is necessary to appropriately examine the areas/parts that are valuable. Color problems are also a major issue, and further attention should be given on the color matching of the post-complementary materials, etc.

Honma: The survey accompanied with the life extension construction of the Hijiri-bashi Bridge revealed that the floating of the arch part occurred in a relatively wide area. The floating part was peeled off and repaired using polymer cement. At the time of repair, we decided on the color of the repair materials, etc., with the advice of Professor Ito Takashi.

Hasegawa: The repair work performed in 1989 of the Hijiri-bashi Bridge was criticized on the fact that the repairs changed the original mortar finish to a stone-like finish, which destroyed the monolithic design integrating concrete, i.e., the intended design of the Hijiri-bashi Bridge.

Honma: In this project, the degradation of the parts that received such criticism advanced, and repairs were performed based on the original design intention. Nevertheless, polymer cement was used for the finish.

Suzuki: The Melan system was adopted for the Hijiri-bashi Bridge, in which a steel arch was made in advance and then covered with concrete. Probably, considering the current deterioration, there was a problem with the adhesion of steel to the concrete. The Melan system is a construction method developed approximately 120 years ago by a professor at Brno University of Technology in the Czech Republic and brought into Japan by Naruse Katsutake, a professor at Nihon University, who was in charge of the structural design of the Hijiri-bashi bridge.

Kitagawa: In the Melan system, are the structures composed of only a steel frame and concrete? Is there reinforcement?

Suzuki: Reinforcement is also included. The Melan system is still used currently in the construction of the Beppu Myoban-bridge Bridge (1989) for example.

Mukai: In relation to the earlier question raised by Hasegawa about what should be preserved at the sites of recent seismic diagnoses of cultural property buildings, no structural role is expected for corroded reinforcement, and adding a new members is sometimes proposed.. It is sometimes questioned whether this is suitable as a reinforcement method as it utilizes the structural features of RC construction (the feature wherein concrete mutually complements the compressive force and the reinforcement complements the tensile force). In the discussion of reinforcement methods, we will examine the priorities of cultural property values, but as the priorities differ for each building, it becomes very difficult to propose a reinforcement method from the structural side. It is not easy to decide the priority because in some cases, not just the appearance design, but also the shape of the reinforcing bars used are period-specific.

Nishioka: That is always a controversial problem. Normally, we will refer to the designated description, and if the design value is evaluated, then design changes should be avoided, and if the technical value is evaluated, then preference will be given to the preservation of technical parts and materials.

Mukai: For repairing the chimney of the Former Maeda Family Main Residence, the method of reinforcing using out-cables was finally selected. However, the method is assumed to result in a form that has not utilized the structural features of the RC structure. Incidentally, the reinforced chimney was neutralized on to inside. However, the corrosion of the reinforcement was not observed because the concrete was maintained dry internally.

Kitagawa: When replacing corroded reinforcement, should the materials be reproduced to match the shape of the original reinforcement (round steel, etc.)?

Nishioka: Presently, it will be repaired using deformed reinforcing bars.

Kitagawa: Is it affected by being invisible after repair?

Nishioka: Currently, it is often judged as such. In the first repair of the Former Yamamura Family Residence, the round steel parts were repaired using round steel when the concrete was recast, whereas some parts were supplemented with round steel, where reinforcement was insufficient for the structure were.

Hasegawa: Are there any explanations in the specification describing the value of materials, such as reinforcement?

Kitagawa: Even if there is a reference to bar arrangement, it seems that the value of the material is not dealt with.

Nishioka: The Otani-ha Branch Hongan-ji Temple Hakodate Branch Temple has been evaluated and designated as an early example of concrete. I think that the evaluation also includes the material value.

Hasegawa: Although transition periods are observed in historical research on technologies, such as reinforced construction methods, concrete mixing technologies, admixture technologies, etc., they are not always visible. In addition to the use of round steel, there are Hennebique type (Mitsui Bussan Building) and Kahn type reinforcing bars. As for the Kahn type, it was banned for a while after the Great Kanto Earthquake due to the vast amount of damage caused. Additionally, there has been a history of round steel being used in buildings instead of Kahn bars after the earthquake. Thus, the technical transition of concrete buildings is included in the parts that cannot be confirmed from the appearance. There is a question whether such technological changes should be included and preserved or whether the formwork marks on the surface should be preserved. While repairing wooden structures, woods are replaced by the same type of material. However, what should be considered when repairing concrete?

Preservation of Materials and Technical Value

Kitagawa: I think that the “same type, same material” concept of wooden buildings can be applied to iron structures with cast iron, smelted iron, steel, etc. Is it possible to extend this to concrete?

Onoda: There may be differences in terms of aggregates, etc. After 1955, crushed stone was generally used, but before that, river gravel was used. Therefore, there would be a lot of gravel.

Imamoto: Concrete mixes were decided based on the Urban Building Law. Just like the present mortar for plastering, 2-parts sand and 4-parts gravel to 1-part cement and water were mixed on-site. Currently, the water-cement ratio is used. The change in this formulation method changed around 1920–30. This period constitutes one standard. This switchover seems to appear particularly as a difference in strength between the horizontal and vertical members. However, the difference is not apparent.

Kitagawa: Is there a repair case that respects the original water-cement ratio?

Nishioka: I have never heard of one. Is it not just about color? In the Former Yamamura Family Residence, the mortar was mixed with the Oya stone during this restoration. However, the main reason why the Oya stone was mixed was simply that it would affect the appearance. Water had penetrated through the crushed stone to corrode the reinforcing bars because the Oya stone that had been previously mixed had large grains. In this repair work, grain size was changed to a specification where it was a fine powder.

Kitagawa: Is the cement was changed depending on the time?

Imamoto: There is a difference in the particle size of the cement.

Nishioka: Recent concrete may appear bluish.

Imamoto: There is a rule in the world of cement that only 5% of something can be included. There used to be no such rule. Presently, slag is often used for this 5%. Because slag is bluish, the concrete seems to be bluish in color.

Onoda: When we checked railway construction records, we found that volcanic ash was used as a cement substitute. Was there any color difference?

Imamoto: I think there was a color difference. Incidentally, volcanic ash was also used for the joint material of the pyramids. It is also the origin of a mixture called “fly ash”. Volcanic ashis hardened by stimulating with alkali. Moreover, it is a material whose history is older than cement.

Kitagawa: How is the strength?

Imamoto: I think it is low.

Onoda: Is it possible to identify whether volcanic ash is being used?

Imamoto: It is possible to identify because volcanic ashcontains different components than that found in cement.

Onoda: Is it possible to identify the amount, etc.?

Imamoto: It is possible to identify to a certain extent on the several assumptions.

Kitagawa: Is it possible to determine the water-cement ratio?

Imamoto: There is a way to analyze it. However, it will appear to be in the range between 50% and 70%. Additionally, there are limitations in the scope of analysis, e.g., analysis is not possible when limestone is used as the aggregate.

Nishioka: Although it is related to the repair by formwork finishing, there are different types of formwork construction methods.

Honma: In terms of civil engineering sites, when repairing using round steel, it is necessary to increase the amount of reinforcement so that the cross section becomes larger. However, there is resistance because it affects the pile foundations, etc.

Kitagawa: Round steel was used in the Hijiri-bashi Bridge. How were the corroded reinforcing bars repaired?

Honma: The bridge was constructed to withstand the earthquake of L2, so reinforcement was not provided. As there was little corrosion of the reinforcing steel, it was only a cross-sectional restoration.

Onoda: In railway structures, RC piles have been used since 1919.

Hasegawa: There are some buildings where the foundation is critical. The Shinko wharf in Yokohama was the first to use pneumatic caissons, and the Dai-ichi Life

Building was the first to adopt pneumatic caissons for a building. Nevertheless, both are valuable. Other technologies that are currently difficult to implement are also included. In eras when the cost of reinforcing bars was high, there were contrivances for reducing the use of reinforcing bars, etc. There is a possibility that valuable bar arrangements from that time may remain, such as in the floor slab of the book house of the Aishu kindergarten, etc.

Furthermore, flat roofs developed together with waterproofing technology. Additionally, there are things, such as fittings, that developed along with concrete. Thus, it is important to focus on technologies that developed alongside concrete technology.

Nishioka: This also includes exterior tiles and ceiling technologies.

Kitagawa: Are waterproofing technologies subject to preservation?

Igawa: In the Former Mikawajima Sewage Treatment Plant Pump Tower, the old waterproofing layer was preserved and a new waterproofing layer was installed over the previous layer. In the case of waterproofing layers, it is possible to install waterproofing layers on top of each other. However, there is no case in which the past waterproofing technology was reproduced. Asphalt waterproofing was performed in the repair work of Takashimaya.

Kitagawa: Are there any technologies that should be conserved among the technologies that are likely to have been lost at present?

Onoda: Probably concrete blocks, etc.

Hasegawa: The history of concrete block in Japan has three characteristic periods. Initially, Onoda Cement imported formworks and distributed them at Yamaguchi from 1897–1906. The second time, RC was recommended for the Urban Building Law in 1919 and the Great Kanto Earthquake in 1923. However, it was a time when concrete blocks were often used instead of RC. The third time was after the war. Cultural properties made of concrete block include important cultural properties, such as the Ijokaku and the Temma Church, which uses Nakamura-type concrete blocks.

Kitagawa: The concrete blocks used in railroads have a history different from that of buildings.

Onoda: Concrete blocks have been used particularly in arches because it is difficult to place concrete in the upper part of tunnels. Concrete blocks have advantages, such as the winding thickness can be ensured and the quality is even. They are also technically easy to handle because they are an extension of brick construction.

Kitagawa: When were they used?

Onoda: There are records of them being used up to the postwar period. When facilities, such as pumps, were developed and improved, they were replaced with cast-in-place concrete.

Hasegawa: There is an effort under a Kaken grant wherein a study is being conducted to ascertain whether wood grains and formwork marks on existing walls can be scanned by a 3D scanner, reproduced on formworks using a 3D printer. In the repair of the Hiroshima Memorial Cathedral for World Peace, the original construction technology was adopted. However, it was not possible to reproduce details, such as wood grains. It is considered that the details may be reproducible using a 3D scanner. Testing is currently underway.

Nishioka: I have heard that the pillars of the Hiroshima Peace Memorial Museum will have their surface finish repaired using materials manufactured by resin molding polymer cement and formwork parts.

Hasegawa: The formwork marks were visible on the surface when the museum was constructed using the design of Tange Kenzo in 1955. However, because of aging and deterioration, the shape of the surface faded in the 1965–74 period. Therefore, the restoration of thin columns was executed using the technique of printing the wood grain. It was designated as a cultural property under the condition that this repair was executed. In this preservation and repair work, as the printed grain parts were remarkably deteriorated, these parts were peeled off and reproduced with the grain printed in 1965. Therefore, it does not correspond to a change in the current state. When the restoration was performed by printing, Tange Kenzo was said to have been alive and had to issue an OK for the repair works. When the renovations of wooden buildings of the Meiji period, such as the Kuroshima Church and Mie prefectural government building, were considered, there were some cases in which a method for drawing wood grains was implemented for doors and ceiling boards.

Onoda: In the case of the Hiroshima Heiwa Memorial Museum, will the same wood grain pattern be maintained?

Hasegawa: Yes.

Nishioka: It is a philosophical matter, but there is a problem regarding how to assess the historical period of the work of architects. If repairs are to be performed while they are still alive, should repairs be based on the values of that time or should they be assessed by including the work of their successors after they have passed?

Hasegawa: I believe that we should not think about how the designer thought about it. I consider the specified point in time as the basis for preservation.

Structural Reinforcement Methods

Kitagawa: Let us move on to structural reinforcement. What are the features of the reinforcement cases so far?

Nishioka: In the case of concrete, as the renovation history of ordinary buildings is more substantial than that of cultural properties, methods that can be applied to cultural properties are being searched from renovation cases of ordinary building. Regarding diagnosis methods, there are a few parts specific to cultural properties. As there are few techniques unique to cultural properties, we hope that this area will improve further.

Kitagawa: How is the deterioration state diagnosed?

Mukai: In the field, it is divided into primary and secondary diagnosis. The primary diagnosis is judged by the appearance, whereas the secondary diagnosis is performed by a more detailed investigation. The degree of rigor by which the diagnosis should be made has not been verified specifically.

Kitagawa: Is it possible that detailed diagnostics will result in less reinforcement work?

Mukai: Considering 1.0 as the maximum diagnostic result value, the deterioration state is judged based on how low the result is to examine the scope of repair.

Kitagawa: What are the criteria for diagnosis?

Mukai: The Building Disaster Prevention Association has a standard for earthquake resistance diagnosis. The guidelines were presented in 1970s, and the Act on Promotion of Seismic Retrofitting of Buildings was established after the Great Hanshin-Awaji Earthquake in 1995.

Kitagawa: Is deterioration considered in the seismic diagnosis of civil engineering structures?

Honma: Reinforcing bars with defective sections due to corrosion, etc., shall not be included in the structural members during diagnosis. When seismic surveys are conducted on existing structures, they are often diagnosed as unqualified. In the Tokyo metropolitan area, when the material strength of concrete shows a high value, it is sometimes diagnosed by incorporating the test value of the material.

Imamoto: How do you check the material strength?

Honma: We check by extracting a core sample.

Mukai: The evaluation value is obtained from the diagnosis, but most cases do require reinforcement. However, it is often rejected on the grounds that the value of a cultural property will be impaired, even after examining the structural reinforcement methods that have been implemented in general buildings. Current reinforcement methods are generally methods wherein an existing structural framework is joined to another reinforcing member. Post-construction anchors are used to join reinforcement members firmly with the existing framework, but this is irreversible and an obstacle in selecting the reinforcement method. Therefore, methods wherein a tensile material or the like is attached to the outside of the member and clamped onto the existing framework are often adopted. Such reinforcement methods can be easily changed when a better reinforcement method is developed because reversibility is guaranteed.

Nishioka: Post-construction anchors are also difficult to adopt when reversibility is considered. For concrete structures, the selection of reinforcement methods is done with care because the assurance of reversibility is very difficult.

Mukai: When a post-construction anchor is installed, a hole of less than 10 cm is drilled in the existing frame at a pitch of 150 to 250 mm, which damages the existing frame. Therefore, this is adopted with hesitation. However, I feel that adhesives will be easier to accept although they roughen the surace..

Honma: In the case of adhesives, do they have sufficient strength?

Mukai: As there is probably no track record of adhesives being used in historical concrete construction, additional research is needed. However, their strength has been confirmed. Adhesives are sometimes used to fix brace materials, etc. of steel frames. Moreover, they can be integrated with reinforcing members to transmit forces.

Honma: For bridges, safety is especially emphasized. To ensure reliable strength, generally, methods that are destructive to the existing fame are adopted, wherein holes are drilled in abutments and piers, followed by the installation of bridge-fall prevention devices using post-construction anchors and the addition of support bearings.

Measures Against Deterioration

Ishida: There are deterioration-prevention measures, such as re-alkalization, but what are the current measures taken against deterioration?

Nishioka: There was a case in which we examined the implementation of re-alkalization. However, it was limited to trial introduction.

Hasegawa: The first experimental introduction in an important cultural property was made in the Umekoji Locomotive House. However, it was tested on only one pillar. At the Hiroshima Heiwa Memorial Museum, re-alkalization was performed on two pillars on a trial basis. In the inspection conducted immediately after execution, the effect of the re-alkalization was apparent.

Imamoto: Was there any change in appearance, etc.?

Hasegawa: I felt that it had become a little darker, but I have not made a precise comparison.

Honma: Was any method for impregnating the surface used?

Hasegawa: An impregnation agent was used. The internal reinforcing bars were scraped partially, and the reinforcing bars were used as cathode for re-alkalization.

Imamoto: Re-alkalization using an impregnating agent turns the reinforcing bars into a cathode to attract anodic component, such as calcium, into the reinforcing bars. This method replenishes the lost alkali components from the surface by applying an impregnating agent, such as an alkaline aqueous solution. In the renovation plan of the main building of the National Museum of Western Art, there was a problem of concrete neutralization, and re-alkalization was raised as one solution. At that time, re-alkalization had been executed in several places, including Osaka Castle. As a result of the investigation, it was concluded that there was no assurance that the re-alkalization would not change the appearance. It would also greatly affect the construction costs, making them more expensive. Ultimately, a method that utilized a surface impregnation agent was adopted.

Hasegawa: In the two test projects, the number of units installed was also limited owing to the fear of side effects.

Igawa: The documentation in which cases of re-alkalization in foreign countries were verified indicated problems with side effects and re-neutralization. However, the validity of the data has not been sufficiently verified yet.

Hasegawa: I have heard from a researcher of re-alkalization that neutralization will not occur after re-alkalization. However, the effect of re-alkalization has not been proven sufficiently.

Igawa: I had read a paper on the re-alkalization of civil engineering structures in the West Japan Railway Co. It seemed to be effective.

Kitagawa: Was it the case of a structure related to the Sanyo Shinkansen line?

Onoda: I think so.

Imamoto: As with Osaka Castle, it is difficult to determine whether it will affect the appearance. In re-alkalization, methods are adopted in which an alkaline solution or the like is applied to the surface and allowed to penetrate. However, in the investigated cases, as the possibility of re-neutralization could not be disregarded, a cement paste was applied on the application surface. Therefore, the change in the appearance could not be confirmed. What about civil engineering?

Honma: The Tokyo Metropolitan Government has no experience with re-alkalization.

Imamoto: Among concrete buildings, there are buildings where the architectural concrete walls are to be preserved, and the re-alkalization method adopted in such buildings may not be the standard method. However, perhaps corrosion of the reinforcing bars may be suppressed by adding some water-repellent layer to the surface. If such a method is adopted, it may be possible to form an environment in which the integrity of the structure can be maintained even after neutralization. Although the re-alkalization method is an effective method in some cases, it is not necessarily the only method. Additionally, it is important to have a diversity of construction methods, including re-alkalization. Therefore, it is necessary to use a method according to the value of the cultural property.

Honma: If it is a bridge, the countermeasures vary depending on how many years the bridge will be in service. A treatment method that adds a protective layer to a re-alkalized surface may be based on such ideas.

Hasegawa: Was some protective layer added to the re-alkalized pillar of the Umekoji Locomotive House?

Nishioka: I seem to remember it being applied.

Hasegawa: In the case of the Hiroshima Heiwa Memorial Museum, although the purpose is to add wood grains using polymer cement after re-alkalization, a protective layer is to be attached to the surface.

Nishioka: The annex and warehouse of the Aishu kindergarten building were also re-alkalinized.

Kitagawa: Does the method without re-alkalization correspond to impregnation like in the Museum of Western Art?

Imamoto: The idea of the Museum of Western Art is close to life-prolonging measures that extend the life of materials.

Igawa: Re-alkalization will also be performed at the Tokyo Central Post Office, and an interview survey will be performed of the people in charge. In the case of re-alkalization, the effect on the surface seems to be great. To perform re-alkalization, it is necessary to wrap a metal mesh around the surface, but when a metal other than the metal used in the framework is embedded, it is necessary to remove that existing metal. Thus, this process is greatly influenced by the condition of the framework.

Repair of Cracks

Nishioka: On another topic, is there any information about the recent topic of self-healing concrete?

Imamoto: Self-healing concrete is used for newly built concrete. It cannot be used in the repair of existing concrete buildings. Self-healing concrete that uses bacteria is also available. The bacteria in the concrete discharge nitrides on contact with air. The discharged nitrides will fill the cracks, etc. Though it is an interesting material, a crack of approximately 0.3 mm wide is as wide as the Nile River when viewed from the scale of bacteria, cannot be repaired.

Kitagawa: How do you judge the repairable crack width?

Imamoto: Although the meanings of “repairable” and “should be repaired” differ, the crack widths that the Architectural Institute indicates should be repaired are 0.3 mm for outdoors and 0.5 mm for indoors. Additionally, 0.5 mm cracks are deemed as possible defects. Cracks in that area are considered as subject to repair.

Kitagawa: Are the concepts of crack repair same for buildings that are cultural properties?

Hasegawa: 0.2 mm is one of the indicators.

Imamoto: It is considered to be the width where an injection agent can be filled.

Mukai: Since the Great Hanshin-Awaji Earthquake, the repair manual for damaged buildings developed by the Architectural Research Institute has stated 0.2 mm.

Hasegawa: There are two types of cracks in concrete: one is a crack-precursor type and the other is a crack accompanied by reinforcement corrosion. The repair method varies depending on the cause of occurrence. In the manual published by the Architectural Institute, it is judged that the necessity of repair for the crack-precursor type is determined based on whether the crack width is 0.4 mm or more. Cracks associated with corrosion may be different. What about them?

Imamoto: The guidelines for investigation and repair/reinforcement of cracks are provided by the Japan Concrete Institute, and the repair methods were differentiated based on the cause of the crack. For the crack-precursor type, such as drying shrinkage, it is considered that cracks of 0.3 mm or more should be repaired. Regarding cracks accompanied by corrosion, it is judged that countermeasures on the assumption of restoration are necessary regardless of the crack width. In some cases, depending on the degree of cracking, the reinforcing bars should be scrapped and replaced, whereas in other cases, repairs with an injection agent may be necessary.

Kitagawa: Were there any problems with previous repairs of the former Yamamura residence, a cultural property that was first repaired as an RC structure?

Nishioka: Waterproofing was difficult. Additionally, while the former Yamamura residence has undergone preservation repair work and disaster restoration work twice, it was refurbished using round steel during the repair work. Additionally, deformed rebar was used in the disaster restoration work without adhering to the reinforcement specification. The original problem was that the reinforcement was insufficient in the initial design stage. Additionally, the slab thickness was only approximately 70 mm.

Kitagawa: Are there any new problems that have emerged from past repairs performed in the civil engineering field?

Honma: Even though 20 – 30 years have passed, deterioration can be observed in the parts repaired using polymer cement.

Kitagawa: Is there a cycle for repairing polymer cement?

Imamoto: No.

Honma: How long is the history of polymer cement mortar?

Imamoto: I think it has been approximately 30 to 40 years since the development began.

Repair Work Cases in Recent Years

Kitagawa: Finally, please introduce some examples of concrete construction preservation and restoration being conducted at present.

Nishioka: The Former Yamamura Family Residence (Yodoko Guest House), the Hiroshima Memorial Cathedral for World Peace, the Hiroshima Heiwa Memorial Museum, and the former Shime Coal Mine Shaft Tower.

Igawa: The Odate Vertical Shaft Winch House of the Former Sado Mine Mining Facilities, the Ominato dam, and the Mikawa residence.

Kitagawa: How about Hashima (Gunkanjima) historic site? What is the current status of Hashima (Gunkanjima)?

Imamoto: Mr. Mukai works as a member of the structures group, and I work as a member of the materials group. We are performing concrete repair experiments. Test specimens are installed in the field, and durability, etc., are being tested. For test specimens, we produced specimens in various conditions, such as those with cracks or corroded internal reinforcement, and tested them for durability by calling on approximately 20 companies involved in the repair of concrete. This is the second year. Some specimens have already lost their repair effect in approximately a year and a half. This exposure testing is being conducted in a 10-year plan.

Kitagawa: What is the current situation in Sado?

Igawa: Construction will start next year or later.

Hasegawa: For historic sites, the Shiroyama Elementary School in Nagasaki can be considered. It was designated as an A-bomb remnant. Presently, a preservation utilization plan has been decided. A subsidy has been provided by the Ministry of Health, Labor, and Welfare.

Onoda: In the railway-related area, we plan to conduct a seismic diagnosis of the Nagahama Station.

Igawa: In civil engineering structures, carbon fiber winding reinforcement of the main tower part of the Mino-bashi Bridge is underway.

Honma: In the Tokyo metropolitan area, repair of the RC slab of the Kachidoki-bashi Bridge is planned.

Kitagawa: In this report, we intend to collect as much information as possible regarding cases related to preservation and repair that have been executed so far so that each case can be verified. Thank you for today.

Summary of a 2nd Study Meeting on Preservation and Restoration of Concrete Structures

Date：November 2, 2018, 16:00 ～ 18:00

Place：Tokyo National Research Institute for Cultural Properties

Participants：Aoki Takayoshi (Nagoya City University), Imamoto Keiichi (Tokyo University of Science), Suzuki Kei (Nihon University), Hasegawa Naoji (National Institute for Land and Infrastructure Management),, Igawa Hirofumi / Nishioka Satoshi Sakamoto Moe (Agency for Cultural Properties), Kitagawa Daijiro / Ishida Shin-ya / Toriumi Hidemi / Nakayama Shunsuke (Tokyo National Research Institute for Cultural Properties)

Topics Related to Earthquake Disaster Countermeasures

Kitagawa: Today, I would like to talk about measures implemented against earthquakes in concrete buildings with Mr. Nishioka from the Agency for Cultural Affairs. The second half of the talk will be about the content of the guidelines for the conservation and rehabilitation of historic concrete structures issued by the Scottish governmental authorities with Mr. Ishida of the Tobunken.

Nishioka: This paper presents domestic cases of seismic diagnosis and seismic strengthening of RC structures. To achieve a broad understanding, we will introduce old cases as well.

To begin with, there are few cases of domestic seismic diagnosis and seismic strengthening at present. Additionally, regarding earthquake resistance diagnosis, concrete buildings are easier than brick buildings, and the guidelines for earthquake resistance diagnosis of existing RC structures are being applied thereto.

One aspect unique to cultural properties is that buildings with extremely low strength are also subjected to preservation. Moreover, until around the Taisho period, buildings with special bar arrangements, such as the Kahn type and Hennebique type, were also included. In the Kahn type, there is a case of reinforcement of the Former Head Office of the Yamaguchi Bank by Shimizu Corporation. An example of the Hennebique type is the Umekoji Locomotive House. The structural degradation countermeasures still seem to be controversial.

Additionally, there have been examples of introducing structural slits in recent years. However, as they damage the frame, it is believed that there is room for investigation regarding their usage.

The Former Yamamura Residence has long been an example of the conservation and repair of RC in Japan. Conservation and repair work was performed from 1985 to 1989, and disaster recovery work was performed from 1995 to 1998 after the Great Hanshin-Awaji Earthquake disaster. Construction is underway at present, and countermeasures for deterioration of waterproofing facilities and reinforcement of eaves and slabs are being implemented. Although it was designed by Frank Lloyd Wright, the structure is fragile because the slab is thin with inadequate reinforcement. Moreover, it is located on a ridge, which causes problems even on granitic ground. In the 1985 repair, correcting the ground subsidence, constructing a new foundation, removing and re-casted the deteriorated concrete of the broken columns, disassembling the brittle second floor slabs, and re-casting the slabs by adding reinforcing bars were carried out. At that time, the same round steel as the existing reinforcing bars was used.

Kitagawa: Has the same slab thickness been restored?

Nishioka: It has probably been restored to the same thickness. As the slabs were thin, the slabs would sag when a person stood on them. Hence, sensors for detecting deformation were installed. Thereafter, in the disaster restoration work, the failure states were ranked, and different repair methods were implemented for each rank. These included conversion of slabs to RC, partial steel frame reinforcement, carbon fiber sheet reinforcement of parapets, new installation of foundation footing, etc. However, unlike the last time, deformed rebar was used.

Next, for the National Museum of Western Art, the first seismic isolation retrofit in Japan was performed between 1996 and 1998, prior to the designation as a cultural property. The reinforcement of the superstructure was not performed in principle, and an expansion joint was newly installed in the periphery. At that time, the external stairs on the south face were dismantled and restored to cut the connection with the main building.

The Umekoji Locomotive House is an example of reinforcement work after being designated as a cultural property. Constructed in 1914, this is the oldest existing concrete-built locomotive depot. Seismic diagnosis was conducted from 2011 to 2012, and seismic countermeasure construction was performed from 2013 to 2016. Various structural reinforcement plans were examined here. Proposal 1 was reinforcement using steel plate wall and RC wall, Proposal 2 was reinforcement using steel plate wall and brace, and Proposal 3 was reinforcement using an external steel frame. Ultimately, Proposal 2 was chosen. Even after the decision was made on Proposal 2, the way the brace was shown was examined, and the reinforcing member was finally installed on the backside. Steel pipes were used for the material, and care was taken to ensure that it gave a neat impression. Moreover, the reinforcing members were also painted using a color different from the existing framework. Additionally, re-alkalization was performed for only one column, and the progress was observed afterwards.

Kitagawa: What was the reason for re-alkalization of only one piece?

Nishioka: It was conducted on a trial basis.

Hasegawa: We performed one initially to observe the progress.

Kitagawa: You did not plan to re-alkalinize all the columns initially?

Hasegawa: No. Because unexpected problems, such as side effects, were considered.

Imamoto: Do you mean monitoring to identify side effects?

Nishioka: Yes.

Kitagawa: Are side effects still under investigation?

Nishioka: We are investigating the matter, but we have not heard about any problems that have emerged so far.

The following is an example of the Hiroshima Heiwa Memorial Museum. Constructionwas performed in conjunction with the renovation of the museum. The examination of the plan started in 2007, and the seismic isolation work was performed from 2016 to 2019. As the museum is not only a building but also a designated object of scenic beauty, it is included in the buffer zone of a global legacy. Hence, special consideration was required for the design. Therefore, seismic isolation work was selected although it was within the national scenic beauty region.

At the time of construction, the museum was designed to be open. It is a space in which light escapes to the Genbaku Dome (Hiroshima Peace Memorial) side when viewed from the front side. However, exposing valuable materials to sunlight gradually became a problem, and it was renovated into a space that blocks external light. Unlike the initial plan, the renovation work was performed on a large scale from 1990 to 1991 because it was renovated to a finish where wood grains were not present on the surface. Additionally, changes were made to add wood grains on the surface using polymer cement and granite was added to the side of the second floor. At that time, the designer was still alive.

This time, apart from the installation of seismic isolation equipment, carbon fiber reinforcement, etc., were performed on the second floor. Furthermore, with seismic isolation work, such as new construction of underground beams, the stair foundations were removed and the second floor corridor part was changed to accommodate expansion joints. Additionally, the width of the crossing corridor was changed by changing the tour flow line.

The following is an example of the World Peace Memorial Cathedral in the same city of Hiroshima. Seismic retrofitting was executed in the renovation work of the cathedral. The difference of wall quantity between the tower and each surface became a problem. As the effect of the wall on the side of the altar was too strong, anti-seismic slits were provided to prevent the bearing capacity from acting. In particular, the small entrance on the front side of the hall, where structural strength was insufficient, was reinforced with steel frames. Furthermore, the staircase was reinforced with additional RC, so that the overall balance was maintained. For the tower, we performed ground improvement, steel brace reinforcement in the upper part, and tensile reinforcement using prestressed concrete (PC) steel bars. Such reinforcement methods were chosen because these were parts where the general public did not enter usually.

Kitagawa: How long were the PC steel bars?

Igawa: The length of the tower from the ground to the seventh floor was combined for each floor height.

Nishioka: Additionally, seismic slits were installed at three places on the back side of the hall. There was some discussion as to whether adjustments could be made in the direction in which the overall proof stress would be weakened even though it was intended to balance earthquake resistance.

Kitagawa: Is it a method that is often implemented in general buildings?

Nishioka: It is sometimes performed even in general buildings. It is often provided to prevent breakage of ultra-short columns. However, the installation of structural slits is seldom considered because of the overall proof stress balance, as in this case.

Igawa: While many slabs entered the front side of the cathedral, the backside was a single high wall. Hence, eccentricity became a problem, which needed to be balanced.

Hasegawa: Of course, there was a plan to reinforce the front.

Igawa: We examined a reinforcement plan wherein a frame was placed in the front pilotis was considered. However, the church rejected the proposal for reinforcement because the impression of the building changed significantly. Therefore, a reinforcing member was installed in the staircase.

Kitagawa: Is this the first case in which a structural slit was introduced in a cultural property?

Nishioka: Yes. Incidentally, as countermeasures for non-structural members, we implemented a peeling prevention pin net for the apse dome and anti-sway measures for the chandelier, etc.

Finally, let us introduce the case of the renovation of the Auditorium (Yasuda auditorium) of the University of Tokyo, a registered tangible cultural property. This is a building with a semi-circular lecture hall on the back, which suffered damage, such as cracks and broken windowpanes, due to the Great East Japan Earthquake. It was feared that the mortar-finished ceiling of the steel frame groundwork would fall. Therefore, it was decided that seismic retrofitting work was necessary. The renovation work was performed from June 2013 to December 2014.

The reinforcement method itself was very simple. RC walls or arches, steel braces, or panels were installed at places where the bearing capacity was insufficient. However, as some of the reinforcing members were visible in the corridors and halls, the design of the building became a problem. Therefore, the arches, which were originally formed with a steel frame and lath base with mortar coating, were replaced with earthquake-resistant walls. For the parts that did not pose a problem in terms of design, the columns were reinforced by winding steel plates.

Structural slits were installed in this building, not for balancing, as in the case of the Peace Memorial Cathedral, but for preventing the columns from folding at the position where the structural slits were inserted. It has been heard that this will be introduced at the Kobe College as well.

As there were other concerns regarding the collapse of the ceiling, the pre-renovation ceiling material was removed, and the work to reproduce the design using a new steel frame was initiated. The existing ceiling suspending the lath, which was more than 100 mm thick, had a three-layer structure made up of mortar in lath, medium plaster, and top plaster. In the renovation work, the slab and the frame were integrated to prevent the ceiling from shaking. Additionally, at some places, the front porch part was changed to accommodate an expansion joint, and a safety net was used to prevent the ceiling from falling.

Kitagawa: There is likely to be a question of whether to use rounded steel for repair or deformed rebar first.

Nishioka: In the Former Yamamura Residence, round steel was used in the first construction to match the original construction.

Kitagawa: It is thought that there is a need to focus on the components to be added.

Nishioka: I have not heard anything else about similar cases.

Kitagawa: If the round steel itself has deteriorated, is there a case in which it was replaced with round steel?

Nishioka: As for repairs of scenic spots, round steel has been replaced with deformed rebar at the Ikeda residence.

Imamoto: From the perspective of reinforcement, we should use deformed rebars instead of round steel.

Kitagawa: It may be acceptable to use deformed rebars based on the principle of minimizing the scope of repair, not only for cases of addition, but for replacement as well.

Nishioka: However, even extremely fragile construction methods have historical value. However, in the case of the Former Yamamura Residence, it also has academic value because it is a design of Frank Lloyd Wright.

Kitagawa: If the substitution range is minimized, the original round steel will remain for the most part.

Hasegawa: How about preserving the bar arrangement technology? I suppose this is a technology that cannot be done at the time of construction, e.g., by bending and arranging the bars.

Igawa: How do you preserve a technology that is difficult to see when preservation repair is one of the problems that need to be addressed

Kitagawa: Kahn bars may be something that you want to keep when you restore it.

Hasegawa: However, Kahn bars are not effective for earthquake resistance. During the Great Kanto Earthquake, many buildings equipped with Kahn bars were damaged.

Kitagawa: I think the Kamiya bar in Asakusa, which is registered as a cultural property, uses Kahn bars. However, I wonder if it has been reinforced.

Nishioka: Reinforcement was done by applying steel plates to the walls.

Hasegawa: The Hakodate Betsu-in also uses Kahn bars.

Suzuki: How about the Hennebique type?

Kitagawa: The Umekoji Locomotive House constructed in 1914 uses the Hennebique type.

Hasegawa: The former Mitsui Bussan Yokohama branch warehouse, built in 1909, was also Hennebique type.

Suzuki: The Hennebique type was invented in France. There was an event in which a Hennebique structure built in Bern, Switzerland suddenly failed. It was probably shear failure. After this incident, the Hennebique-type buildings lost their popularity. Later, some countermeasures, such as shear reinforcement measures, were taken because the use of such buildings continued in Japan.

Kitagawa: Was the Hennebique type no longer used in Switzerland afterwards?

Suzuki: I have not followed the case, so I do not know exactly. However, the guidelines for RC were first made in Switzerland in response to this incident. It was argued at that time that the installation of shear reinforcement was necessary.

Hasegawa: In Japan, the Kahn-style proliferated, but the

Hennebique style was not as popular.

Kitagawa: Regarding the Umekoji Locomotive House, there is the impression that using oblique braces and curved members for reinforcement does not necessarily match a building design with multiple square columns, where horizontal and vertical lines are clear and sharp.

Nishioka: There might be a problem from the perspective of the railway turntable. The impression of internal reinforcing members changes by placing a locomotive inside it.

Kitagawa: Regarding structural slits, was the structure used primarily an RC-type structure? Was it constructed using bricks, etc.?

Nishioka: It seems that there are no brick buildings. The structural slits are often installed so that short columns do not fail.

Suzuki: The reinforcements are quite fine, including the slits.

Nishioka: Certainly, there are elaborate structural reinforcements of buildings. However, there is also a problem of confidence in elaborate methods. As these shapes are not simple, careful selecting judgment is required for selecting the reinforcement methods and reinforcement parts.

Hasegawa: As Naito Tachu was in charge of the structural design of the cathedral, he had a discussion with a master of the structural system, and decided to install the structural slits.

Kitagawa: Is there any special ingenuity observed in the structure of the original cathedral?

Igawa: Professor Naito Tachu was in charge of the structure, and he installed a wall on the main body side of the cathedral as a substitute for the partition.

Suzuki: Was the conservation and repair work done by referring to the original design documents?

Nishioka: They were referred to.

Kitagawa: How about the Hiroshima Heiwa Memorial Museum?

Hasegawa: I think we have found some materials for sure. Professor Matsushita Kiyoo was in charge of the structure.

The Scottish Guidelines

Ishida: We will now present the three-volume Historic Concrete in Scotland from the Short Guides series. The series is supervised by Historic Scotland (a government agency in charge of cultural properties in Scotland).

The first volume, "History and Development", introduces the history and background, development of concrete buildings and structures in Scotland, characteristics of early concrete, principles of repair of historical concrete, etc. It is written therein that, as a principle of repair of historical concrete, substitution of materials is not the best way for concrete, unlike conservation and repair of masonry structures. It should also be considered that historical concrete plays an important role as a part of the function of infrastructure rather than just a monument of the past. Moreover, it is necessary to ensure that historical concrete withstands large stresses while respecting the original concrete etc.

In the second volume, "investigation and evaluation of defects", defects and collapse of concrete, investigation and evaluation, diagnosis investigation, etc. are introduced.

In the third volume, Maintenance and Repair, maintenance, repair methods and materials, etc. are introduced. We would like to introduce them in detail below. First, regarding maintenance, the following four points are cited as improper designs: ① insufficient covering thickness, ② insufficient treatment of wastewater for chlorides, contaminants, etc., ③ insufficient preparation for deterioration, and ④ use of improper aggregates. Subsequently, the contents of concrete maintenance have four points: ① removal of contamination on the surface, ② repair of minor cracks, ③ protection of surfaces (coatings), and ④ wastewater treatment (cleaning of drainage ditches). Additionally, rust fouling, growth of organisms, graffiti, and precipitation of salts are mentioned as stains that are subject to maintenance. Additionally, 12 cleaning methods were introduced, and in particular, dry blasting (① low pressure + micro air abrasive, ② low pressure + soft abrasive), and chemicals (alkaline cleaner), ③ alkaline wet cloth, ④ latex film were recommended.

Kitagawa: Let us compare Japan in regard to cleaning.

Nishioka: Is high-pressure cleaning not recommended?

Ishida: It is believed that there is a possibility of damage.

Imamoto: Apart from the names of the chemicals, the idea that the use of acid detergent should be avoided is the same as in Japan. As far as the table shows, we believe that alkaline cleaning agents and highly alkaline cleaning agents should not be used.

Hasegawa: The method of changing the temperature of water used for cleaning bricks was used for the Yokone Lock Gate.

Nishioka: We know about the example of mixing baking soda with water.

Ishida: In the Peace Memorial Cathedral, we heard that the timing of washing was very important because color matching with the repair locations was difficult in the past.

Igawa: As repair work was performed several times at the cathedral, such a problem is likely to occur, but it is not so conspicuous because it is an exterior wall that was originally uneven.

Ishida: The guidelines introduce nine important factors to consider before maintenance and restoration. Among them are: ① the urgency and importance of deterioration, and ② the expected life of the structure; but are these being tackled in Japan as well?

Imamoto: In general structures, the term “urgent” may be used with respect to those causing third-party damage. In some cases, deterioration is evaluated according to the severity of deterioration with respect to importance, whereas in other cases, it is evaluated according to the importance of the building (hospitals, nuclear power plants, etc.). However, in the case of cultural property buildings, it is considered to be the latter. The expected life of the structure is not clear at present, and it will be based mostly on the concept of the root rule where "the time when the neutralization reaches the reinforcement" is treated as the limit state. However, this is not really the lifetime itself, and the idea around this is changing.

Nishioka: Regarding the expected life of a structure, we need to preserve permanently as it has become a cultural property. However, in the case of civil engineering structures, the useful life of the material may be considered to continue using it as a part of the infrastructure.

Suzuki: In civil engineering structures, the service life is considered to be 100 years, if they are newly constructed. The Eurocode may have been followed.

Ishida: Are the figures obtained after the maintenance work?

Suzuki: I think so. In the Highway Bridge Specifications, it is described as 100 years.

Imamoto: This is a standard established by the "Japanese Architectural Standard Specification for RC Work (JASS5)[建築工事標準仕様書]" provided by the Architectural Institute that sets a planned service period of 200 years, which is an ultra-long period (the planned service period is divided into four stages). In JASS5, no maintenance is considered, and the number of years is set during the period when the concrete becomes neutralized.

Ishida: The next point is surface repair. While repairing, removal is done as deep as 20 mm from the reinforcement, and the aggregate is assumed to be of the same size.

Kitagawa: Does Japan have a standard similar to this 20 mm?

Imamoto: To remove harmful substances around reinforcing bars when repairing the cross-section, they say that removal is done deeper than the reinforcing bars, but their depths are not shown in figures. Nevertheless, this does not mean that the figures are far from those of Japan.

Kitagawa: Similar to the story of round rebar and deformed rebar, but what about using aggregates of the same size?

Nishioka: We have not pursued this until now.

Ishida: We will introduce 6 items as important considerations on the selection of the restoration system. In information and application of repair aggregates, it is difficult to match the original aggregate based on size, grade, color tone, shape, and material type. Additionally, it is considered inappropriate to use sea sand when repairing buildings in which sea sand was used because it may lead to deterioration. In the repair of shrinkage degradation, shrinkage degradation generates cracks between the original and repaired parts, which may be broken at the interface of the old concrete.

Nishioka: In Japan, mortar used for restoration tends to be stronger, but non-shrink mortar is often used.

Imamoto: Non-shrink mortar shrinks less than normal mortar, but that does not mean it does not shrink at all.

Ishida: In color matching, it is difficult to achieve a color match that does not look inappropriate, and white cement and general-purpose cement can assist in color matching by choosing the right aggregate.

Kitagawa: Is there a history of using white cement and general-purpose cement in Japan?

Nishioka: White cement is used in Japan. In repairing brick joints, white cement is sometimes used to make the color of existing joints closer to that of existing joints because the blueness of cement is strong in general cement.

Ishida: As for insufficient quality control, it is common for small patch repairs to use off-the-shelf products. However, they may be replaced by polymers because they cannot accommodate the possible changes in existing materials and impart properties, such as improved durability, frost resistance, and reduced shrinkage.

Imamoto: Regarding the use of polymer cement mortar, attention is being paid to the types and amounts of polymers used owing to fire resistance problems. Note that patch repairs do not seem to be criticized in the guidelines.

Ishida: We did not find any sentence that patch repairs should not be performed. For adhesion to existing concrete, cement slurry coating on exposed concrete surfaces within the repaired area may improve adhesion to the repaired area. Care should be taken while using adhesives that may lower the pH. There are cases where the use is restricted depending on the environment, such as chemicals that cannot be used in wet conditions, etc.

Kitagawa: Is there any actual problem with adhesion between the existing frame and the restored parts?

Imamoto: Yes. Though it is a repair, it is sometimes roughened as a groundwork treatment because it includes improvements to the structure.

Suzuki: In case of additional pouring, is it uncommon to perform this after the aggregates have been removed?

Kitagawa: Cultural properties are places where I want to avoid roughening. I guess what I am trying to say here is that we can use slurry coating as an alternative to roughening.

Imamoto: I think that the adhesive strength also depends on the type of slurry.

Ishida: Continuing with the introduction, conventional concrete without admixture should not be used for repair in environments where deterioration of concrete is aggressive (environments where salt damage occurs). If this is difficult, measures, such as shortening the repair cycle, are required.

Imamoto: I think that conventional concrete, which does not contain slag or fly ash, should not be used because salt will infiltrate again, triggering deterioration, but this is one of the concepts that is more advanced in Japan. Cement containing slag is resistant to salt damage.

Hasegawa: Cement containing slag seems to be characterized by low calorific value.

Imamoto: That is right. As the heat generated is less, the strength development is slow in conventional slag cement. Hence, measures were taken to accelerate this process by making (the slag) a powder. However, cracking occurred in mass concrete. Presently, this has been changed within the scope of the standard to make repair concrete closer to the old slag cement concrete.

Ishida: Let me give an outline of patch repair. Short guides include diagrammed patch repairs, which are also shown therein to remove reinforcement up to 20 mm deep in patch repair cases. Processing of patch repair interfaces into dovetail joints is shown as another characteristic treatment.

Imamoto: The shape was reversed in Japan because it was processed by a feather edge, and I was surprised that they were thinking of repairing it with such a shape.

Kitagawa: I think it changes the degree of processing difficulty.

Imamoto: The Japanese process is overwhelmingly easier.

Hasegawa: Considering flaking and peeling, it seems that the dovetail joint shape is reasonable.

Imamoto: Although I think physical retention will improve, I am wondering if repairs are really being performed using this shape.

Ishida: Next, we will introduce two types of anticorrosion: electrolytic protection (forced current cathode protection) and sacrificial anode.

Imamoto: Electrolytic protection makes the reinforcement part negative and the concrete surface positive. The phenomenon of reinforcement corrosion is arrested by the Fe of the reinforcement becoming Fe2+. In the case of electrolytic protection, anodes are installed at a certain interval. Similarly, cathodes are installed at multiple places because it is not known whether all the reinforcing bars are connected. The sacrificial anode is often made of zinc, which is more corrosive than the reinforcing bars. However, electricity flows in the direction that is easiest to flow, such as wet areas, areas with thin cover, etc. Therefore, when performing electrolytic protection, it is necessary to identify the features of the location where the anode is installed, and adjust the flow of electricity. Construction costs will also be incurred to conduct such processing. Although some of these methods have been implemented in Japan (e.g., civil engineering structures along the coast), only a few workers in specific companies have this knowledge. Hence, technology transmission is an issue.

Kitagawa: Are there cases of sacrificial anodes in Japan as well?

Imamoto: I have never heard of a case of sacrificial anodes alone. In many cases, sacrificial anodes are installed as insurance for electrolytic protection.

Kitagawa: Is there a history of being used in cultural properties?

Nishioka: I have heard that electrolytic protection will be implemented in the steel pipe pile sections of the Hiroshima Heiwa Memorial Museum.

Imamoto: In Japan, there is almost no actual history in buildings, and majority of them are civil engineering structures. Presently, in the refurbishment specifications prepared by the Architectural Institute, it is argued that the electrochemical methods are given lower priority.

Kitagawa: How long does the current continue to flow?

Imamoto: Approximately eight weeks in the case of desalination. Re-alkalization takes approximately 1–2 weeks. In the case of electrolytic protection, if the current is stopped, the corrosion will resume, so I suppose it will continue to flow.

Ishida: Finally, let us touch upon the risk assessment of hidden reinforcement corrosion. It is conceivable to provide corrosion hazards (degrees of risk) by conducting detailed investigations to identify fragile cover thicknesses and areas of structures. In investigations for early-stage corrosion, investigation methods, such as drawing small-diameter cores as samples and confirming alkali depth using phenolphthalein, are used. In stages where corrosion has progressed, electrochemical methods, such as the use of electrochemical treatments or the installation of supplementary anodes at reinforcing bars in patch-repaired areas, are described as options when neutralization has reached the reinforcing bars, but the corrosion is minimal. That is all.

Kitagawa: I would like to organize the issues based on these stories and decide on the direction of my research. Thank you for today.

Chapter 1

Current issues related to the conservation and restoration technology used for historically important concrete constructions

Current issues related to the conservation and restoration technology used for historically important concrete constructions

Imamoto Kei-ichi

Professor, Department of Architecture, Faculty of Engineering, Tokyo University of Science

1. The history of reinforced concrete construction

Many of the reinforced concrete buildings constructed before Japan's high-growth era (mid-1950 to the early 1970s) are now more than 50 years old, and some of them are almost 100 years old. Some have been designated as historically important cultural properties. It is inevitable that there will be a rapid increase over time in the number of reinforced concrete buildings over 50 years of age requiring judgment as to whether they can continue to be used or need to be dismantled. However, since only 100 years have passed since Japan's first reinforced concrete building was built at the beginning of the 20th century, little is known about the durability of Japanese reinforced concrete construction and its service life. It is important to note that the technology involving reinforced concrete, such as the methods of producing and pouring concrete, changed a great deal during the period from the dawn of reinforced concrete to the economic high-growth period. Therefore, when investigating historically important reinforced concrete buildings as part of a conservation and restoration project, it is necessary to evaluate the technology used to produce the concrete and rebar that was actually used at the time of the structure's creation, keeping in mind the extensive technological changes that occurred during that period [cited from 1].

As an example of this point, the results of an investigation of the Dojunkai Uenoshita Apartment Building (completed in 1929) will be discussed below (**table 1** and **photo 1**)[2].

Figure 1 shows the compressive strength of core samples taken from various parts of the building. At the time when the building was built, concrete members used to make buildings required a compressive strength of at least 90 kg/cm^2. As the graph shows, all the components sufficiently meet that requirement. In addition, it was also found that the floor was extraordinarily strong. This is probably attributable to the method of proportioning concrete that was widely used at that time. That is, as shown in **table 2**, at

table 1　Overview of the building[2]

Investigation Object	Dōjunkai Uenoshita Apartment Building
Location	Ueno, Taito ward, Tokyo
Completion	1929 (84-year-old)
Structural design and finishes:	Reinforced concrete construction, four stories External wall: mortar + lithoid finish Inner walls: mortar + plaster finish
Use	72 dwelling units and 4 stores

photo 1　Dojunkai Uenoshita Apartment Building

Part	Average	SD
Column	15.9	3.0
Beam	22.5	7.0
Wall	20.4	6.4
Floor	43.5	1.4

Unit：N/mm²

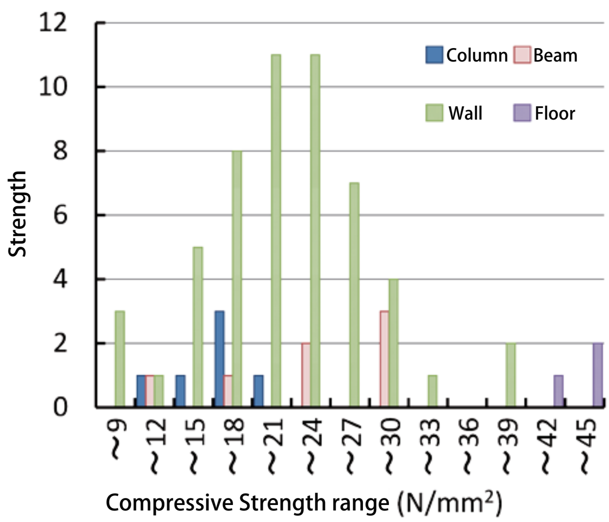


figure 1　Compressive strength[2]　(Made by Professor Hamasaki Hitoshi, Shibaura Institute of Technology)

the time when the Uenoshita Apartment Building was built, the concrete mix proportions were determined according to the Urban Building Law Enforcement Regulation. Concrete was produced by mixing cement, river sand, and river gravel in a ratio (by volume) of 1:3:6, with the amount of water adjusted more finely at the discretion of a site foreman. In other words, concrete was produced in a relatively primitive manner, much like that used by a wall plasterer, by placing great reliance on the intuition of the particular worker responsible for that job. To make vertical components such as walls, concrete of higher workability needs to be used. Therefore, concrete that has more than the average amount of water (i.e., a high ratio of water to cement) is often used to make walls and vertical beams while cement with a lower than average amount of water (i.e., a low ratio of water to cement) is generally used to make the floors, because even when it is rather firm it can be put in place to make horizontal components without problems. This is probably the reason why such a difference in strength between the components can be found in a single building.

The specifications currently in use for the mix proportions of concrete (the water-cement ratios) were established by the Architectural Institute of Japan in 1929, after the apartment house was completed. As mentioned above, it is important to understand the specific technology used to construct a building when evaluating the materials used to restore the building and selecting the parts of the building for detailed investigation.

2. The deterioration of reinforced concrete constructions

As the number of reinforced concrete constructions increased, the deterioration of reinforced concrete became a subject of discussion. **Figure 2** shows the relationship between the deterioration of reinforced concrete and the identified causative factors.

When it comes to the deterioration of reinforced concrete structures, particularly regarding cultural properties, the corrosion of rebar and the flaking off of concrete caused by it are probably the most conspicuous problems of deterioration

table 2 Changes in the specifications for the concrete mix properties[2] (Made by Professor Hamasaki Hitoshi, Shibaura Institute of Technology)

Year	Changes in statutes and standard specifications related to concrete mix proportions
1919	Establishment of the Urban Building Act
1920	Establishment of the Urban Building Act Enforcement Regulations
1923	Establishment of the Building Specifications for the materials, mix proportion (ratios by volume), manufacturing and pouring procedures for concrete) (Architectural Institute of Japan)
1926	Revision of the Urban Building Act Enforcement Regulations (The materials, mix proportion (W/C strength equation), test methods, etc.)
1929	Completion of the Uenoshita Apartment Building
1929	Establishment of the Standard Specifications for Concrete and Reinforced Concrete (materials (aggregate sizes), mix proportions, allowable stress, etc.)
1930	Revision of the Urban Building Act Enforcement Regulations (mix proportions (W/C strength equation), consistency, allowable stress, test methods,

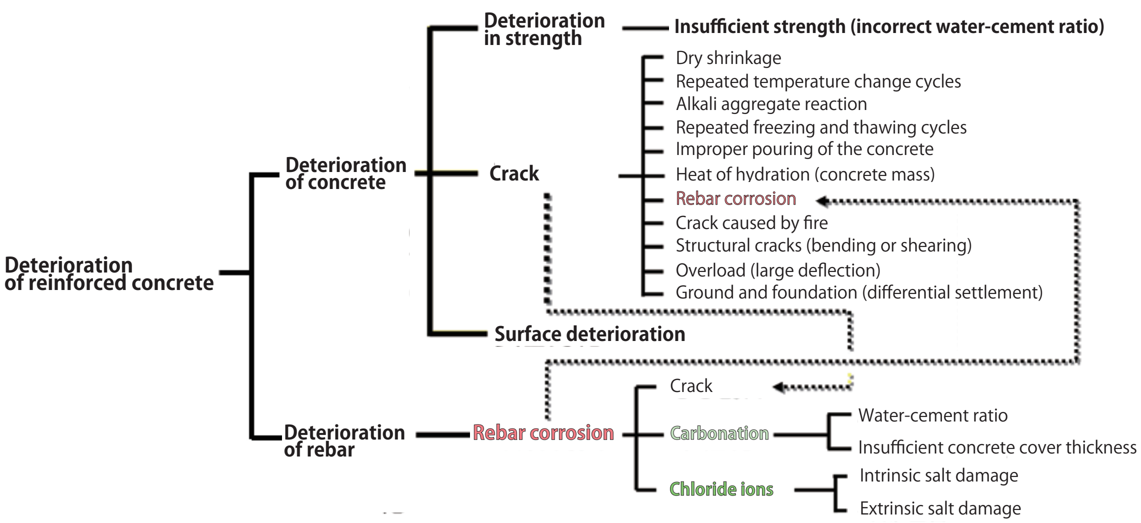


figure 2 Relationship between the deterioration of reinforced concrete and the identified causative factors (Made by Mr. Shimizu Akiyuki, former professor of Tokyo University of Science)

(**photo 2**). This deterioration is generally caused either by chloride attack or carbonation. There are two likely causes of chloride attack: one is that an excessive amount of salt was included in the concrete and the other is that various chloride molecules carried on the air from the nearby seacoast have been deposited on the concrete. When a building is damaged by airborne salt, in most cases the extent of damage depends upon the distance of the building from the seacoast. Roughly speaking, reinforced concrete buildings are likely to be subject to damage if they are located within a distance of 0.5 to 1 km from the seacoast. The concrete itself does not change very much in its physical properties due to the infiltration of salt. However, the salt destroys the passive film on the surface of the rebar embedded in the concrete. This allows the rebar to corrode and expand, thus causing the concrete to crack and flake, resulting in deterioration of the structural members and eventually the structure itself. While reinforced concrete buildings are damaged by the corrosion and expansion of the rebar inside, they may also be damaged when rebar corrodes due to the carbonation of concrete. This phenomenon is often characterized by the generation of a large amount of rusty water.

It is understood that if the natural alkalinity of concrete is maintained, the rebar will also retain a chemically-stable passive film on the surface, preventing or limiting the corrosion of the rebar. That is, when carbonation progresses inside the concrete and neutralizes the alkalinity of the concrete surrounding the rebar, the passive film on the rebar's surface is broken through, allowing corrosion to get a foothold. Therefore, carbonation is an important aspect of reinforced concrete structure deterioration and should not be ignored.

The concrete carbonation chemical reaction is generally expressed using the following equation.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

It is said that the corrosion of rebar starts when carbonation reaches the concrete near rebar (**photo 3**). Carbonation inside concrete has been investigated in detail by the Architectural Institute of Japan [4].

3. Concrete repair methods[cited from literature in footnote 3]

The following chart shows how concrete repair methods can be classified.

Progressive cracks are generally caused by the following factors: reactive aggregate, chlorides contained in the concrete, too-thin layers of concrete over rebar, repeated cycles of freezing and thawing, the chemical action of acids and salts, the corrosion of rebars due to the carbonation of concrete, and the corrosion of rebars due to the infiltration of chlorides. Progressive cracks are also a serious type of deterioration found in many cases to negatively affect reinforced concrete buildings designated as cultural properties. Therefore, when these cultural properties need to be repaired, the causes of deterioration in the form of progressive cracks, just discussed, must also be kept in mind.

Therefore, progressive cracks, even if severe loss of structural material is not observed, should be repaired correctly, not only by using an appropriate crack repair method but also by applying a surface coating or using the patch repair method. The techniques used to repair lost parts of the structural frame will vary with the factors causing deterioration and the magnitude of the defect (depth and area) (**figure 3**).

3.1 Crack repair[cited from 3]

Generally, cracks are repaired by: (1) sealing cracks with the appropriate material, (2) injecting resin or cement into the cracks, or (3) routing (or enlarging) the cracks and filling these widened or deepened cracks with an appropriate joint sealant. The width of the cracks to be repaired and the purpose of the repair are the primary factors affecting the selection of the appropriate repair method. In recent years, an electro-deposition crack repair method is being developed whereby cracks are sealed electrochemically. Yet

photo 2　Example of deterioration (left[3]：extracted from（公社）日本コンクリート工学会、コンクリートのひび割れ調査，補修・補強指針 2009)
right：building no. 65 on Gunkan-jima：photo taken with special permission by Nagasaki City)

another new crack repair method has also been proposed that hides cracks temporarily. In this method, cement-based powder or paste is sprayed directly into cracks to cover the cracked surface, and this is principally done for the purpose of improving the appearance of cracked reinforced concrete buildings. However, this is not a method of repairing cracks which improves the durability of a reinforced concrete construction by eliminating the cause of damage.

(1)Sealing cracks with concrete repair mix[cited from 3]

This method is used to improve the waterproofness and durability of reinforced concrete. It involves coating minor cracks (generally 0.2 mm or less in width) with an appropriate concrete repair mix and smoothing the repair mix until it is level with the surrounding concrete.
This method is used to coat the cracked areas only (**figure 4**). However, this method of sealing cracks with concrete repair mix has some shortcomings. One is its inability to adequately repair cracks that reach deep into the concrete. Another is that it is difficult to follow up sufficiently on the possible extension of cracks in the future, if the crack widens excessively or if the length of the crack progresses. Here, the expression "if the crack widens excessively" indicates the case in which changes in crack width exceed the ability of the concrete repair mix used to stretch without breaking. In such a case, there is concern that the cured coating will itself become cracked, if the width of the original crack increases very much. To prevent this from happening, sometimes a flexible material is used as the repair mix or is put in place as an insulator (**figure 4**, right).

(2)The injection method[cited from 3]

The injection method used to improve the waterproofness and durability of reinforced concrete involves injecting resin-based or cement-based material into cracks. This method is also used to repair reinforced concrete constructions if the cladding has become detached from the structural frame. Conventionally, the injection method has involved the use of a hand- or foot-operated resin or cement injection machine. However, such an injection machine posed some problems: ① the accuracy of the injection depends upon the skill of the responsible worker; ② it is difficult to control the amount of material being injected; and ③ an accurate control of the injection pressure is required, because when the injection pressure is too high, resin might be forced into the shallowest parts of the crack and either never reach the very bottom of the cracks, or else it might break the sealing material.

In recent years, however, a low-pressure injection method using an injection device as shown in **figure 5** at an injection pressure of 0.4 MPa or less has come to be widely used. Organic compounds (epoxy resin or acrylic resin), or cement-based or polymer cement-based materials are generally used as the injected material for this type of crack repair.

(3)Routing and sealing (for use when the rebars are not corroded) [cited from 3]

The routing and sealing method is suitable for the repair of relatively large cracks (0.5 - 1.0 mm or larger in width)

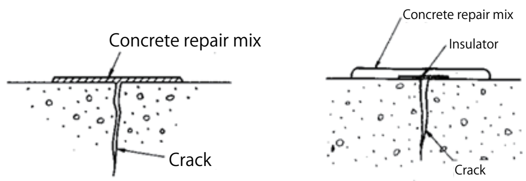


figure 4 Sealing cracks with concrete repair mix[3]
(right：example if crack widen excessively)

photo 3 Example of carbonation[3]

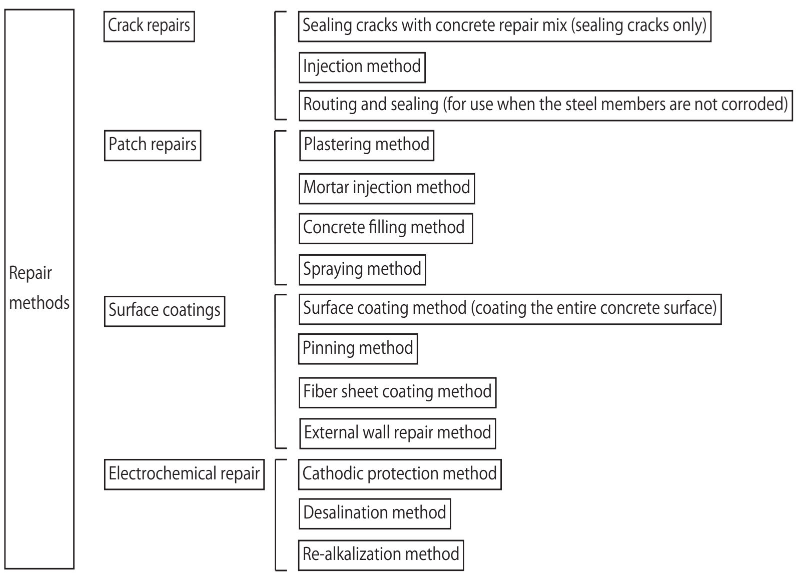


figure 3 Classification of repair methods[cited from 3]

and if the rebars are not corroded. The procedure consists of preparing a U-shaped groove in the concrete's surface, following the path of the crack and placing sealant in the groove (**figure 6**). More specifically, a U-shaped grove, about 10 mm wide, is cut in the concrete surface following the crack, which is then filled with sealant, flexible epoxy resin, or polymer cement mortar. The U-shaped groove may be made by cutting into the concrete surface along the crack, using an electric router fitted with a U-shaped conical diamond bit. The choice of the type of material to place in the groove depends on whether or not the crack is active. It is necessary to use a sealing agent (sealant or joint filling material) such as urethane resin or silicone resin to repair active cracks.

3.2 Patch repair[cited from 3]

In the patch repair technique, concrete patches are applied over damaged or deteriorated concrete. This technique is used to repair concrete constructions that suffer from the loss of concrete due to corrosion and consequent expansion of the reinforcement inside the concrete, repeated cycles of freezing and thawing, or cracks caused by alkali aggregate reaction. It is also used to reintegrate spalled or delaminated areas of concrete caused by such deterioration factors as carbonation or chloride ions.

As shown in **figure 7**, this technique is usually performed as follows: the concrete is chipped away from around the rusty rebar (including the concrete on the back side of it) inside the member being repaired; the rust is removed from the rebar and then the rebar is rustproofed, primer is applied to the concrete surface; and a cement-based material such as polymer-cement mortar is used to fill the cavity.

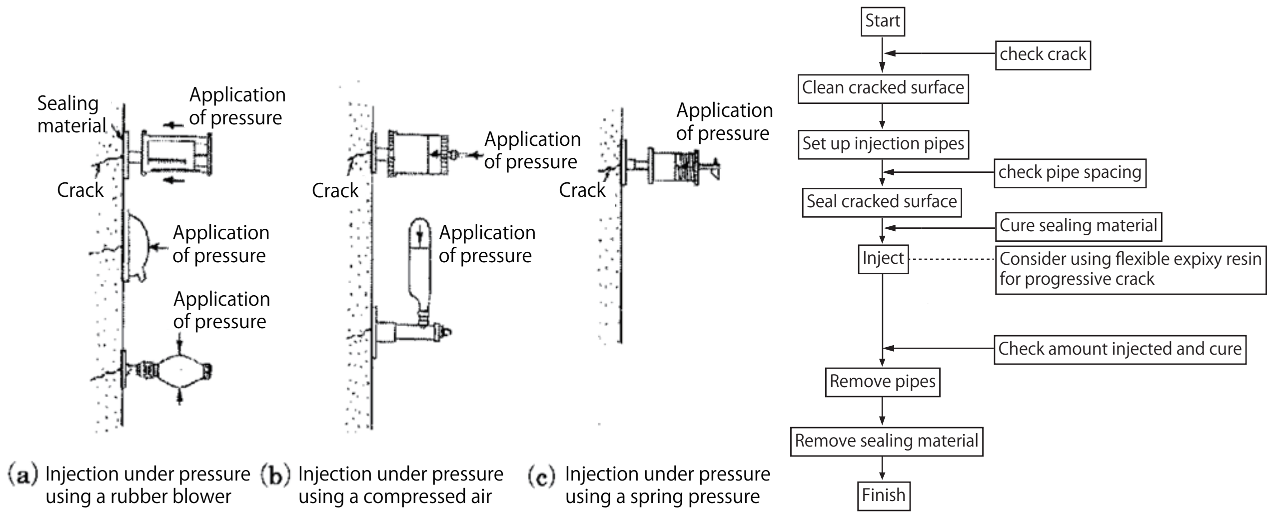


figure 5 Work flowchart and repair example using the low-pressure, low-speed injection method [3]

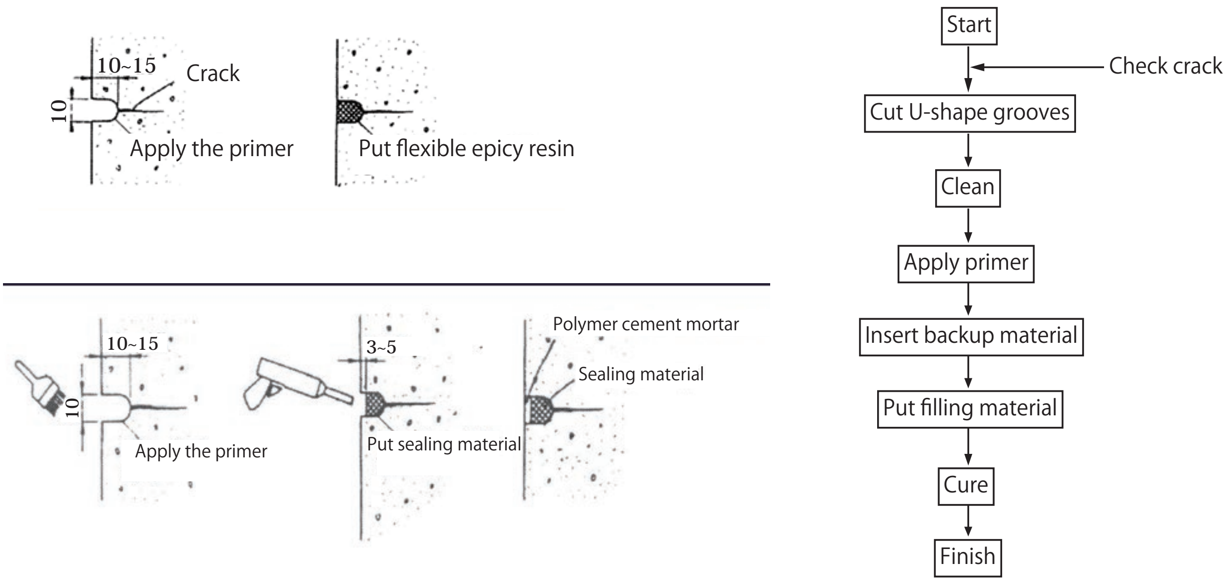


figure 6 Routing and sealing method (top: flexible epoxy resin, bottom: sealing material) [3] and flowchart of the method (right)

3.3 The electrochemical process[cited from 3]

The electrochemical technique is used to attempt suppressing the progress of corrosion of rebars embedded in a reinforced concrete structure by feeding direct electrical current from an anode to the rebars inside the concrete (such as the rebar or steel frame). There are several electrochemical methods available at present to suppress cracks in reinforced concrete. The appropriate method can only be selected by correctly identifying the causes of the cracks and the effects expected, not by simply judging the width of the cracks. The electrochemical techniques described below are not intended to result in the direct repair of cracks in reinforced concrete. If cracks are already developing on the surface of a reinforced concrete construction, it is indispensable to repair the cracks or perform patch repairs as a pretreatment before using an electrochemical technique. In addition, if spalling, flaking, or other concrete deterioration is already present, it is necessary to repair the deteriorated concrete by, for example, applying concrete patches, prior to the use of an electrochemical corrosion preventive method.

(1)Electrical corrosion preventive treatment [cited from 3]

Electrical corrosion preventive techniques can be divided into two types: the external power supply system (**figure 8 (a)**) and the galvanic anode system (**figure 8 (b)**).

With the external power supply system, the protective current (a DC current from 10 to 30 mA/m^2) is provided by a power supply unit through an anode to the rebars embedded in the concrete. In contrast, the galvanic anode system makes use of the difference in potential between the rebars embedded inside the reinforced concrete and a galvanic anode (a sacrificial electrochemical anode) that has a more negative reduction potential than the rebar members have. Specifically, the electric current generated by oxidation of the anode is supplied to the rebars as the protective current.

In either system, the presence of the protective current suppresses the corrosion reaction, or ionization (Fe^{2+}) of iron. Therefore, this treatment is effective for preventing the rebars from corroding as long as the protective current is supplied appropriately.

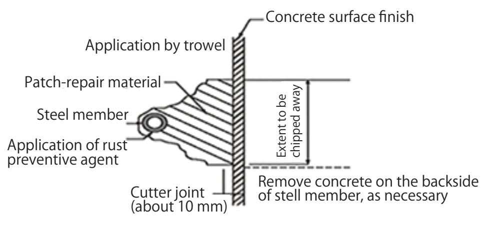
(2)Desalination[cited from 3]

Desalination is an electrochemical technique used to suppress damage when salt attacks reinforced concrete. As shown in **figure 9**, for this technique we install a temporary anode containing an electrolytic solution such as calcium hydroxide ($Ca(OH)_2$) or lithium borate (Li_3BO_3) on the concrete surface and leave it there for about eight weeks, during which time a larger DC current (typically 1 to 2A/m^2) than is used for the electrical corrosion preventive method is supplied to the rebars inside the concrete from the temporary anode. That is, the reinforced concrete is deionized by allowing chloride ions Cl- inside the concrete to migrate to the surface (toward the temporary anode). If it is anticipated that chloride ions from outside will enter the concrete over time, it is a good idea to apply a surface coating after removing the temporary anode.

(3)Re-alkalization[cited from 3]

Re-alkalization is an electrochemical method used to repair reinforced concrete structures that have deteriorated due to concrete carbonation.

This technique, as shown in **figure 10**, involves installing a temporary anode containing an alkaline solution such as



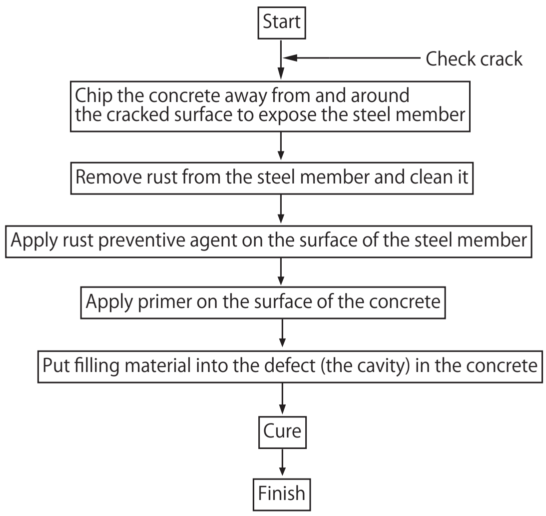
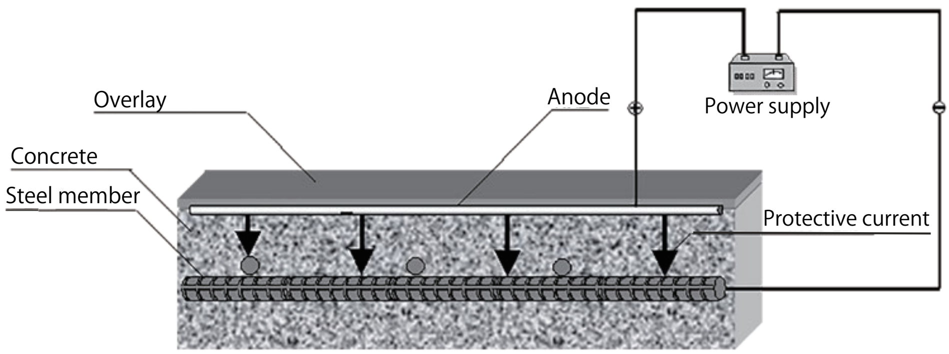
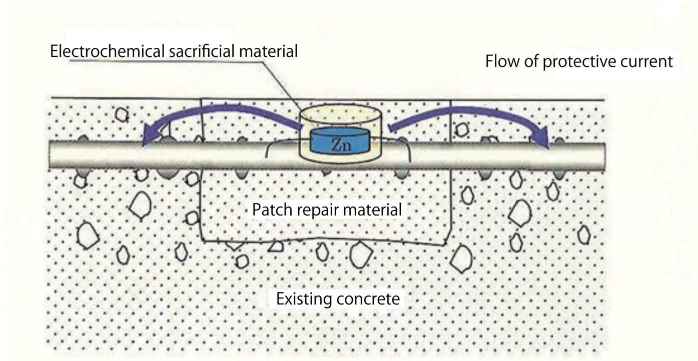


figure 7 Patch repair method (overview of the concrete construction being repaired[3])



(a) External power supply system



(b) Galvanic anode system

figure 8 Principle of cathode protection[3]

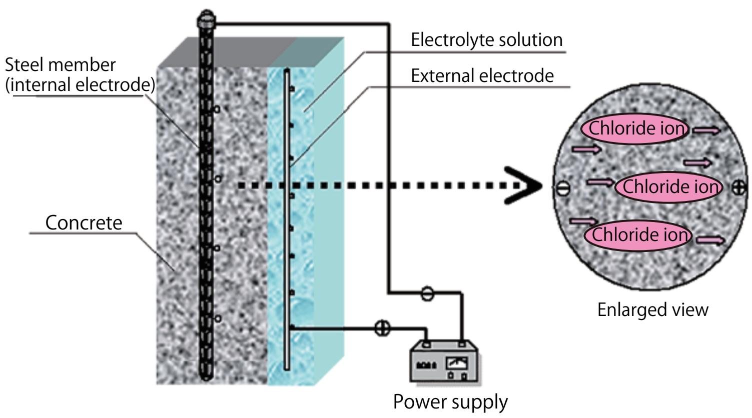


figure 9 Desalination[3]

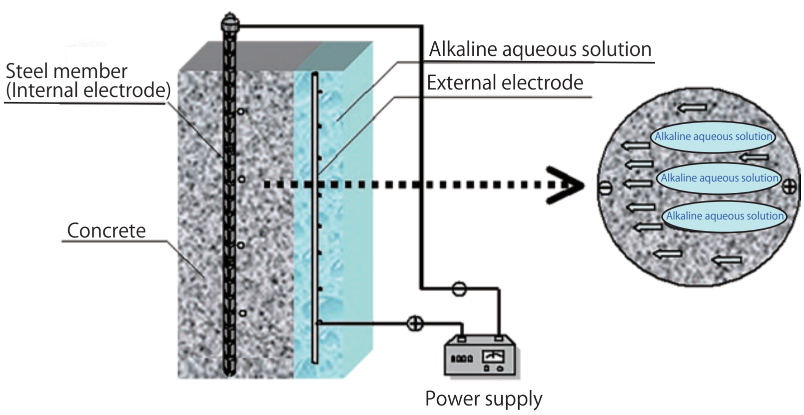


figure 10 Re-alkalization[3]

potassium carbonate (K_2CO_3) on the concrete surface and leaving it there for about one to two weeks. During that time, as is the case of the desalination method, DC current (1 to 2mA/m^2 in general) is supplied from the temporary anode to the rebars embedded in the concrete. This causes the alkaline solution to move by electroendosmosis toward the rebars inside the concrete. If the concrete surface is always exposed to rainwater or other liquids, it is likely that the alkaline solution will ooze out of the concrete. It is a good idea to consider using the surface coating technique in addition, as it proves necessary.

4. Repairing deteriorated reinforced concrete constructions focusing on the suppression of water infiltration into the concrete

In section 3 above, we explained several types of concrete repair methods. However, if a reinforced concrete construction designated as a cultural property has deteriorated and needs to be repaired, it may not be a good idea to apply one of those concrete repair methods as they were described in section 3, because they might impair the appearance of the cultural property. As shown in **figure 11**, it is understood that a supply of oxygen and, in particular, water is essential for rebar corrosion. That implies that it is possible to suppress the development of corrosion by cutting off the supply of either oxygen or water. Below, we will present a concrete repair project in which a reinforced concrete construction that had carbonation-type deterioration was restored, with the focus of conservation measures placed on suppressing the ingress of water into the concrete.

4.1 The National Museum of Western Art (NMWA)[5]

The Main Building of the National Museum of Western Art (NMWA) was first investigated for deterioration in 2010. This building was designed by the internationally renowned French architect Le Corbusier (1887 - 1965) and was completed in March 1959. In about 2010, a campaign was being carried out around the world to nominate the architectural works by Le Corbusier on UNESCO's World Heritage List in a special category: "The Architectural Work and Urban Planning of Le Corbusier." In Japan, too, a similar campaign was launched, with the aim of including the Main Building of the NMWA as one of Le Corbusier's important architectural works to be inscribed on the World Heritage List. As part of this campaign, a plan to maintain and repair this Main Building was mapped out, with a view to continuing to make it possible to use the building for over 100 more years. This plan originated with a working group organized within the Architectural Institute of Japan for establishing a Conservation and Usage Plan for the Main Building of the NMWA. This group was chaired by the late Professor Hiroyuki Suzuki of Aoyama Gakuin University and managed by Professor Yoshiyuki Yamana of Tokyo University of Science.To make an appropriate repair plan that takes into account materials engineering, it was necessary to correctly identify the condition of the reinforced concrete in the Main Building. At that time (about 2010), as can be seen in **Photo 4**, the corrosion of the rebar caused by the carbonation of concrete had been observed in some places.

photo 4 Corrosion of the reinforced concrete around a skylight

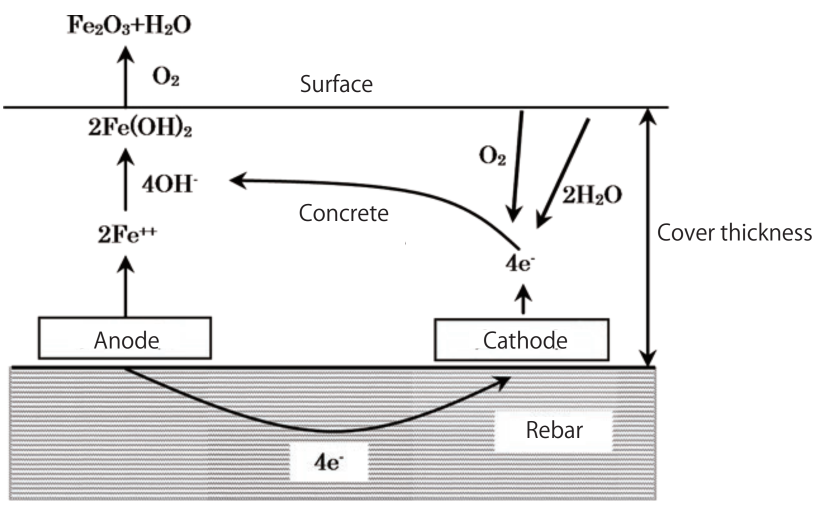


figure 11 Mechanism of Rebar corrosion

4.2 The status of the carbonation of the reinforced concrete in the Main Building

To identify the degree of deterioration of the Main Building's reinforced concrete, an investigation was performed into the progress of the concrete carbonation and the thickness of the layers of concrete over the rebar. First, as a preliminary step, a micro-destructive test was performed that involved taking small-diameter core specimens from external walls (belt-like areas) of the Main Building. The test revealed that the carbonation of the concrete of this 50 year-old building had nearly reached the rebar inside the concrete (under a concrete covering that was 30 - 40 mm thick) (**photos 5** and **6**).

During the full-fledged investigation, however, the depth of carbonation in the belt-like areas of the external walls of the Main Building was estimated using a non-destructive test (an air-permeability test of the concrete covering the rebar), in an effort to minimize damage to the building (**photo 7** and **figures 12** and **13**). In addition, the thickness of the covering concrete was also investigated non-destructively using radar. It was thus decided to use the results of this non-destructive test for the prediction of the progress of carbonation in the areas examined, assuming that the graph (**figure 13**) correctly showed the relationship between the results of the air-permeability test of the covering concrete and the progress of carbonation as measured by the core specimens.

The non-destructive test was performed on a total of 122 areas of the external walls (belt-like areas). If it is assumed that the service life of a reinforced concrete construction expires when the carbonation of the concrete reaches the rebar, it was predicted that the service life of the Main Building (if the corroded rebar were to suffer a volume reduction to the corrosion limit of 20%[6]) would end about 25 years after the year (2010) when this investigation was performed (**figure 14**).

After the implementation of the non-destructive

photo 5 Concrete core drilling

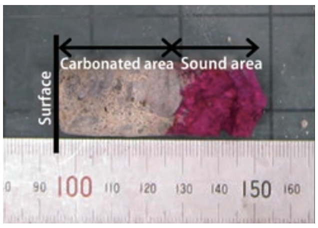


photo 6 Depth of carbonation observed in a core sample

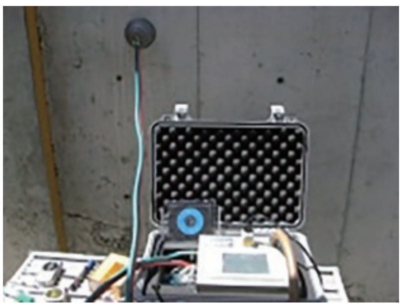


photo 7 Air-permeability test of the concrete covering the rebar

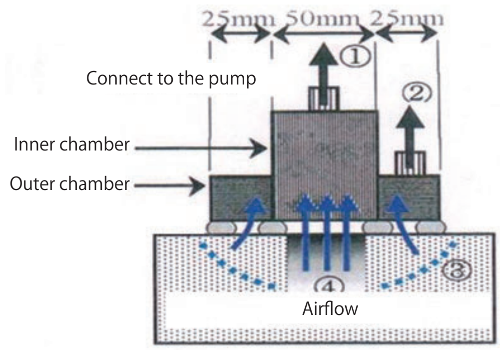


figure 12 Descriptive figure of air-permeability test of the concrete covering the rebar

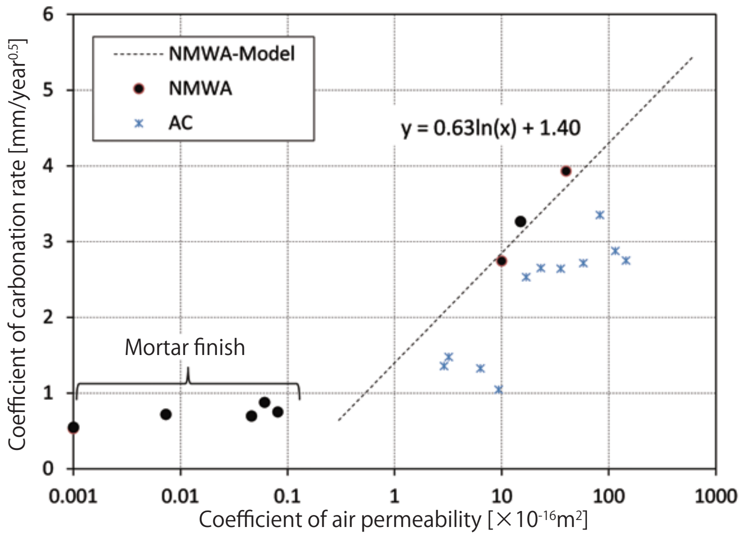


figure 13 Relationship between a non-destructive air-permeability test and carbonation

test, another investigation was performed to gain an understanding of the general condition of the Main Building, by checking the following items: a total of 22 columns on the first, second, and third floors; beams and underside of slabs of the second floor exposed to the outside environment (**figure 15**); and the round columns on the 3rd floor.

4.3 Overview of the whole Main Building

Figure 16 shows how the radar system is used to measure the thickness of the concrete covering the rebar. An electromagnetic wave is emitted from the concrete's surface toward the inside of the reinforced concrete. The radar picks up the waves reflected from the rebar and identifies the position and depth of the rebar non-destructively, thus yielding an inferential measure of the thickness of the concrete covering the rebar (**figure 16** and **Photo 8**). **Photo 9** shows a permeability test being performed.

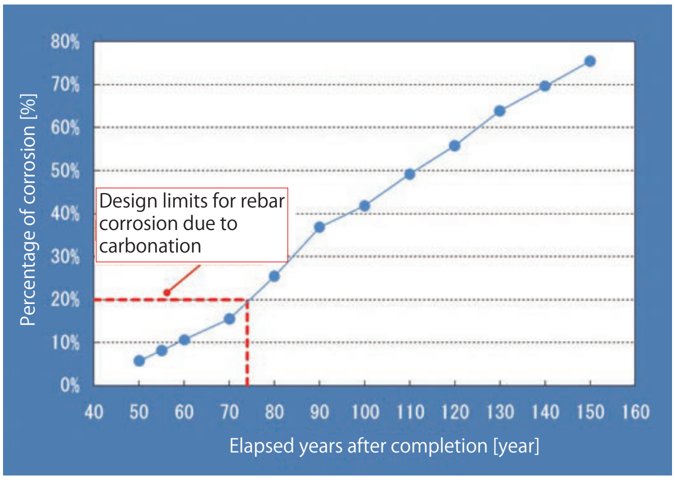


figure 14 Corrosion of rebar estimated from non-destructive test results

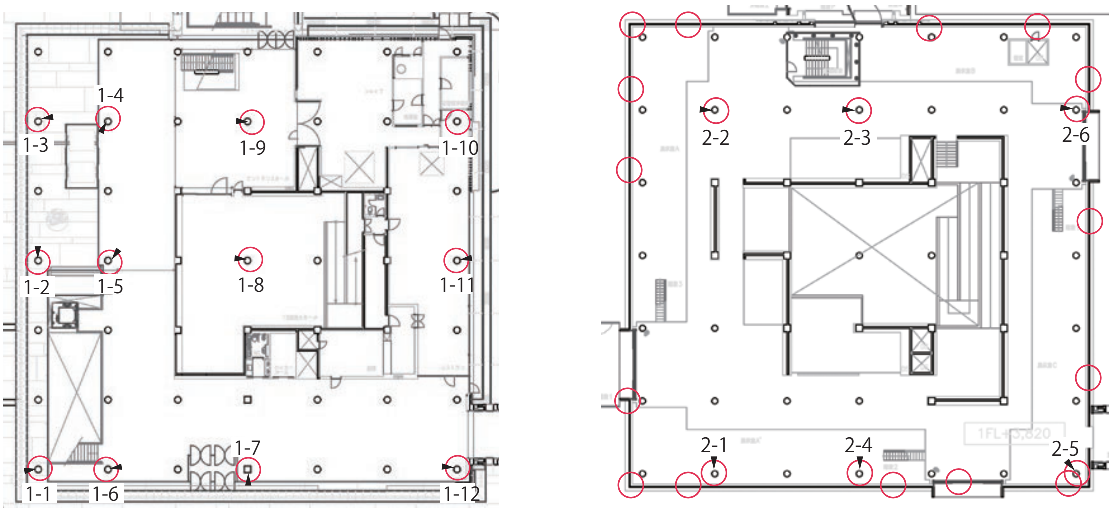


figure 15 Checked areas (left：1st floor, right：2nd floor)

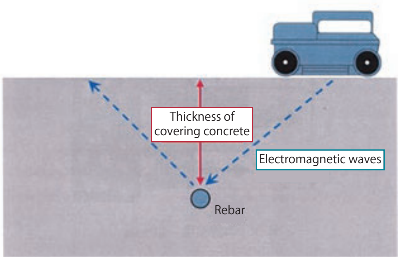


figure 16 Radar system

photo 8 Radar system

(1)The thickness of the concrete covering the rebar

Figure 17 shows a histogram of all measured data on the thickness of the concrete covering the rebar in the Main Building. The concrete was reasonably thick in many of the outer beams but it was quite thin in many of the areas under the slabs. JASS 51, the specification for concrete construction which was widely used at the time when the NMWA was built, required that concrete over rebar measured at the fair face of the concrete, whether indoors or outdoors, must be 30 mm at a minimum. The concrete covering rebar in the Main Building did not meet the criteria required in that specification at 64.3% of the measurement points on the indoor columns, 63.3% of those on the outdoor columns, and 76.9% of those in the areas under the outside slabs. Of particular note, the concrete over rebar in almost all the areas under the external slabs was as little as less than 10 mm thick (**table 3**).

On the other hand, some round columns, which are emblematic of the style of the Main Building, tended to have thinner concrete coverage on one end, the closer to the top of the column it was, and thicker concrete coverage on the other end (**figure 18**).

That is, displacement or distortion of the rebar could be seen in some round columns. This is probably because at that time the placement of the concrete was done without using a spacer, a convenient tool to assure the appropriate thickness of the concrete over the rebar, which is widely used for concrete placement in the present day.

According to the records of the construction of the Main Building, it seems that the placement of concrete was often performed as follows: the rebar was arranged upright and secured in place using fasteners; these fasteners were removed when the concrete form was installed; and then concrete was poured into the form.

(2)Depths of the Museum's concrete carbonation

Figure 19 shows a histogram of the data on the depth of carbonation in parts of the Main Building (as measured). On the whole, the concrete in the outdoor areas had a carbonation depth of around 30 mm while the concrete in the indoor columns also had indications that it had been suffering from carbonation (**figure 19**).

photo 9 Air-permeability test for the estimation of carbonation

table 3 Minimum thickness values of covering concrete specified in JASS [5]

Types of structural members		minimum thickness of the covering concrete(mm)
Load-bearing walls, columns, and beams	Outdoor areas exposed to weather (vs. indoor areas), which were not finished effectively enough to promote the durability of the rebar.	30
	Areas exposed to the indoor environment, which were finished effectively enough to promote the durability of the rebar, such as by the application of mortar, plaster, or tiles.	20
Floors and walls other than load-bearing ones		20
Columns, beams, walls, and floors that are in direct contact with the ground		40
Foundation		60

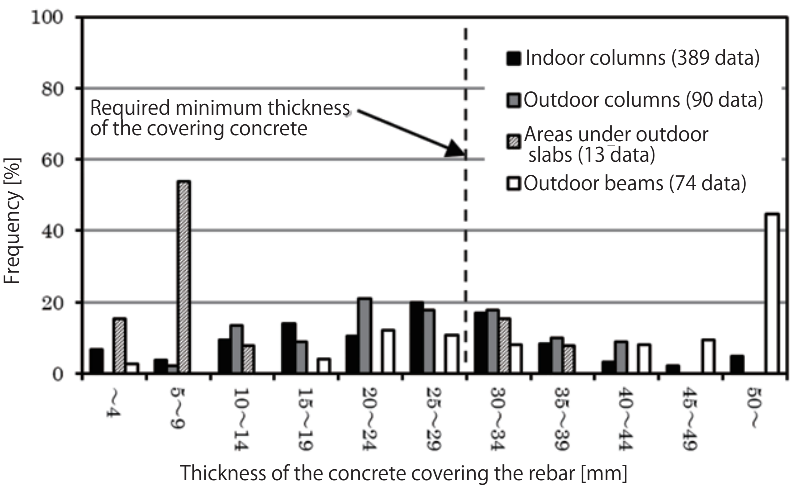


figure 17 Distribution of the thickness of the concrete covering the rebar

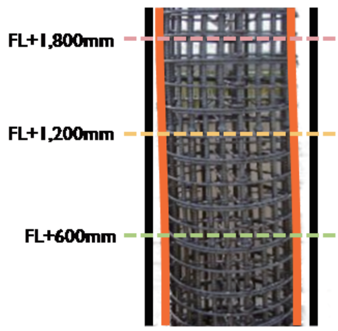


figure 18 Example of the results of measuring the distribution of the rebar inside a round column

(3)The degree of risk of rebar corrosion

We classified three levels of the degree of risk that the rebar at various locations in the Main Building would corrode (great, moderate, and small) using the data on the thickness of the concrete covering the rebar and the depth of carbonation obtained in the above investigation and referring to the Recommendations for the Practice of the Survey, Diagnosis and Repair of Deterioration of Reinforced Concrete Structures[7] (Architectural Institute of Japan). **Figure 20** shows the results of our application of the classification process. In particular, locations that are subject to rainwater exposure and those whose corrosion can be easily identified by the naked eye were given a plus (+) sign within each risk level. The result was that about 1/3 of the locations examined turned out to have a "great" or even greater risk level, with the risk of the rebar's corroding in areas on the underside of slabs and in parts of the outdoor columns and beams scoring a risk level of "great +". The graph demonstrates that the progress of corrosion differs from one location to another and this helped to determine which areas we should prioritize when developing the repair schedule for the Main Building.

4.4 Conservation and restoration of the Main Building[8]

Generally, as mentioned above, conservators use the patch repair method, in which deteriorated concrete is replaced with new concrete, or the re-alkalization method, in which alkalinity is electrically supplied to repair carbonated concrete constructions. However, the use of these techniques, as they are, is somewhat controversial as methods for repairing reinforced concrete constructions designated as cultural properties, because they may cause conspicuous changes in the appearance of the reinforced concrete structure or involve chipping away concrete from around the rebar. Since rebar corrosion is triggered by supplies of both oxygen and water, if the infiltration of either oxygen or water into the concrete can be suppressed, the rebar won't corrode even if the concrete undergoes carbonation. Therefore, to restore the Main Building, it was decided to use a surface impregnation agent as a method of suppressing the infiltration of water into the concrete without changing the appearance of the building.

Although the details of the discussion about selecting the surface impregnation agents are omitted here for lack of space, we can report that the surface impregnation agent

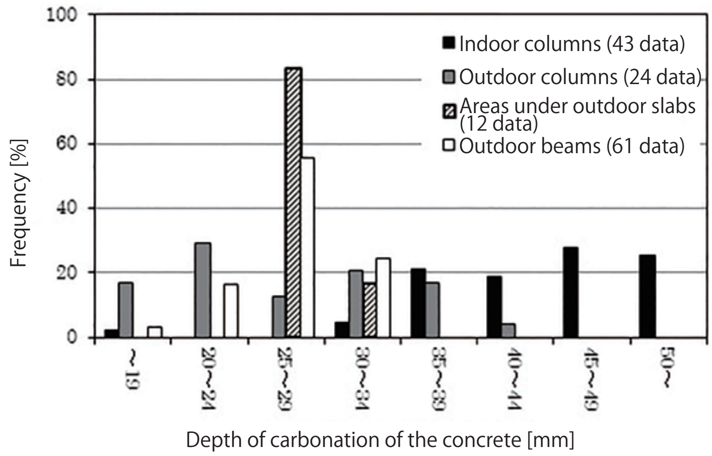


figure 19 Distribution of the depth of carbonation of the concrete

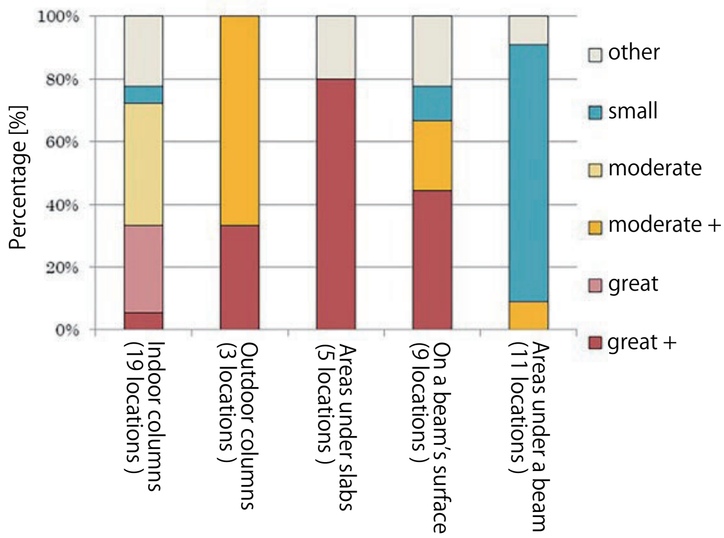


figure 20 Classification of the degree of risk that the rebar at various locations will corrode

that was selected was the most capable of suppressing the infiltration of water effectively without affecting the appearance of the building. After performing an impregnation test of the agent (**figure 21**, **photo 10**), it was finally applied during the restoration of the NMWA's Main Building.

Figure 22 and **photo 11** show the water repellence of a concrete surface repaired using a surface impregnation agent. The water repellence of the concrete surfaces was evaluated using a non-destructive electrical method, as shown in **photo 11**.

Use of this type of method makes it possible not only to check the water repellent effect of the surface impregnation agent, but also to evaluate the future durability of the effect non-destructively, which contributes greatly to the maintenance of the building.

Figure 23 shows changes in the water content of the concrete surface versus the length of time after the application of the surface impregnation agent. The values on the graph are the averages of from three to five measurement points examined 9. After the application of the surface impregnation agent, the concrete surfaces of the external walls on the four sides of the building had lower water content than before being treated with the agent. In addition, a certain level of water repellent effect continued for three years after the surface impregnation agent was applied. The external walls (belt-like areas) on the east and west sides also had lower surface water content after being treated with the surface impregnation agent. Of particular note, they underwent a large change in surface water content between the beginning of measurement and the end of measurement, indicating that those concrete surfaces retained a high level of water repellence. In contrast, after two months had passed, the concrete surfaces of the external walls (belt-like areas) on the south side, although they retained a certain level of water repellence, did not have as much of it after being treated with the surface impregnation agent as was retained on the surfaces on the east and west sides. It was thought that this was because the silane treatment layer for some reason disappeared from those concrete surfaces.

Therefore, it was decided to use the 4-probe method (also called the Wenner method) to identify more accurately the water infiltration suppression effect of the surface impregnation agents. This method, as illustrated in **figure 24**, evaluates the electrical resistance of a specimen using four equally spaced electrodes placed on the surface of the specimen, and applying AC current to that surface to measure the voltage differences between the four probes and the current flowing through the specimen. The 4-probe method is relatively simple so it has become widely used to evaluate the electrical resistance of specimens in various industries, including construction and civil engineering. In addition, since the specific resistance of a specimen can be obtained

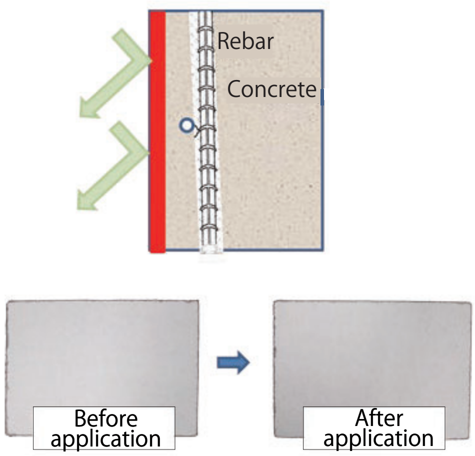


figure 21 Schematic diagram of the effect of surface impregnation agents

photo 10 Impregnation test

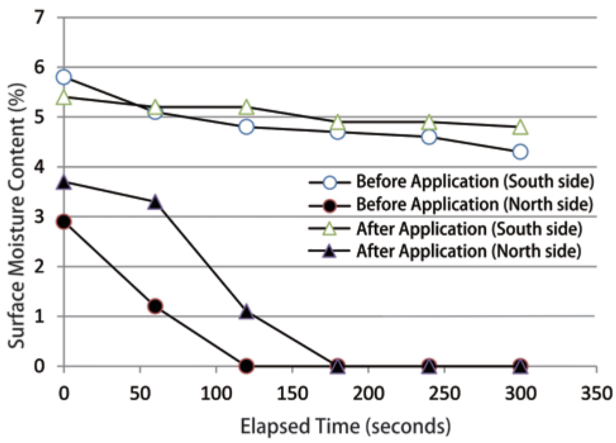


figure 22 Checking the water repellent effect of surface impregnation agents


photo 11 Water repellency test on the concrete surface

in the depths of material (wherever the measuring current reaches), it is also possible to measure changes in specific resistance in the direction of depth from the surface by enlarging the distance of the four probes from center point 0, as shown in **figure 24** (**photos 12** and **13**).

We performed an indoor experiment and a water exposure test using concrete specimens. Figure 25 shows the relationship between water content by mass and specific resistance of concrete that was obtained from the results of our indoor experiment and water exposure test.

Figure 25 also shows the specific resistance value P, which was obtained from previously performed research10. As shown in **figure 25**, it was found that there is a correlation between the specific resistance of concrete and its water content by mass. Therefore, we obtained an approximation formula taking into account the difference between the test units by which specific resistance values for P and FP had been obtained.

Our experiment also showed that there was a tendency for the specific resistance to increase in correlation with the effect of the surface impregnation agent. For these reasons, we concluded that the use of the 4-probe method made it possible to evaluate the water content of the concrete covering the rebar while avoiding the effect on the measurements of the disappearance of the surface impregnation agent from the concrete surface.

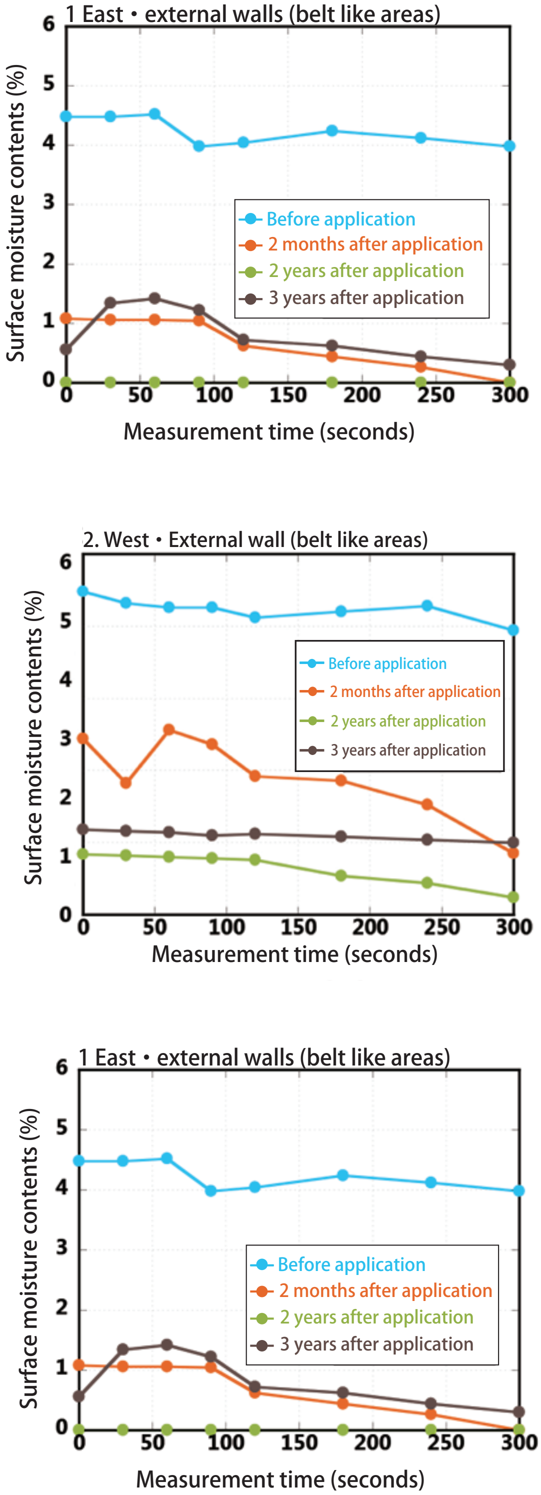


figure 23 Changes in surface water content[9]

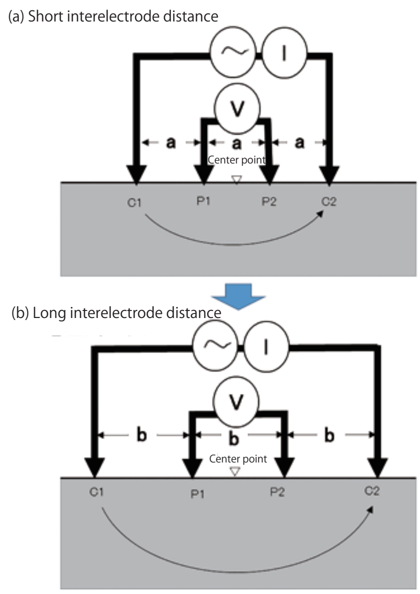


figure 24 4-probe method[9]

photo 12 Specific resistance meter[9]

photo 13 Specific resistance meter[9]

On the basis of the results discussed above, the measurement of specific resistance was performed on the external walls on all four sides of the Main Building (the belt-like areas). At the same time, a similar measurement was carried out on the columns on the first floor inside the Main Building. There were three measurement points chosen on the surface of each object (the columns on the 1st floor and the external walls). **Figure 26** shows the results of these measurements. The specific resistance of the indoor columns was the highest. This was probably because the interior of the Main Building was always kept at a temperature of 21℃ and a relative humidity of 51%, an environment that helped keep the water content inside the columns' concrete low and stable.

In the previous investigations, the ability of the surface impregnation agent to suppress the infiltration of water into the concrete could not be sufficiently identified on the concrete of the south side of the Main Building. However, using the 4-probe method, regardless of the amount of space left between the probes, it was found that the concrete on the external walls on the south side had the highest specific resistance of the concrete of all the external walls (those belt-like areas), indicating that the water content on that side was indeed low. When we examined the specific resistance values shown in **figure 26** against the relationship between the specific resistance and the water content by mass shown in **figure 25**, it was also found that all the measurement points had higher specific resistance values than the specific resistance value at which the water content by mass would be less than 3.5%[11], a value at which rebar is unlikely to corrode. Therefore, we concluded that the surface impregnation agent had effectively treated all four sides of the external walls (belt-like areas) and had sufficiently suppressed the infiltration of water into the concrete.

5. Our approach to the restoration of reinforced concrete constructions designated as cultural properties

The term "restoration" is defined as returning the performance of an object to its original level. However, this Main Building restoration project was intended to maintain the current condition of the building or substantially reduce the speed of its deterioration (**figure 27**). This preemptive approach will increase the number of options for the

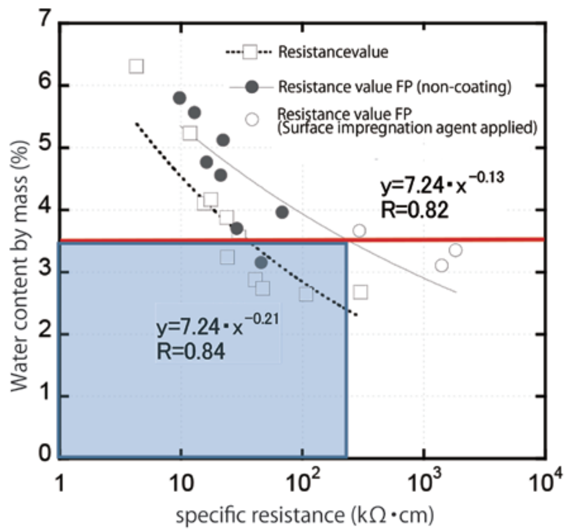


figure 25 Relationship between specific resistance and water content by mass[9]

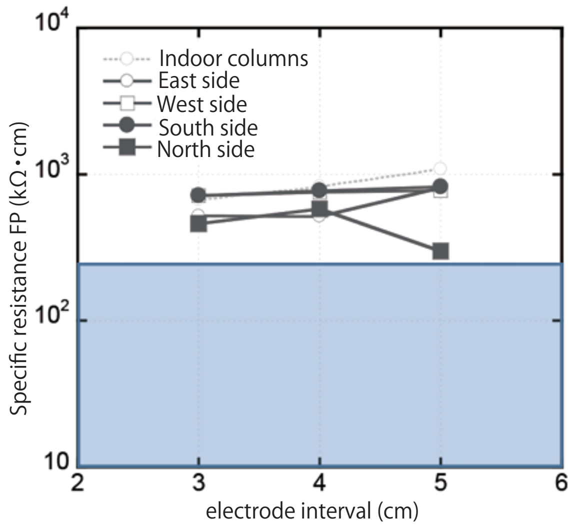


figure 26 Results of specific resistance measurements of the NMWA's Main Building[9]

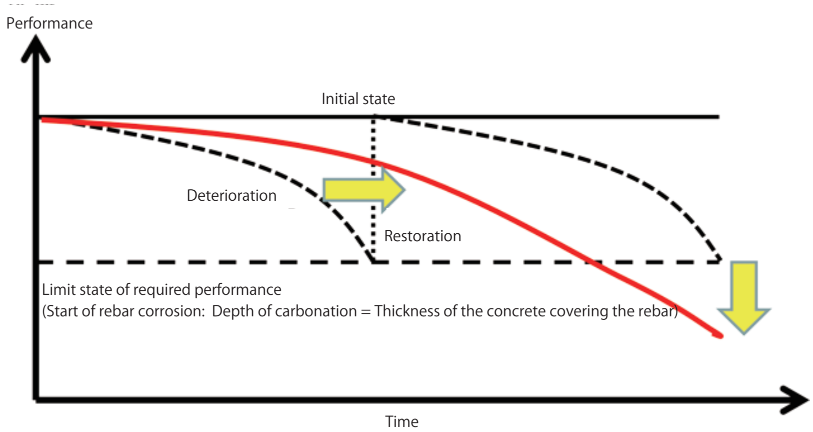


figure 27 Repair concept aimed at suppressing the progress of deterioration

selection of restoration methods without changing the appearance of the cultural property to be restored. We hope and expect that this approach will in the future become one of the tools in the restorers' toolbox kept in mind as a useful method for conserving reinforced concrete constructions, especially from the perspective of the conservation of structural members.

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Chapter 2

Restoration of Mitani Old Fountainhead Water Facilities and Early Reinforced Concrete Structures in Japan

Restoration of Mitani Old Fountainhead Water Facilities and Early Reinforced Concrete Structures in Japan

Hasegawa Naoji
Senior Fellow, National Institute for Land and Infrastructure Management

1. Introduction

Although reinforced concrete have now become a common construction method for architecture and civil engineering structures, in historic structures, the same word of “reinforced concrete” pertains to a wide range of types including those of almost completely different construction methods, requiring attention in undertaking surveys and repairs.

Regarding Mitani Old Fountainhead Water Facilities (**photo 1**), reinforcement used in the original concrete construction of the water control shed (building area: 6.88 m²) connected to each of the five filtration ponds as well as the shed (building area: 7.40 m²) of the Junction Well, of which there is one, was made not of reinforcement bars but metal wire mesh. In literature on architectural techniques of the time, reinforcement for “iron mesh concrete” referred to a woven wire mesh; at Mitani Old Fountainhead Water Facilities, it was expanded metal lath that was used, so it may not be accurate to categorize these structures as “iron mesh concrete.” However, the aim of development and handling of both of these construction methods was very similar. How they completely differed from “reinforced concrete” was that no formwork was necessary. They were both construction methods in which the lath provided the substrate onto which concrete or mortar was plastered for constructing walls and roofs.

In this chapter, the restoration processes of the first lath substrate concrete structure of a nationally designated Important Cultural Property to be restored will be dealt with. (The restoration project was nationally funded and was undertaken from April 24, 2013 to March 31, 2018 over a period of 59 months.)[1]. Focus was also placed on describing the various types of reinforced concrete construction developed and attempted in the early years. They, of course, cannot be evaluated under the present guidelines for anti-seismic analysis or those for inspecting durability and making repairs. They need to be viewed and evaluated uniquely according to each of their specifications. On the other hand, there may be historic significance and distinctive values to be found in these construction methods that are no longer seen today. This paper intends to provide information for studying such evaluation methods as well as for discovering significance in these construction methods.

2. An Outline of Mitani Old Fountainhead Water Facilities, Nationally Designated Import Cultural Properties

According to the property description in the designation documents, Mitani Old Fountainhead Water Facilities are components of a former water supply system located approximately five kilometers to the east of central Tottori City, upstream of the Mitani River of the Chiyo River system. These facilities were developed with the main purpose of providing drinking water to the urban areas of Tottori City and improving public hygiene. Construction work headed by the Tottori City municipal government was started in June 1912 and was completed in October 1915. Later when facilities including the reservoir dam and filtration pond were damaged in the floods of September 1918, recovery work was executed from July 1919 to June 1922. Operations of these facilities were ceased in 1978, on the occasion of construction of a new water source, and the reservoir dam was altered into an erosion control dam during the period of 1992 to 1999.

These facilities are historically significant as a representative heritage property from the early years of Tottori City’s waterworks, which was the first to be established in this region. Also, among the water sources with a reservoir dam, this is one of the few waterworks equipped with a slow sand filtration pond. Thus, these facilities including the water meter facilities upstream and downstream from the reservoir are precious as artifacts that retain the original composition of modern waterworks.

3. Lath-substrate concrete: characteristics and restoration

As already mentioned, the five water control sheds and one of the shed of Junction Well are made of lath substrate concrete. To put it precisely, the early works are of “mortared lath substrate” construction. These water control sheds are numbered from one to five. Although their appearances are very similar, No. 1 to 4 were completed in 1915, with walls and roof made of “lath substrate mortar-finish” construction. On the other hand, No. 5 was completed around 1927, with walls made of “lath substrate concrete” construction and no lath in the roof. The shed of the Junction Well with a circular floor plan was completed in 1915. It has brick masonry walls of header bond and the roof is of "lath substrate mortar-finish." The framework of the "lath substrate mortar finish" is composed of angle steel (L-5 × 64 × 64) and strip iron (including PL-3 × 39) and the lath is made of expanded metal; 0.5mm thick steel plates have been expanded to create diamond shapes of 30mm width and 12mm height. In building No. 5 built in later years adopted thin steel wire reinforcement of 3mm diameter placed at 150mm intervals on the outer side of the lath, which supposedly was introduced for crack prevention of concrete.

Although the water control sheds No. 1 to 4 were completed at the same time under the same conditions, differences were found in the extent of deterioration due to continued use over the years. No. 2 was the most damaged (**photo 2**). Also in the flood of 1918, No. 1 was toppled over by water current, which can be seen in a historic photograph. On the building placed back in its original position, traces of restoration, including deformation of the steel frame and additional lath inserted for reinforcement, can be found.

In the process of studying preservation methods, various opinions were raised. For example, Building No. 2 which was the most severely damaged could be left as is, to be preserved indoors in a different place as sample material of deterioration, and a reproduction created to replace the removed building. As a result of further surveys, it was discovered that No. 2 could be preserved without going through full-scale restoration. Thus, it was decided to restore and preserve in its original location, while restoration work was began with structures No. 3 and 4 with comparatively less damage, to be followed by No. 1 and 5. Lastly, after having gained further experience, work on No. 2 was begun.

Each of the structures was more or less damaged with corrosion expansion seen in steel frames and metal lath, resulting in detachment and pop offs of the mortar and concrete surfaces. Nevertheless, the sound areas were confirmed to retain sufficient strength and therefore, the damaged portions were repaired and preventive methods for corrosion and water infiltration were taken. This was to enable easier maintenance and recover the originally intended performance of the structural elements composing the upper structure.

These repairs followed contemporary conventional methods for recovering sectional dimensions in reinforced concrete structures. First, the sizes of detached areas and deformation were inspected in the walls to be repaired. Then, the areas to be removed were decided. After partially removing these damaged areas, the extent of corrosion on the rebars was visually inspected for carefully re-examining and finalizing the areas to be removed. If there was fear of further losing the original materials, the restoration method was to be reviewed.

For repairing smaller damage of cracks and detached areas, cement slurry was injected for filling small pockets inside the walls. Repairs on sectional dimensions were executed by filling the cracks with polymer cement using a trowel. The roof surface was then waterproofed.

The materials for repairs were chosen following those original used, as long as they would not deter future

photo 1　Water control shed No. 5 (rectangular plan, in center) on the edge of filtration pond (right). Wells No. 4 and No. 3 can be seen toward the back. On left is the shed of Junction Well (circular plan) after restoration.

photo 2　Water control shed No. 2 before restoration. This was the most severely damaged of all wells.

photo 3　The original diamond-shaped metal lath and steel frame members, after removal of damaged mortar finish

maintenance procedures. However, with industrial products including metal lath and steel frames that did not meet present-day standards and were no longer available or were difficult to obtain, the use of contemporary standard products was studied. For example, because the original metal lath with diagonal openings (**photo 3**) was difficult to find, it was replaced with the presently available product with a hexagonal pattern of similar sized openings.

The speed of carbonization of cement and concrete was slower than that commonly seen, which was possibly due to the preferable surrounding environment. Nevertheless, because the concrete cover thickness of steel framework and metal lath was generally small, anti-corrosion paste was applied on the surfaces, not only on the areas to be repaired but entirely on other areas as well, for mitigating further carbonation of mortar and concrete.

The roofs of structures No. 1 through 4 were constructed without waterproofing as with the walls. The roof of structure No. 5 was covered with asphalt roofing and mortared, inducing damage due to mortar detachment. Repairs on all five structures were done in the same way as the walls, by entirely applying anti-corrosion paste then finishing with waterproofing paint.

The same method was employed for repair on the roof of the upper structure of the Junction Well.

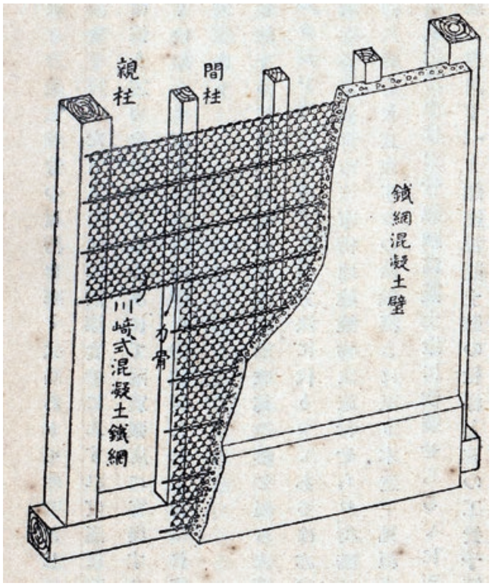

figure 1　Kawasaki style wire netting concrete wall structure

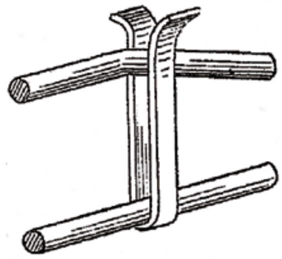
figure 3　Hennebique style, main reinforcement and shear reinforcement (hoop flat) (Source: 日比忠彦、鐵筋混凝土ノ理論及其應用 上巻、丸善株式会社、1916.1 初版、photo provided by: Japan Society of Civil Engineers, JSCE Library、http://library.jsce.or.jp/Image_DB/s_book/jsce100/pdf/20612/20612_03.pdf、p.299)


figure 4　Kahn style reinforcement for beams. Although the diagonal reinforcement is said to have been designed to bear shear force, it does not appear effective.(Source: 日比忠彦、鐵筋混凝土ノ理論及其應用 上巻、丸善株式会社、1916.1 初版、photo provided by: Japan Society of Civil Engineers, JSCE Library、http://library.jsce.or.jp/Image_DB/s_book/jsce100/pdf/20612/20612_03.pdf、p.315)

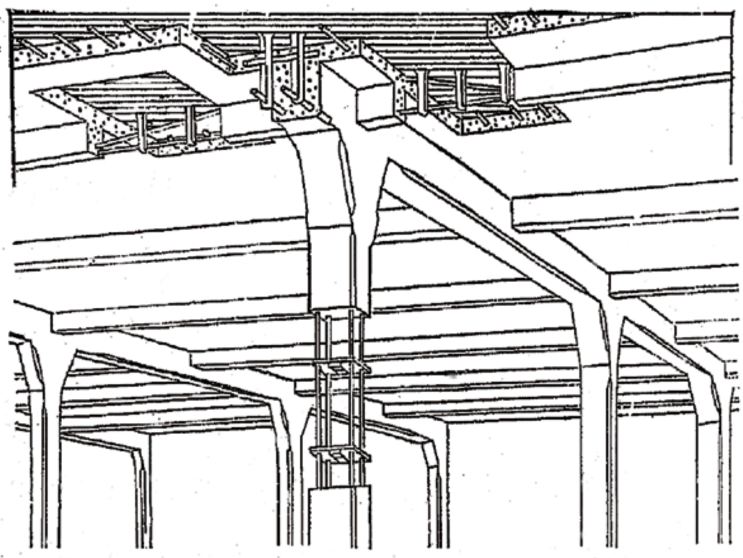
figure 2　Hennebique system (Source: 日比忠彦、鐵筋混凝土ノ理論及其應用 上巻、丸善株式会社、1916.1 初版、photo provided by: Japan Society of Civil Engineers, JSCE Library、http://library.jsce.or.jp/Image_DB/s_book/jsce100/pdf/20612/20612_03.pdf、p.298)

4. Early Reinforced Concrete Construction Methods in Japan

According to "Principles and Application of Reinforced Concrete"[2] written by Hibi Tadahiko in 1916, in volume 1, series 3 'Theory of Styles,' chapter 4 deals with "wall styles." The topics of each of the sections are Section 1: styles of general walls, section 2: Hennebique system, section 3: Chaudy and Dégon systems, section 4: Wayss system, in section 5: Styles employing metal wire netting including 1) Golding system、2) Roebling system, 3) expanded metal, section 6: Matrai system. Introduced in section 7 under Other styles are the various construction methods of 1) Wire net with terracotta、2) Kawasaki-style, 3) Suzuki-style, and 4) Hye rip system.

The "lath substrate mortared structure" and "lath substrate concrete structure" of Mitani Old Fountainhead Water Facilities are similar to the style mentioned as 3) expanded metal in section 5 in the abovementioned literature. The illustrations show the method being used between columns in a wood-frame structure, which is different from the way is it employed at Mitani. The explanations read, "The framework is made of section shape steel to be covered by 'expanded metal.' ... and mortared with concrete with small aggregate from both sides."

Also 2) Kawasaki-style in Section 7 is a construction method called "metal netting concrete metal netting reinforced concrete developed by architect and architectural academician Mitsuhashi Shiro (1867-1915) and a metal netting manufacturer Kawasaki Hiromi (1863-1926) for which applications were handed in on January 2, 1911 and registered as Utility Model No. 22053 on October 20 of the same year. This is characterized by the metal netting made of wire lath (**figure 1**). In the Taisho period, up to the 1923 Great Kanto Earthquake, this method was widely disseminated[3] as "reinforced concrete employing metal netting with concrete applied with a trowel that could be constructed without formwork." There are designated cultural properties that were made using this method. Among nationally designated Important Cultural Properties, the warehouse of Old Yamazaki Family Villa (Kawagoe City, Saitama Prefecture/ built in 1925) is one. The warehouse at Former Ranpo Edogawa House in Toshima Ward, Tokyo Prefecture completed in 1924 and restored in 2003 has its exterior and interior walls made of Kawasaki-style metal netting concrete structure. According to a restoration report[4], a spiraling wire lath was originally employed. In restoring this building, the wood frame was left intact while the roof and exterior walls were completely disassembled. Therefore, the original Kawasaki-style wire netting concrete seems to have been lost, with a new wall substrate of stainless steel wire lath with diamond-shaped openings, which were chosen to restore the original style. Also, following historic documents, considerations were made to match the material composition of the original plasterwork in the base and middle coats.

Although it seem that application of the foreign methods introduced in "Principles and Application of Reinforced Concrete [鐵筋混凝土ノ理論及其應用]" was rare in Japan, actual works of the Hennebique and Kahn systems (which is hardly dealt with in chapter 4 Wall styles) can be seen. Regarding these two systems, an excerpt from "Principles and Application of Reinforced Concrete" volume 1, series 3 'Theory of Styles,' chapter 1 on construction methods for floorboards and beams will be given below:

Section 19 "Hennebique system" (France) "There are many variations to this "Hennebique system" patented in 1879 of which the most common is that for creating a floor slab single-layer floor slab above beams with a typical construction methods depicted in **figure 2** (The figure number has been changed by the author) ... The merit of this system is that stirrups made of strip iron are used, of which a large number of them have been installed to bear shear force particularly close to the fulcrum. These stirrups, as seen in **figure 3**, are flared at the bottom with the top ends bent about 3/8" outwards from the edge of the concrete. (The rest omitted)"

photo 4 Umekoji Locomotive House


photo 5 Worship Hall of Otani-ha Branch Hongan-ji Temple Hakodate Branch Temple

Section 33 "Kahn system" (U.S.A.) "The Kahn system patented in 1903 is sold in Japan exclusively through Yokohama Trading Company as an agency for "Trussed Concrete Steel" Company. Kahn system reinforcing steel (Kahn bar) is as seen in **figure 4**, the sectional dimension is diamond-shaped and has wings that jut out to the left and right sides. These wings are sheared along both sides of the Kahn bar and bent upwards by which the shear strength reinforcement becomes tightly connected and unified with the main reinforcement, which is a feature that surpasses other methods. (The rest omitted)"

photo 6 Yamaguchi Bank Head Office

To name some examples among designated cultural properties, the Hennebique system can be seen in Umekoji Locomotive House (Important Cultural Property, Kyoto City, 1914) (**photo 4**)[5] and the Kahn system in Otani-ha Branch Hongan-ji Temple Hakodate Branch Temple (Important Cultural Property, Hakodate City, 1915) (**photo 5**) and Yamaguchi Bank Head Office (Yamaguchi Prefecture designated tangible cultural property, Shimonoseki City, 1920) (**photo 6**)[6].

Other notable structures are the oldest reinforced concrete apartment building no. 30 on Gunkan-jima (Hashima) (Historic Site, Nagasaki City, 1916) (**photo 7**)[7] and Former Kurosawa Building (Chuo Ward, Tokyo Prefecture, 1910; demolished) 8 that were reinforced concrete structures built without the involvement of architectural engineers. Therefore, although their historic significance is apparent, they have not been sufficiently analyzed from the viewpoint of construction methods.

Lastly, concrete block construction will be focused on as peripheral technology of reinforced concrete.

Ijokaku (Sun Yat-sen Memorial Hall), an Important Cultural Property completed in 1914 and relocated to Maiko Park in Kobe City, Hyogo Prefecture, is a wood-frame concrete block masonry structure[9]. During the Taisho period (1912-1925) in which this was built, numerous applications for

photo 7 Building no. 30 on Gunkan-jima (Hashima)

photo 9 Chin blocks acquired at the time of dismantlement of Suma Church

photo 8 The United Church of Christ in Japan's Shimanouchi Church, Registered Tangible Cultural Property

photo 10 Motono House (DOCOMOMO Japan listed)

patents and utility models were made for concrete blocks, reaching its peak in 1921 with more than 30 cases; during the fourteen years from 1918 to 1931, there were more than 150. These developments were aimed at improvements in cost, construction period, as well as properties regarding insulation and humidity control of reinforced concrete. Lowered costs could be expected owing to the fact that formwork was no longer necessary and that these hollow blocks enabled lighter structures which could be burdened by simpler foundation systems. Many inventions appeared relying on these properties, but perhaps there were no more than ten that were actually used in construction.

According to Cultural Heritage Online, an official internet database of the Agency for Cultural Affairs, structures listed as “Nakamura-style reinforced concrete” among nationally Registered Tangible Cultural Properties are The United Church of Christ in Japan’s Shimanouchi Church (Chuo Ward, Osaka City, 1928) (**photo 8**), Temma Church (Kita Ward, Osaka City, 1930)[10], and Kurihara Family Residence (Yamashina Ward, Kyoto City, 1929). ” Nakamura-style reinforced concrete” is a patented concrete block construction method under the official name of “reinforced hollow concrete block structure” with the application date of August 30, 1919, registered on September 19, 1921 as Patent No. 39976.

The architect Nakamura Mamoru (1890-1933) who invented this system was also known as an architectural and social critic, having taken the role of editorial chief of an architectural critique magazine while he was still a student at Waseda University. This construction method developed by Nakamura was employed in 119 buildings nationwide during the years from 1921 until his death in 1933. The concrete blocks of a characteristic L-shape were called Chin blocks, taking after the Chinese pronunciation of his first name. These Chin blocks can be considered as reinforced concrete block masonry of L-shaped concrete blocks. However, it was not just a concrete block construction system that he was aiming for. His goal was 1) to increase structural durability, 2) to perfectly match the use of the structure, 3) affordable prices, and 4) create beautiful architecture (**figure 5** and **photo 9**).

Although it seems that a large number of Chin-block

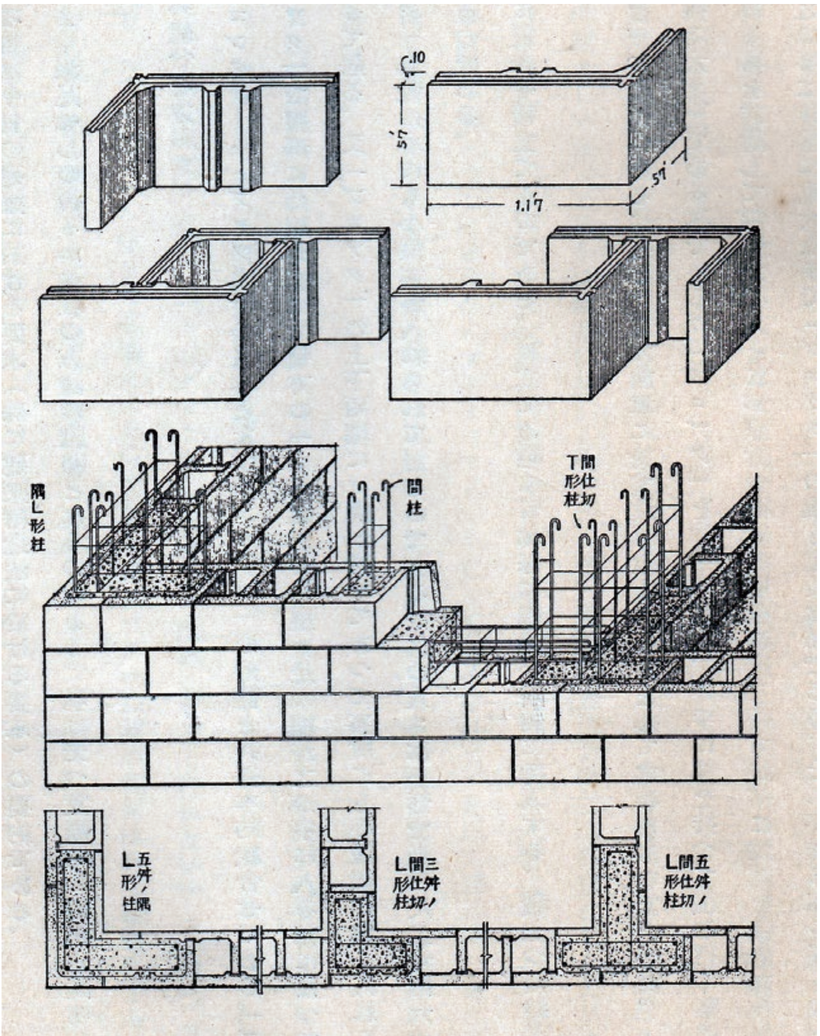

figure 5 Wall construction of a Chin block structure『中村鎮遺稿』(中村音羽 編、中村鎮遺稿刊行会、1936.9)

structures have been lost over the years, there are other structures aside from those mentioned above including Arai Ryokan Tenpyo Bathhouse (Registered Tangible Cultural Property, Izu City, 1934) of Shuzenji Hot Springs and Motono House (DOCOMOMO Japan listed, Kita Ward, Kyoto City, 1924) (**photo 10**).

5. Conclusion

In recent years, national designation and registration of reinforced concrete cultural properties continue to be undertaken. Although many restoration projects have been executed on this structural category and studies are being made on principles and methods for restoration, it cannot be denied that we are still at the stage of trial and error. There is an urgent need for immediate establishment of basic principles for restoration of reinforced concrete structures.

Although they are simply called "reinforced concrete," it needs to be noted that because the structures introduced in this chapter, particularly those from the early years of development, vary greatly in construction method, they require careful attention in their handling.

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Chapter 3

Issues in Anti-Seismic Technology for Historic Concrete Structures

Issues in Anti-Seismic Technology for Historic Concrete Structures

Nishioka Satoshi

Senior Conservator of Cultural Properties, Agency for Cultural Affairs

1. Introduction

The number of designated concrete cultural property structures, represented by reinforced concrete structures, has constantly been on the rise as the significance of those built during the Taisho (1912-1925) and Showa (1926-1989) eras becomes recognized.

Among the nationally designated Important Cultural Properties with a total of 5,033 structures, the number of concrete structures (including reinforced concrete structures and steel-frame reinforced concrete structures) is 175 as of March 2019. It is gradually increasing, of which Former Yamamura Family Residence (Yodoko Guest House) in 1974 was the first to be designated.

Also among the nationally Registered Cultural Properties, concrete structures comprise approximately 1,200 of the total of 11,690 or about 10% in number. As studies are continued to clarify the rating of post-war buildings in the coming years, more registrations can be expected (**photo 1**).

A majority of concrete cultural property structures is located in urban areas and have been adapted to modern usage, making anti-seismic treatment such as structural analysis and structural reinforcement inevitable in most cases. Because concrete structures are common in general contemporary construction, there are abundant cases of research and execution of structural analysis and structural reinforcement. Therefore, compared to traditional wood frame or brick masonry structures, there may not be as many specific characteristics requiring unique treatments in those that are designated as cultural properties. However, there are older and fragile buildings as well as those with unusual structures or placement of reinforcement bars, which require greater consideration in designing for their seismic reinforcement in ways that would not to affect their characteristics as cultural properties.

photo 1　Recently designated concrete Important Cultural Properties (Designated on August 17th, 2018)

Firstly, in this paper, recent principles and methods for research regarding seismic analysis of historic concrete structures as well as analysis methods will be introduced. This will then be followed by specific issues owing to their unique qualities, referring to certain cases. Although in the category of concrete structures, there are other types including non-reinforced concrete and steel frame reinforced concrete structures, in this paper, reinforced concrete structures will mainly be focused on.

2. Extant Principles and Research

Regarding seismic analysis and seismic reinforcement of historic structures, the following principles and research cases are known.

○ "Guidelines for Evaluation of Seismic Performance of Non-reinforced Masonry Structures and Reinforced Concrete Structures from the Urban Building Law Era [無補強煉瓦造建築及び市街地建築物法期の鉄筋コンクリート造建築耐震性能評価ガイドライン]" (Japan Institute of Country-ology and Engineering [財団法人国土開発技術研究センター] March 1998)

This is a guideline for evaluating seismic resistance of non-reinforced brick masonry and reinforced concrete structures constructed during the Meiji period up to the years before the Second World War. Regarding reinforced concrete structures, those constructed during the period when the Urban Building Law was in effect from 1921 to 1931 are dealt with. This literature focuses on the aspect that buildings of those days were designed based on elastic design principles, rather than ultimate design on which today's buildings rely on. Thus, in order to evaluate their strength quantitatively, such indexes as the material safety factor up to the elastic limit and inter-level deformation angle should be employed.

○ ”A Report of the Committee for Analysis and Restoration of Historic Structures in the Fields of Architecture and Civil Engineering [建築・土木分野における歴史的構造物の診断・修復研究委員会報告書]” Japan Concrete Institute [社団法人日本コンクリート工学協会] June 2007

This is a record of research on deterioration surveys, seismic analysis, and seismic reinforcement regarding non-wood frame structures and civil engineering structures such as those of brick masonry, reinforced concrete, and stone masonry. Pertaining to seismic analysis of concrete structures, cautionary viewpoints for applying extant standards onto historic structures for seismic analysis were analyzed, particularly focusing on the employment of these seismic analysis standards onto those of mainly low-strength concrete.

Also in seismic reinforcement, it is noted that considerations are necessary to reinforce in a way that would 1) minimize deformation (stress-type reinforcement), 2) involve dispersed placement to avoid stress concentration, and 3) create allowances for reserve capacity.

○ “Conservation and Restoration of Concrete Structures” Tokyo National Research Institute for Cultural Properties, 2011 (English edition can be viewed online at https://www.tobunken.go.jp/image-gallery/conservation/10e/HTML5/index.html)

A specialized seminar on concrete structures held at Tokyo National Research Institute for Cultural Properties in 2009 has been recorded in this report. This is a compilation of foreign and domestic cases focusing on issues in preservation and restoration work on concrete structures, of which there were not many then, referring also to the field of seismic reinforcement.

3. Writings Regarding Concrete Structures in Guidelines and Handbooks for Seismic Analysis of Important Cultural Properties

Japan’s Agency for Cultural Affairs in “Guidelines for Seismic Analysis of Important Cultural Properties (Structures) [重要文化財（建造物）耐震診断指針]” (April 8, 1999, revised in June 21, 2012) has presented guidelines for seismic analysis of Important Cultural Properties. However, the methods provided here are based on those for wood frame structures. Regarding concrete structures and civil engineering structures, they are only touched upon as follows without any further specific details: “Seismic analysis should be executed through a method that is appropriate for the structural characteristic for the said structure conforming to the intended aim of this guideline.”

“Revised Handbook for Seismic Analysis of Important Cultural Properties (Structures) [重要文化財（建造物）耐震診断・耐震補強の手引（改訂版）]” (September 2013, revised in March 2017) is a handbook intended for interpreting the guideline. Regarding reinforced concrete structures from the early eras, it is mentioned that considerations are necessary in applying general seismic analysis methods, because there were variances in material strengths and the placement and types of reinforcement bars were different from those we see today.

When revisions were made in 2017, additional information on preventive measures for structural deterioration was included. Because concrete carbonization itself does not necessarily directly influence building life, but rather greater damage is brought about by rainwater entering into areas that have been affected by carbonization which induce corrosive expansion of reinforcement bars, avoiding water infiltration was identified as the basic preventive measure to be taken.

4. Regarding Standards for Seismic Analysis of Extant Reinforced Concrete Structures

“Standards for Seismic Analysis of Extant Reinforced Concrete Structures [既存鉄筋コンクリート造建築物の耐震診断基準]” widely used for general structures was first published in 1977 and was revised in 1989, 2001, and 2017, the last of which is the present edition.[1]

These standards are used in seismic analysis of extant reinforced concrete structures in which on-site analysis and structural analysis are both performed. The structure’s generally expected seismic performance is evaluated quantitatively by the two parameters of seismic structural index Is and seismic index for non-structural members IN. There are three methods of analysis - first, second, and third analysis methods which vary by the extent of calculations involved.

First analysis method is mainly used for simplified structural analysis of seismic performance of high-strength resistance buildings with bearing walls or numerous anti-seismic walls. This is the simplest method where wall strength can be roughly calculated based on concrete strength and sectional dimensions.

Second analysis method is a method which was developed for evaluating seismic performance of pillar collapse-type buildings. Because this takes into account the influence of reinforcement bars into the strengths of columns and walls, calculation results are more accurate as compared tofirst analysis method. In this method, the seismic performance of each level can be directly evaluated relying on calculation of durability and toughness of the vertical members of each floor.

third analysis method was developed with the aim of evaluating buildings of the type strongly influenced by their properties as those in which the beams collapse or the beams first fail before structural collapse. In addition to the vertical members of columns and walls, beam strengths are to be evaluated for studying the possibility of framework collapse leading to a beam collapse, for determining the type of collapse the framework is vulnerable to, as well as the ultimate strength.

General structural seismic resistance determining index values Iso are for first analysis method 0.8, for second and third 0.6 while it is required for Is to be larger than Iso. Because analysis of a higher level than second analythis method is normally undertaken, often the Is value is required to be more than 0.6 and over. In Notification 2 of the Ministry of Ministry of Land, Infrastructure and Transport, it is determined that the possibility of falling or collapsing of a building with an Is value of 0.6 or above is low; those with the value of 0.3 and above but below 0.6, there may be possibilities; and if under 0.3, there is a high possibility.

There is another set of standards created by the Ministry of Land, Infrastructure and Transport to be employed mainly for management of national government buildings called "Comprehensive Standards and Commentary for Seismic Analysis and Anti-Seismic Treatments of Governmental Buildings, 1996 Edition [官庁施設の総合耐震診断・耐震基準及び同解説 平成 8 年度版]" (Building Maintenance Management Center [財団法人建築保全センター]).

5. Seismic Analysis of Reinforced Concrete Cultural Property Structures

Seismic analysis of reinforced concrete cultural property structures is most of the time executed following the aforementioned "Standards for Seismic Analysis of Extant Reinforced Concrete Structures."
Generally with old buildings, the second analysis method is employed, which goes the same for many of the nationally designated Important Cultural Properties. With bearing wall structures or those presumed to be sufficiently strong, there are cases in which only the first analysis method is undertaken.

In analysis, judgments can generally be made according to the standards for seismic analysis, but with unusual structures, they may have to be considered separately, as will be explained referring to the following specific cases.

○ Structures with no slabs at the top, but instead have roofs made of wood or steel frame trusses

Although most contemporary generic reinforced concrete structures have flat roofs made of slabs, among buildings from the Taisho era to before the Second World War (from 1912 to around 1940), there are those without a roof slab but instead have roof structures made of wood or steel frame. For example, Mikawa Family Residence (Tokushima City, Tokushima Prefecture/ Important Cultural Property) is a three-storied bearing wall reinforced concrete structure constructed in 1928 (**photo 2**). Because the third floor with a wooden trussed roof structure was not constructed with a roof slab, this structure was categorized as a non-rigid floor and was studied through zoning for seismic analysis in 2015-2016. The results showed that seismic performance of the third floor was insufficient.

○ Structures with walls not made of reinforced concrete, but of brick masonry or concrete blocks with no specifications or measurements available in extant drawings
There are cases where the walls of a reinforced concrete column-and-beam Rahmen frame structure are made of brick masonry or concrete blocks, particularly with interior partition walls. Also, when the walls are not designed as structural frames, wall thicknesses or placement of reinforcement bars may not be indicated in the structural drawings. There are also buildings that are composite structures made of reinforced concrete and brick masonry.
When the surfaces of such buildings have been finished, it is difficult to determine the structural material and thus require non-destructive testing such as radar testing for reinforcement or destructive testing methods such as core testing and partial sampling of the structural material are undertaken.

○ Composite structure of reinforced concrete and stone masonry

In the seismic analysis of Meiji Jingu Homotsuden Treasure Museum Middle Storehouse (Shibuya Ward, Tokyo Prefecture/ Important Cultural Property) built in 1921, evaluation of the stone clad columns of the first floor was found to be problematic (**photo 3**). The thick reinforced concrete columns with sectional dimensions of 580 mm by 580 mm with 120 mm thick stone veneering on all four sides were actually constructed by using the stone slabs as formwork, placing steel reinforcement inside, and then pouring concrete. They were judged to be structurally weak, when only the reinforced concrete portion of the columns was tested. As the stone material was found to be sufficiently integrated with concrete through core testing, this was together analyzed and the first floor area was found to meet the required performance in seismic resistance.

photo 2 Mikawa Family Residence (Important Cultural Property)

○ Structures with areas of defective construction in the structural frame

In architecture from an era when construction techniques had not yet been fully developed, many cases of defective construction including honeycombs could be found.

Former Ikeda Family Residence Western-style Residence (Daisen City, Akita Prefecture/ Important Cultural Property) built in 1922 is one of the earliest reinforced concrete structures in Japan's Northeast region. Prior to restoration before national cultural property designation during 2006 to 2010, structural analysis was performed following the first analysis method as per "Standards for Extant Reinforced Concrete Structures." As a result, it was determined that it would be structurally stable under the condition that the structural frame was sound. However, defective construction including numerous honeycombs was found and there were places where it was too weak for core testing. This meant that the entire structure could not be evaluated as being sound. After having studied various repair methods such as increasing wall thickness by pouring concrete onto the extant wall or not relying on the weak areas and replacing them with new concrete structural frames, it was decided to adopt a method of preserving as much as possible of the extant structure, which would at the same time enable the interior and exterior finishes to be placed back into their original positions. Thus, cement slurry was poured into the weak areas for obtaining the necessary structural strength.

6. Seismic Reinforcement of Reinforced Concrete Cultural Property Structures

There already have been various methods employed for seismic reinforcement of reinforced concrete structures including steel frame, bracing, addition of anti-seismic reinforced concrete walls, increasing wall thickness, wrapping columns with steel plates or continuous lengths of fibrous materials, and installation of anti-seismic slits. There are also cases in which seismic isolation systems are adopted. Reconstruction of the structural frame could also be an option. Reinforcement of other non-structural building members such as tiles and ceilings need to be considered as well.

In the following section, aspects requiring particular care in treatment of cultural properties together with case studies will be given.

○ Reinforcement with steel frames and bracing

This is a method employed in general structures and there have been many cases of application on cultural property structures.

Some considerations required in installing reinforcement onto cultural properties include 1) they are not to stand out from the cultural property itself, 2) they are to be designed well when placed in visible places, and 3) they are not to harm the cultural property in areas where new elements are to be attached.

The bracing reinforcement adopted at Umekoji Locomotive House (Kyoto City, Kyoto Prefecture/ Important Cultural Property) (**photo 4**) was designed particularly focusing on where they were to be attached, to minimize influences on the significant exterior appearance of the train shed and turntable as well as interior spaces (**figure 1**). The bracing members were designed to be simple using steel pipes and colored slightly different from the original structural frame to distinguish the two (**photos 5, 6**).

Takashimaya Tokyo Department Store (Chuo Ward, Tokyo Prefecture/ Important Cultural Property) was reinforced in the least number of places, by employing steel bracing of extremely low yielding point designed to give in before shear fractures appeared in the extant concrete walls. The exposed steel bracing was covered and decorated with molding to match the store's interiors (**photo 7**).

Waseda University Okuma Memorial Hall (Shinjuku Ward, Tokyo Prefecture/ Important Cultural Property) (**photo 8**) was reinforced using steel frame bracing together with reinforced concrete anti-seismic walls. Specially designed vertically-latticed steel frames were installed between the columns in the basement small hall, so that the magnificent interior design would be least affected. They were installed by attaching with synthetic resin adhesive instead of directly

photo 3 Meiji Jingu Homotsuden Treasure Museum Middle Storehouse, first floor column

photo 4 Exterior, Umekoji Locomotive House

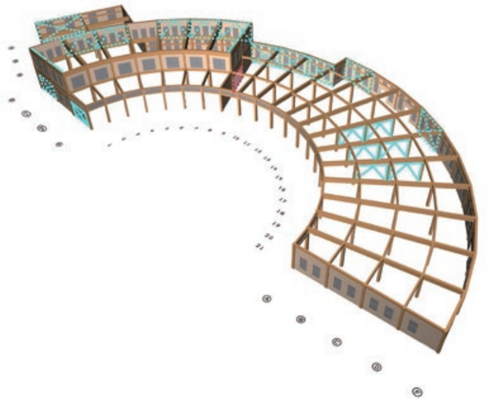

figure 1　Diagram of reinforcemed areas (Reinforcement shown in light blue)（reprinted from『重要文化財梅小路機関車庫耐震対策小路報告書』、西日本旅客鉄道株式会社、平成 28 年、p.3-9、図 3.3.1-1）

photo 5　Interior, reinforcement with steel frame bracing

photo 6　Exterior, reinforcement with steel frame bracing

photo 7　Takashimaya Tokyo Department Store, reinforcement with bracing decorated to match the store interiors

photo 8　Waseda University Okuma Memorial Hall

photo 9　Vertically latticed sttel frames (reprinted from『早稲田大学大隈記念講堂保存再生工事報告書』（早稲田大学、平成 20 年（2008）3 月）P.209)

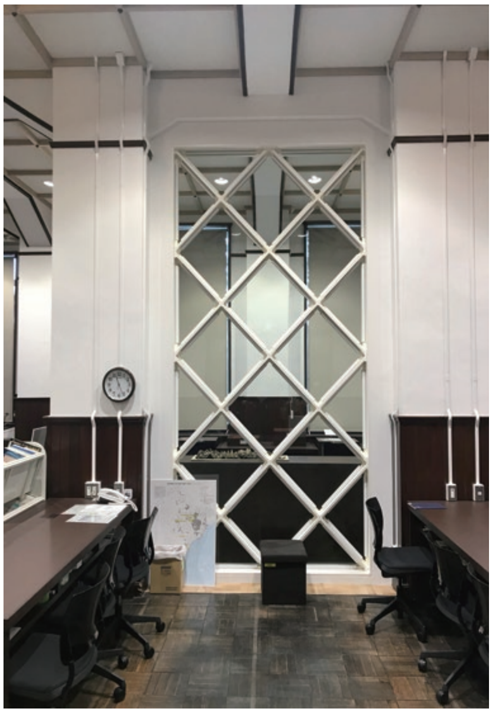

photo 10　Visible reinforcement at Former Institute of Public Health (Minato City Local History Museum)

anchoring onto the structural frame (**figure 2** and **photo 9**).

Lastly, at the Minato City Local History Museum (Minato Ward, Tokyo Prefecture) housed in the newly restored Former Institute of Public Health, visible reinforcement was carefully designed and reinforcement adopting transparent materials such as glass was adopted (**photo 10**).

○ Anti-seismic slits

There are cases where silts are made into hanging walls or low walls in order to avoid fracturing of columns with low shear strength. Although this method does slightly harm the structure itself, this is chosen when it is considered to be the most appropriate method and some damage is judged to be unavoidable. On the other hand, there are cases where anti-seismic slits are made into 1) surrounding walls to disable resistance of the anti-seismic walls according to an imbalance made apparent through calculations for structural analysis or 2) to separate by installing an expansion joint between adjacent structures with ill effects on the cultural property regarding structural balance clarified through analysis. Because these methods damage the structure to some extent and there are uncertainties as to whether they would function as calculated, effects of their application need to be sufficiently studied beforehand.

○ Treatment of adjacent structures

When structures of different structural composition stand next to one another, sometimes it is necessary to decide whether to integrate the two and treat them as one or to employ expansion joints for considering them as different structures. It needs to be noted that great care must be taken in introducing expansion joints, for this involves harming the extant structure.

In Former Tokyo National Museum of Nature and Science Main Building (Taito Ward, Tokyo Prefecture/ Important Cultural Property), present National Museum of Nature and Science, Tokyo, the expansion allowance between the steel frame reinforced concrete central tower and reinforced concrete north and south exhibit halls was found to be insufficient and therefore the connecting areas were reinforced and integrated.

At University of Tokyo's Yasuda Auditorium (Bunkyo Ward, Tokyo Prefecture/ Registered Cultural Property), the front portico was separated from the main structure and an expansion joint was installed.

○ Seismic isolation

Seismic isolation was introduced for the first time in a reinforced concrete structure in 1998 at The National Museum of Western Art Main Building (Taito Ward, Tokyo Prefecture) before national Important Cultural Property designation and there have since been many cases and are on the rise.

Examples of Important Cultural Property concrete structures that have had seismic isolation systems introduced are as follows. Before cultural property designation: The National Museum of Western Art Main Building, Nagoya City Hall (Nagoya City, Aichi Prefecture), Aichi Prefectural Hall (ditto), and Mitsukoshi Nihonbashi Department Store (Chuo Ward, Tokyo Prefecture); and after designation: Hiroshima Peace Memorial Museum (Hiroshima City, Hiroshima Prefecture).

The greatest merit of this method is that the extent of reinforcement of the upper structure placed on the isolation system could be significantly decreased and for buildings that are in use, construction can be worked on while the building continues to be occupied. The demerits are that construction fees are comparatively high and seismic expansion joints need to be created all around the structure. From the aspect of cultural property protection, the extant foundation system and structure of the basement level or intermediary levels in some cases could be greatly altered. In designated areas of Historic Sites, Places of Scenic Beauty, or areas within designated boundaries of buried cultural properties, permission for alteration of the present state needs to be obtained from the Agency for Cultural Affairs and archeological surveys might become necessary. According to the significance of the discovered underground artifact, the project might be required to make changes in plan. Because structures completed before the

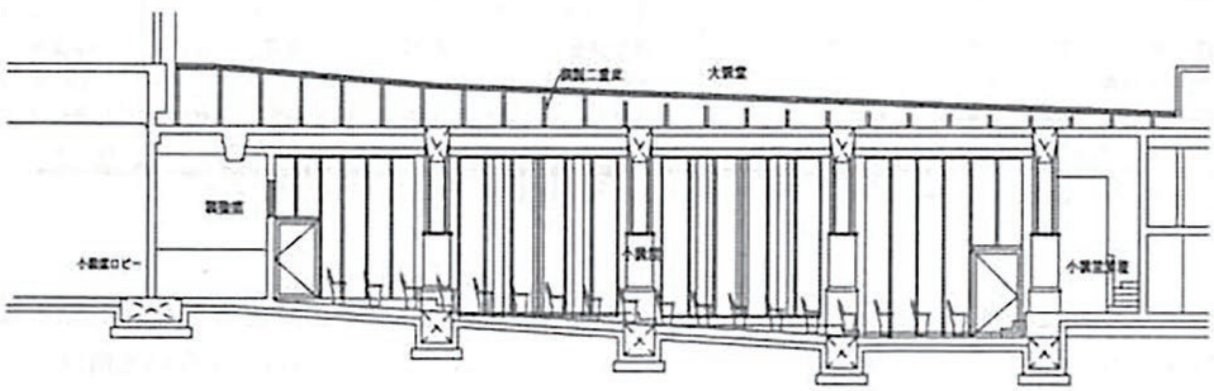

figure 2 Small assembly hall, reinforcement between columns with vertical lattice bracing (Reprinted from『早稲田大学大隈記念講堂保存再生工事報告書』(早稲田大学、平成 20 年（2008）3 月）p.116)

Second World War were designed to be comparatively rigid, conventional structural reinforcement might be sufficient and therefore, repeated studies are necessary to determine whether seismic isolation is the only method that could be employed.

○ Replacement of the structural frame

Although this may be considered as an exceptional method for cultural properties, in some cases, the structure could be newly reconstructed for reinforcement. Such cases are when the extant structural frame is weak or severely deteriorated and is no longer durable as a structure, or when it can in no way be reinforced without sacrificing the original design. It is difficult to make decisions to employ this method, as it involves complicated decisions regarding prioritization of certain cultural values of the property.

The following are exemplary cases among Important Cultural Properties.

At Former Yamamura Family Residence, the fragile floor slabs and concrete walls damaged by an earthquake were reinforced with reinforcement bars and replaced with new concrete.

In the storehouse of Aishu Kindergarten (Osaka City, Osaka Prefecture) **(photo 11**) built in 1927, defective construction was found in numerous places. Although grout injection and re-alkalization were attempted, it was judged that the aimed strength could not be expected and thus, after having been permitted alteration of the present state, a reinforcing concrete layer was added onto the inner side of the walls and roof, with the floor slab being completely reconstructed with new reinforcement (**figure 3**).

Regarding nationally Registered Cultural Properties, there is a case in which a part of the structure was carefully reconstructed considering effects on design, as can be seen in the restoration of Sumi Kaikan (Ichinomiya City, Aichi Prefecture) (**photo 12**). It is a reinforced concrete office building designed by Kenzo Tange completed in 1957. In reinforcing the area around the piloti, steel frame bracing was first considered, but it was decided to prioritize preservation of the open interior design. Surfaces of the extant concrete columns were carved off and reinforced by slightly enlarging the sectional dimensions with the addition of reinforcement bars (**photo 13**).

○ Non-structural members

Aside from reinforcement of the structural frame, such building members as exterior tiles and interior ceilings

photo 11 Aishu Kindergarten storehouse

figure 3 Aishu Kindergarten storehouse, thickness of wall and roof slabs was increased, Diagram of locations where slabs were replaced

require preventive measures to avoid falling off and collapse.

Examples of work to prevent exterior tiles from falling off on Important Cultural Properties were undertaken at Takashimaya Tokyo Department Store and Former Maeda Family Main Residence. In non-designated buildings, there are cases where the tiles were completely replaced with new tiles. Because it is difficult to reproduce the same tiles which are fired products, the basic idea would be to make efforts for reusing the original tiles as much as possible.

Regarding ceilings, the danger of hung ceilings falling has been pointed after the Great East Japan Earthquake of 2011, especially of those grouped as “particular ceilings.” They are ceilings that are higher than six meters from floor level and larger than 200 square meters requiring preventive measures. Even with designated Important Cultural Properties, preventive measures of the same level should be employed. Particularly with ceilings from prior to the Second World War, there are examples, such as that of University of Tokyo’s Yasuda Auditorium to be later dealt with, that had very heavy plastered ceilings insufficiently attached onto the substrate, in need of danger prevention. Also, there are ceilings, although not hung, that are finished with plaster or mortar applied directly on the structural frame, which also require measures to prevent collapse.

photo 12　Sumi Kaikan

7. Case Studies of Structural Analysis and Reinforcement

○ The Former Yamamura Family Residence (Yodoko Guest House) (Ashiya City, Hyogo Prefecture/ Important Cultural Property) (**photo 14**)

The Former Yamamura Family Residence is a four-storied reinforced concrete residential structure designed by Frank Lloyd Wright located on a hill in Ashiya City, Hyogo Prefecture. This is known as one of the few completed works by Wright in Japan and was the first reinforced concrete structure to be nationally designated as an Important Cultural Property on May 21, 1974. This was restored during 1985 to 1988, then again in 1995 to 1998 for recovery after being damaged in the Great Hanshin Awaji Earthquake.

Seismic analysis and reinforcement were undertaken as disaster recovery work after the earthquake. The building was considered as a wall bearing structure and the average shear force that would be burdened by the wall was calculated to meet the required design force of 1G (average shear force coefficient = 1.0)and then the short term permissible shear stress was taken as approximately 70% of the average shear force and also with the strength of the earthen partition walls added, it was confirmed that as a whole, the force to be burdened would be approximately 80%. The damaged condition was meticulously surveyed and comparative studies concluded that if structurally sound, it would meet the required structural strength, and thus reinforcement on the entire structure would not be executed. However, the walls that were cracked by the earthquake were reinforced for recovering strength by reconstruction or attachment of a gate-shaped steel framework.

Reconstruction of the concrete structure was undertaken in areas including the south wing balcony and around the main staircase (**photo 15**). The original reinforcement bars of round sectional dimensions and smooth surfaces were left intact while inserting additional reinforcement of anti-corrosive deformed bars in the reconstruction. Concrete used

photo 13　Reinforced concrete column
The sectional dimension of those shown circled in red were enlarged by reinforcement

photo 14　Exterior, Former Yamamura Family Residence (reprinted from『重要文化財旧山邑家住宅（淀川製鋼迎賓館）保存修理工事報告書』（株式会社淀川製鋼所、平成元年（1989）2 月））

in reconstruction was specified for a compressive strength of more than 210 kg/sqcm four weeks after pouring, while core testing of the extant structure had resulted in an average of than 210 kg/cm^2.

On the other hand, the first floor walls of the storehouse were reinforced with gate-style steel framework for burdening earthquake forces, so that future earthquake damage could be visually inspected (**photo 16**). Other reinforcements included attachment of carbon fiber sheets on some areas of the floor slab and parapet.

This was the first case in which seismic analysis and reinforcement were undertaken on a reinforced concrete Important Cultural Property. This restoration is very informative in that comparative studies were undertaken focusing on earthquake damage and seismic performance, and that it included reconstruction of some portions of the building.

Because the concrete slab was only six centimeters thick in some areas and the surfaces of the round reinforcement bars were smooth, there were issues from the beginning regarding lack of structural strength in the vertical direction. Therefore, in the restoration begun in 1985, the floor slab of the upper level was reconstructed in which the original reinforcement bars of smooth surfaces were left intact, while bars of the same type were additionally inserted for reinforcement (**photo 17**). In the restoration from 2016 to 2018, steel frame supports were introduced under the sagged eaves on the south side and a temporary floor was installed, so as not to burden the fourth floor balcony slab. How these reinforcements are to be treated are issues to be dealt with in the future.

○ Hiroshima Peace Memorial Museum (Hiroshima City, Hiroshima Prefecture/ Important Cultural Property) (**photo 18**)

This museum completed in 1955, known as one of Kenzo Tange's representative architectural works, is the central facility of Hiroshima Peace Memorial Park. It is composed of a rectangular box with the long edge facing forward raised by columns to create a piloti. Through this piloti, a view towards the Memorial Cenotaph and the A-Bomb Dome lined up along the park's axis can be had.

On the occasion of the renewal of exhibits, it was decided to introduce anti-seismic measures as well. Following seismic analysis in 2011 to 2012, preliminary surveys were worked on from 2013, and restoration including seismic

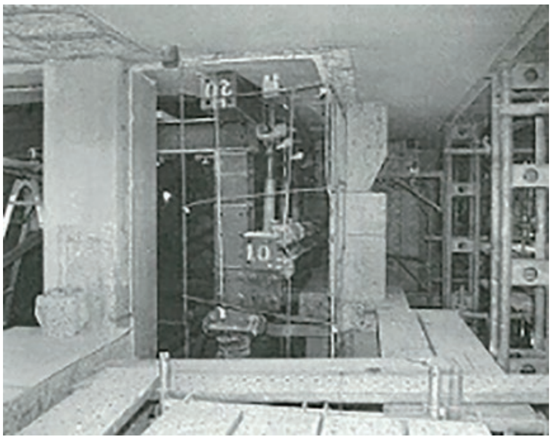

photo 15　Reconstruction of concrete wall. Southeastern area of second floor being dismantled（reprinted from『重要文化財旧山邑家住宅（淀川製鋼迎賓館）保存修理災害復旧工事報告書』（株式会社淀川製鋼所、平成10年（1998）3月））

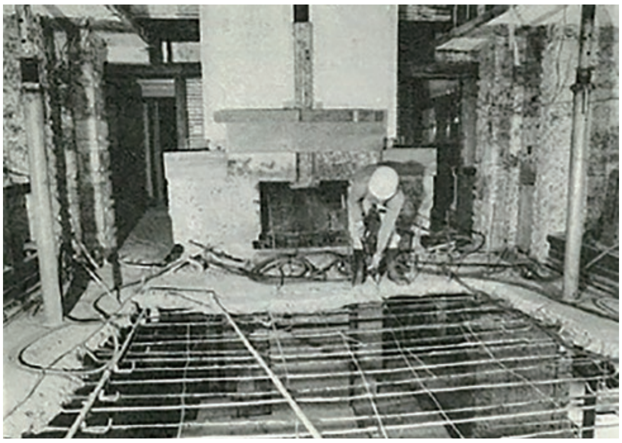

photo 17　Reconstruction of second floor slab. Dismantlement of extant slab（reprinted from『重要文化財旧山邑家住宅（淀川製鋼迎賓館）保存修理工事報告書』（株式会社淀川製鋼所、平成元年（1989）2月））

photo 16　Reinforcement with gate-shaped steel framework (in an area not open to the public)

photo 18　Hiroshima Peace Memorial Museum

reinforcement scheduled for 2016 to 2019 was started.

Seismic analysis followed the procedures in "Comprehensive Standards and Commentary for Seismic Analysis and Anti-Seismic Treatments of Governmental Buildings, 1996 Edition" and aimed at category II (importance coefficient = 1.25). The results indicated that reinforcement was necessary. Although the long end (east-west direction) of the rectangle met the required performance, the short end (north-south direction) of first floor and in both directions on the second floor lacked performance.

Various seismic reinforcement plans were studied including methods of (1) installing steel frame bracing or a seismic control system on the first floor while adding anti-seismic walls on the second floor, (2) carving off concrete from columns and major beams and making changes in placement of reinforcement bars for partial structural reconstruction, and (3) underground installation of a seismic isolation system. The seismic reinforcement plan (1) was considered to have large influences on the exterior design and the landscape, and although partial reconstruction of the structure (2) would retain the visual design, it was judged to have too large an impact on the structure itself and would not be appropriate. Therefore, the seismic isolation plan (3) was adopted for having the least influences on design and landscape as well as on the structure (**figure 4**).

Ref. : Cross-sec. view of underground structure for seismic isolation measures

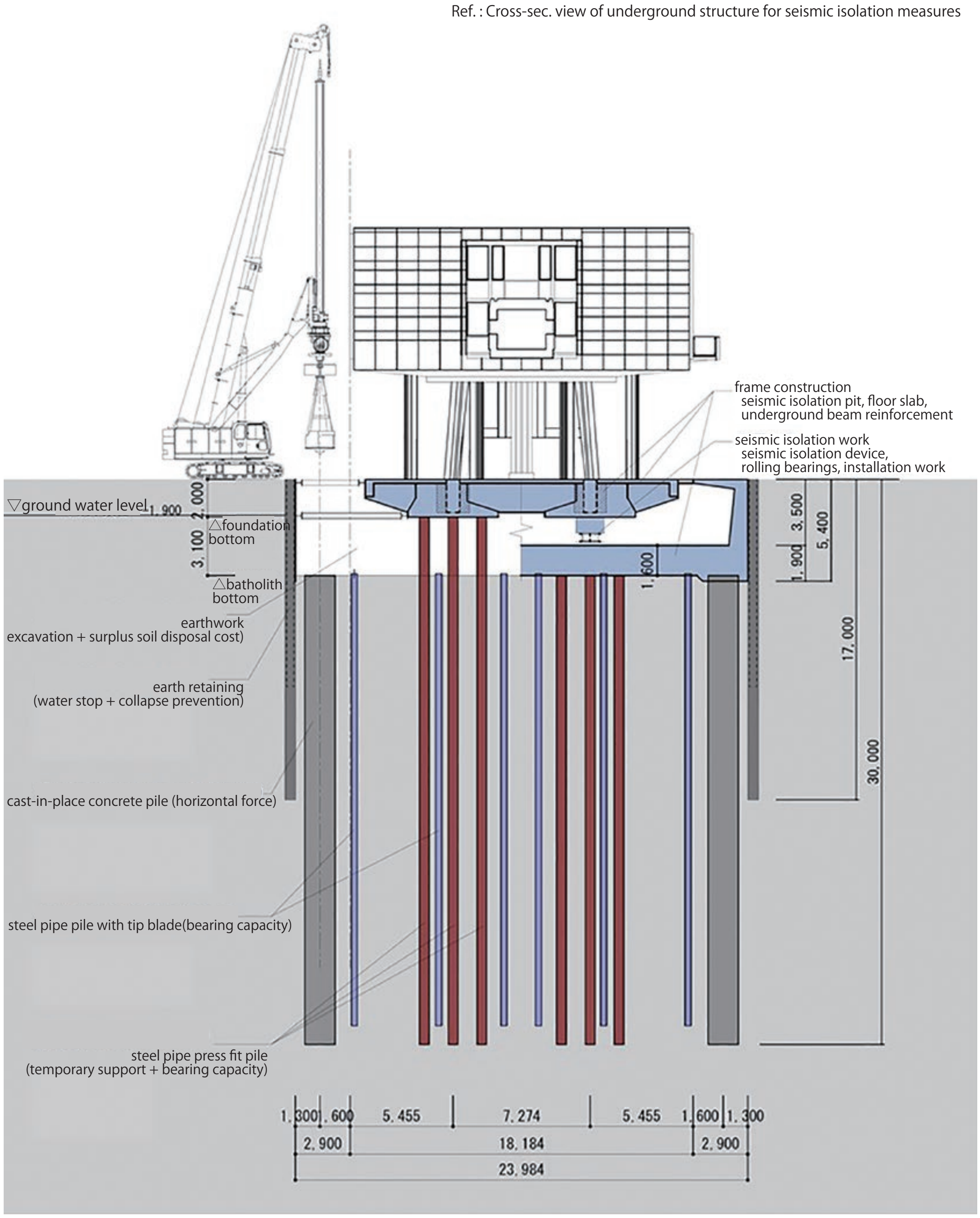

figure 4　Diagram of seismic isolation system

In the process of seismic isolation, a new underground beam system was added onto the extant system to be unified by steel bars for pre-stressed concrete for placing the structure on the seismic isolation system. Below the stairs were independent foundations that would interfere with the stairs when placed on the new underground beam system. Therefore, permission for alteration of the present state was obtained for their removal and records were made for those partially removed. Major members were removed in large pieces avoiding complete dismantlement (**photo 19**). Also, because the Hiroshima Peace Memorial Park is a nationally designated Place of Scenic Beauty, permission for alteration of the present state was necessary, and archeological surveys were undertaken on a large area of the premises before start of construction that involved excavation. Where non-designated corridors attach onto the east and west ends of the second floor, installation of expansion joints became necessary, which were made in forms that least affected the exterior design.

Also, the cantilevered floor beams of the second floor supporting the floor slabs were reinforced on the upper side with carbon fiber sheets (**photo 20**).

The exterior finish of the structure before restoration with an appearance of exposed concrete was actually a polymer cement-based mock-exposed concrete finish applied in 1991. In the recent restoration, this was completely once removed for repairing the honeycombed areas and then, recovered using the same method. Removal of the extant finish, as a result, revealed defective construction in more than expected places.

Repeated discussions were made among specialized commissions and other organizations for deciding on the restoration plan involving the entire park designed by an architect, regarding to what extent preservation should be prioritized for retaining the significant design elements and later alterations.

○ University of Tokyo Yasuda Auditorium (Bunkyo Ward, Tokyo Prefecture/ Registered Cultural Property) (**photo 21**)

This building symbolizing the University of Tokyo constructed in 1925 is characterized by the so-called "Uchida Gothic" tiled exterior design emphasizing verticality and the auditorium with a semi-circular floor plan (**photo 22**). In the Great East Japan Earthquake of 2011, cracks appeared in the structure, glass in windows broke, and there was danger of the auditorium ceiling collapsing, limiting the continued regular use of the hall. Seismic analysis was undertaken in 2011 and restoration from 2013 to 2014.

photo 19 Independent foundations underneath the staircase were removed following permission for alteration of the present state.

photo 21 Exterior, after restoration, University of Tokyo Yasuda Auditorium

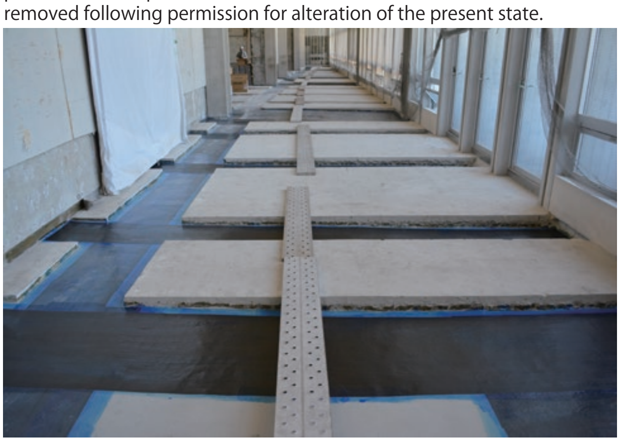

photo 20 Reinforcement of second floor upper surfaces with carbon fiber

photo 22 After restoration, University of Tokyo Yasuda Auditorium

Seismic analysis was executed following second analysis methodfor extant reinforced concrete structures, by dividing the structure into the semi-circular auditorium and all other areas. The aimed Is was set at 0.7 which was a little higher than that generally adopted for university facilities. Although the structure is comparatively uniform, there were columns with main reinforcement lacking and thin extant walls with 9mm diameter reinforcement bars placed at 300mm intervals, from which sufficient strength could not be expected in many areas. As a result, all areas other than the fourth floor did not meet the required level of Is 0.7. On the lower levels of the tower, it was found to be smaller than 0.3 requiring reinforcement (**figure 5**).

The concept of restoration was to maintain the appearance at the time of completion and to make the building available for use by many students and the faculty. At the same time, seismic safety would have to be met while improving interior conditions and providing barrier-free access. Seismic reinforcement was realized through installation of additional reinforced concrete seismic walls on each floor (**photos 23** and **24**) and creating anti-seismic slits in some of the walls to prevent extremely short columns with low shear strength from cracking (**figure 6**). On the first floor, some columns were wrapped with steel plates (**photo 25**). In the corridor around the auditorium, steel frame panel walls were installed (**photos 26** and **27**). Also, the front porch was once cut off from the main structure to create an expansion joint.

The extant ceiling of the auditorium suspended from the roof truss, composed of a steel framework substrate covered with thick layers of mortar and plaster on a lath substrate, was extremely heavy and was in danger of collapse (**figure 7**). Therefore, it was decided to remove the entire roof structure including the steel framework substrate to recreate the ceiling structure entirely and replace with glass fiber reinforced gypsum (GRG) panels designed to match the original ceiling (**photo 28**). Other areas worked on included the main circulation spaces of the lobby and corridors, in which the extant ceiling was removed as with the auditorium for restoration as semi-structure. On the staircase ceiling where the original plaster finish was retained, netting hardly visible to the eye was installed for safety in case the finish should fall (**photo 29**).

From the point of view of material preservation, there may be issues in the methods taken such as replacing the auditorium ceiling entirely with completely different materials and structure or removing arched openings with decorative mortared lath details for replacing with seismic

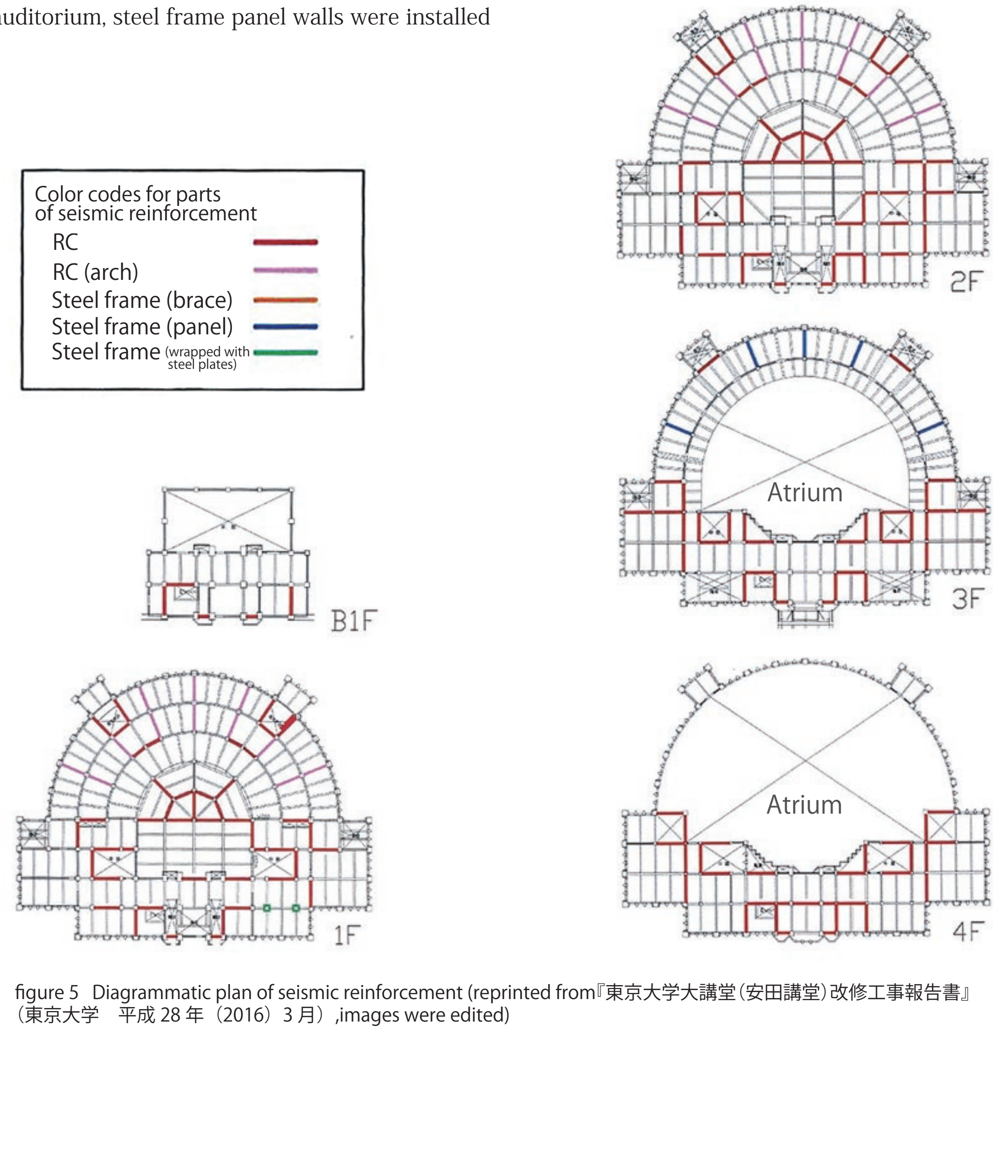

figure 5 Diagrammatic plan of seismic reinforcement (reprinted from『東京大学大講堂（安田講堂）改修工事報告書』（東京大学　平成 28 年（2016）3 月）,images were edited)

photo 23　Before installation of reinforced concrete anti-seismic wall. Removal of decorative mortared arch of lath substrate

photo 24　Reinforced concrete anti-seismic wall, placement of reinforcement bars

photo 25　Reinforcement of first floor columns by wrapping with steel plates reprinted from『東京大学大講堂（安田講堂）改修工事報告書』（東京大学　平成２８年（２０１６）３月））

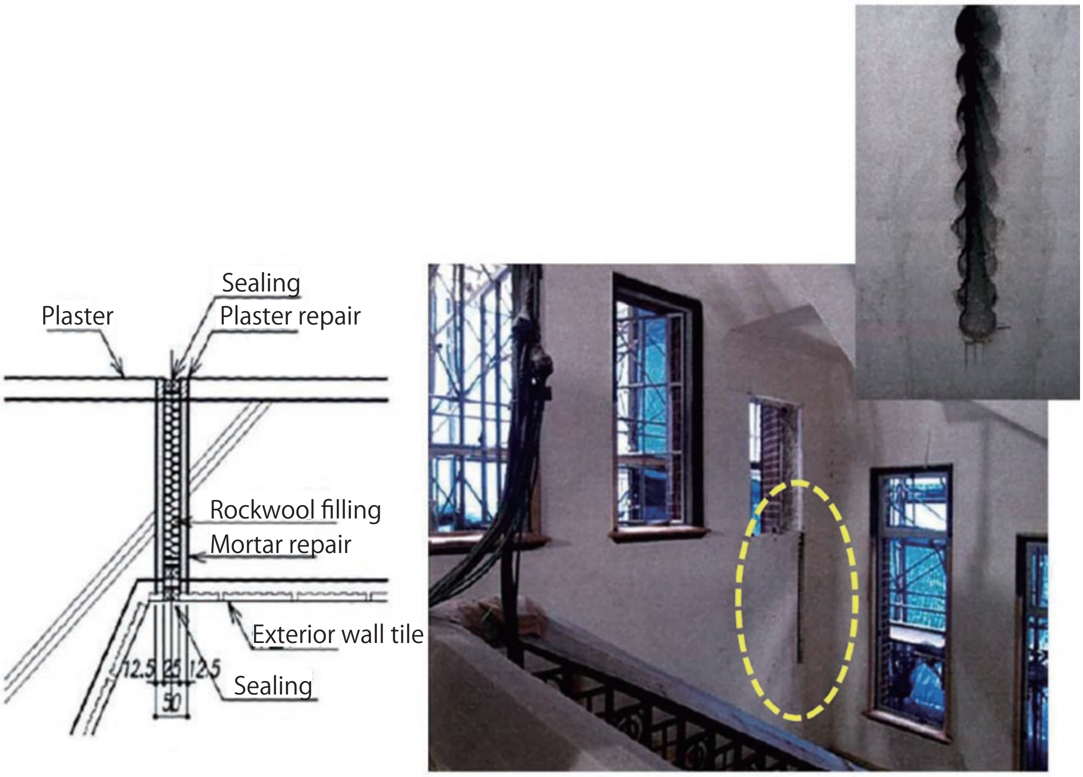

figure 6　anti-seismic slits（reprinted from『東京大学大講堂（安田講堂）改修工事報告書』（東京大学　平成 28 年（2016）3 月）, images were edited)

photo 26 Steel fframe panel walls ,corridor around auditorium

photo 27 Completed assembly hall corridor reinforcement wall. The opening was made with a pointed top to match the interior design

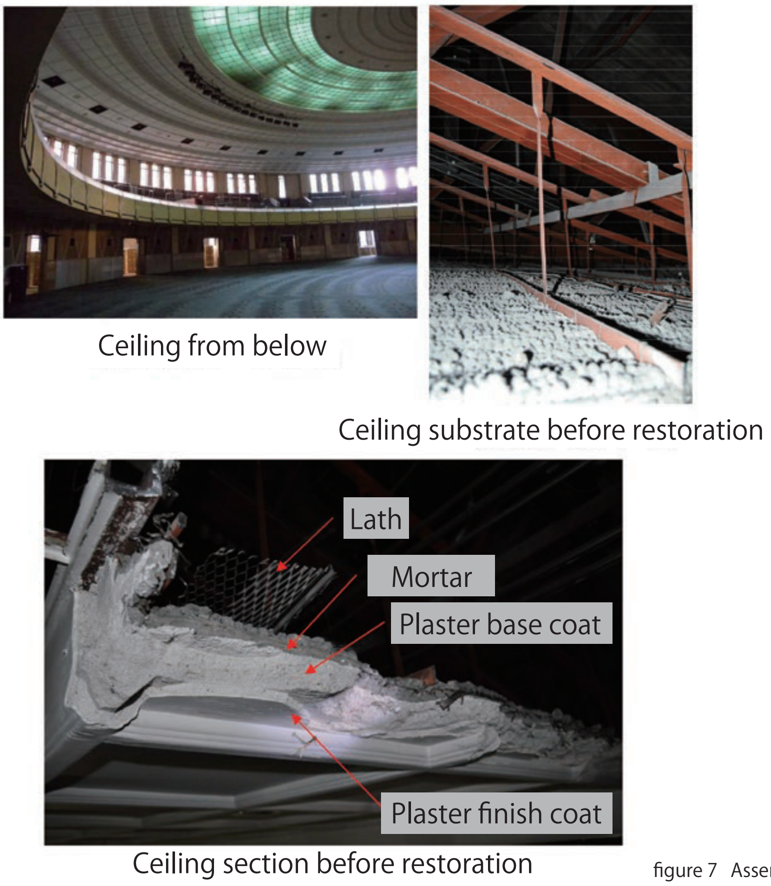

figure 7 Assembly hall, ceiling before restoration

photo 28 Newly installed ceiling of glass fiber reinforced gypsum (GRG) panels

photo 29 Staircase, safety netting for ceiling plaster finish collapse

walls with openings of a different design. However, when these treatments are viewed as acts of preservation of design, major elements have overall been successfully maintained. Because these methods for analysis and reinforcement are typical and can be referred to for seismic reinforcement of other projects, details of this restoration are provided as one exemplary case of restoration of a large-scale reinforced concrete cultural property structure.

8. Issues

Seismic analysis and seismic reinforcement of concrete structures could be generalized according to the various cases introduced here that conventional methods could to be used as a basis, while at the same time some judgments are necessary in order to maintain the structures' significance as cultural properties. However, because there are not many preceding cases to refer to, perhaps the following issues that come to mind can at least be raised. There are those that would naturally be solved following technological developments and those that would be gradually accepted through experience. It is important that the processes of studies made and experiences are recorded for sharing, so as to provide a resource for future projects.

○ Issues in applying extant methods

Because there are numerous extant methods for analysis and reinforcement, their effective application onto cultural properties could be considered. However, because these reinforcement methods have mostly been developed for lowering costs and improving workability, those that meet the aims of avoiding harm onto the extant structure or reversibility, although this might be unrealistic, are few. There are methods such as adhesion with minimum effects on the structure, which can effectively be employed.

Also regarding survey methods, limiting testing cores to small diameters or using a rebound hammer with the least influence on the structure should be chosen, developed, and disseminated.

○ Treatment of specialized concrete reinforcements

In buildings from the Taisho period, those with specialized reinforcement including the Hennebique or Khan systems can be found. Among Important Cultural Properties, the Hennebique system was employed at Umekoji Locomotive House, although this did not cause large problems in structural analysis. Surveys, analyses, and treatments of such specialized specifications can be expected in the future.

○ Treatment of fragile or deteriorated structural frameworks

In "Revised Handbook for Seismic Analysis of Important Cultural Properties (Structures) [重要文化財（建造物）耐震診断・耐震補強の手引（改訂版）]," it is explained that carbonization of concrete is not necessarily deterioration of the structural framework, and it is important that water infiltration be stopped. In structures where reinforcement corrosion has not progressed, preventing water leakage could be effective, but those with reinforcement already corroded, there are no other ways than to repair the corroded areas.

Re-alkalization, which is one method of preventing carbonization, has not yet been widely used on Important Cultural Properties. It was employed in restoration of Aishu Kindergarten Storehouse, Umekoji Locomotive House, and Hiroshima Peace Memorial Museum, but in the latter two cases, this method was applied onto only limited areas to observe their effectiveness. There are also obstacles including high costs, and therefore it is not clear whether this method will be widely used in the future.

Also, as the number of post-World War II buildings designated as cultural properties rises, the emergence of structures constructed of reinforced concrete with high water content or with sea sand as fine aggregate, which might be fundamentally defective, can be expected. Treatment methods for such structures are still unknown.

○ The decision to sacrifice the original structure

There are cases where the structure or material of certain areas in a building is replaced prioritizing design, while at the same time assuring structural soundness and seismic performance, as has been seen in the treatment of slabs of Former Yamamura Family Residence and the ceiling of Tokyo University Yasuda Auditorium. From the viewpoint of principles regarding cultural property protection, these procedures might be seen as problematic with regard to preservation of materials as well as reversibility. However, there are cases where the structures are extremely fragile and almost impossible to retain; in buildings with significant designs that need to be prioritized in protection, by sacrificing the structural framework, the overall loss of significance could be minimized. Such methods may be considered as possible options, but it is always very difficult to compare and make decisions on a building's value as a cultural property, which cannot be quantitatively evaluated. Although such decisions would need to be made through committee discussions involving numerous specialists, there are differences in personal values and therefore, it seems as though a long period of time would be still necessary to reach a unified conclusion.

○ Patented construction methods and specialized construction ordering methods

In recent years, cultural property restoration projects have become large in scale more than ever, attracting the involvement of major general contracting firms and architectural design offices that are capable of handling specialized techniques for seismic analysis and structural reinforcement. This itself is to be welcomed, but there are now often cases where these unique technologies are patented limiting capable contractors, making it difficult to adopt particularly in public projects. Increasing availability of various construction methods is preferable, but it can be imagined that there would be cases where the method considered as the most appropriate cannot be introduced for reasons of limitations in construction ordering methods for public projects. Therefore, an ordering system that would not be affected by such conditions as patents is awaited.

Also, there are now ordering methods in the form of proposals and design-build contracting. Such methods might be ideal in terms of costs and workability, but they may not be the best permissible method for protecting cultural properties. The worst-case scenario could occur when the construction method chosen through a design-build system cannot be permitted for use in cultural property restoration. Therefore, a system that enables smooth handling of such processes would be indispensable.

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footnote

1. 『既存鉄筋コンクリート造建築物の耐震診断基準　同解説』（一般財団法人日本建築防災協会・国土交通大臣指定耐震改修支援センター　2017 年改訂）
2. In reality, in addition to the new index Is of each floor, it is necessary to meet the required levels regarding the horizontal load-carring capacity of index q.

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- 『早稲田大学大隈記念講堂保存再生工事報告書』（早稲田大学、平成 20 年（2008） 3 月）
- 『重要文化財（建造物）耐震診断・耐震補強の手引（改訂版）事例集』（平成 25 年（2013） 9 月、平成 29 年（2017） 3 月改訂）』辻英之：鉄けた火災発生時の運転再開に伴う判断基準の作成、鉄道施設協会総合技術講演会、2006.10

Chapter 4

Lessons learned from recently examined information
about the conservation and restoration projects
of historically important concrete structures in Switzerland

Lessons learned from recently examined information about the conservation and restoration projects of historically important concrete structures in Switzerland

Suzuki Kei

Professor, Structural Engineering Lab, Department of Transportation Systems Engineering, College of Science and Technology, Nihon University

1. Introduction

The purpose of this document is to discuss how the citizenry of Switzerland conceive of the conservation and restoration of their historically important concrete structures. We will focus on some concrete structures as examples that have been appropriately conserved and restored and that are still in service in that country today. We hope that this document will contribute to the maintenance of historically important concrete structures in Japan.

In Switzerland, the conservation of historically important concrete structures in order to protect their cultural value has been achieved by keeping them at their original sites of construction to the extent possible, and by maintaining and repairing them appropriately. In the process, conservators have taken into account various factors, including theoretical discussions of the meaning and value of cultural properties and practical and political measures that are entailed. This is because the general public sees historic buildings as being important to their understanding and appreciation of the intellectual activities, artistic creations, and social life of their national and regional past. For about 100 years, the Swiss government had been responsible for the conservation of historically important concrete buildings within the country. On January 21, 2004, the Swiss Federal Commission for Monument Preservation issued a report that contains a collection of the latest knowledge about the conservation of historically important concrete buildings. After thorough discussions, on March 22, 2006, the Commission compiled its Guidelines1. Here is the overview of the Guidelines:

- Objects of heritage value should be maintained, preserved and restored in such a way as to retain their original appearance and assure that they will be conserved for a long period of time.
- As with any public task, the preservation of built heritage requires a legal basis. The rights and obligations of the public and the owners are to be defined.
- The principle of sustainability is to be observed when intervening in built heritage.
- Regular care is the best conservation measure.
- Before any measures are laid down, extensive knowledge of the heritage object is required.
- Preservation questions require an interdisciplinary approach.
- Before starting an intervention, compulsory measures and a program are to be agreed upon.
- Objects of heritage value are to be preserved in such a way that the evidence of their age remains.
- For the conservation or restoration of heritage objects, the materials and the techniques used must be tried and tested.
- After a conservation or restoration work, the object is to be checked periodically and, if necessary, further interventions are to be implemented.
- Building norms may not be applied to heritage objects without careful examination. Each case has to be judged individually. Either the observance of a norm is to be fully or partially waived, or the objective of the norm may be achieved through other appropriate means.

This document discusses conservation and refurbishment projects that were conducted, involving the following concrete structures: three steel reinforced concrete bridges (one 3-hinged box-girder bridge with an arch rib and two stiffened arch bridges) designed by Robert Maillart (1872 - 1940), a Swiss civil engineer; and two concrete shells and one bridge railing designed by Heinz Isler (1926 - 2009), a Swiss structural engineer. The three RC bridges include the Rossgraben Bridge (a 3-hinged box-girder road bridge with an arch rib, constructed in 1932) and the Schwandbach Bridge (a stiffened arch road bridge, constructed in 1933) in Bern, and the Valtschiel Bridge (a stiffened arch road bridge, constructed in 1925) in Donat, Graubünden. These three bridges were repaired under the guidance of Professor Eugen Brühwiler of Ecole Polytechnique Fédérale de Lausane (EPFL).

The two concrete shells include the concrete shell roofs over a tennis center in Grenchen and a supermarket in Belinzona. In addition, the railings on a concrete pedestrian bridge that spans a tennis court in Belinzona will be taken as an example of a bridge railing refurbishment project. Apart from those concrete structures that have been conserved and repaired under the guidance of Professor Eugen Brühwiler, we will also discuss the conservation and restoration projects for the Salginatobel Bridge (a 3-hinged box-girder road bridge with an arch rib, constructed in 1930), the Töss Fussgänger Bridge (a stiffened arch pedestrian bridge, constructed in 1934), and the Felsenau Bridge (a 3-hinged box-girder road bridge with an arch rib, constructed in 1933) (**Table 1**).

2. State of conservation of each structure

2.1 Concrete arch bridges

(1)The Rossgraben Bridge (**Photo 1**)

The Rossgraben Bridge is a 3-hinged box-girder bridge with an arch rib which spans Schwarzwasser Ravine. It is located 5 km east of Schwarzenburg, a municipality located 15 km south of the canton of Bern. Its 82 m single span is second only to the 90.04 m span of the Salginatobel Bridge (**Photo 2**) having the same type of construction, which was also designed by Robert Maillart. In 1931, Maillart proposed a plan for the construction of a new bridge with an arched span of either 60 m or 80 m, based on the Salginatobel Bridge. After discussion, it was decided that the new bridge would be constructed with an arched span of 82 m. The general structural diagram of the Rossgraben Bridge is shown in **Figure 1**.

The thickness of the bridge's arch ring is 18 cm at the central hinged part of the arch and changes gradually to 20

photo 1 Rossgraben Bridge (2019)

photo 2 Salginatobel Bridge (2019)

table 1 Concrete structures studied

Type of construction	Name of structure	Location	Year of construction	Structural overview
3-hinged box-girder concrete arch bridge	Rossgraben Bridge	Schwarzenburg, Canton of Bern	1932	As a 3-hinged box-girder arch bridge, the arch span of 82 m long is second only to the arch span of 90.04 m of Salginatobel Bridge.
	Salginatobel Bridge	Schiers, Canton of Graubünden	1930	The longest arch span (90.04 m) among the 3-hinged box-girder arch bridges Maillart designed
	Felsenau Bridge	Felsenau, Canton of St. Gallen	1933	A 3-hinged box-girder arch bridge with an arch span of 72 m. Since this bridge was intended to span a highway, the girder height was raised by using pointed arch-shaped lower chord members and polygonal upper chord members.
Deck-stiffened concrete arch bridge	Schwandbach Bridge	hinterfultigen, Canton of Bern	1933	The highway is curved in design, with a radius ranging from 22 meters to 30 meters. The arch ring is straight, with the inner arc following the curve of the highway deck.
	Valtschiel Bridge	Donat, Canton of Graubünden	1925	Maillart's first deck-stiffened arch bridge, with an arch span of 43.2 m. The floor slab works together with balustrades to withstand live loads while the polygonal arch ribs transmit only axial force.
	Töss Footbridge	Winterthur, Canton of Zürich	1934	The arch span is 33 m long. It is a deck-stiffened arch bridge with a notably elegant shape.
Concrete arch bridge	Lorraine Bridge	Bern, Canton of Bern	1930	A concrete arch bridge with the inside of the arch completely closed. The arch span is 80 m.
Concrete shell arch	Tennis Hall	Grenchen, Canton of Solothurn	1979	Concrete shell arches are connected side by side to provide a roof over tennis courts. No large-scale refurbishment work has been performed on the concrete shell itself for the 40 years since construction, except for a small-scale repair project that repaired the joints between the shells.

cm at a point halfway down from the top toward the hinge at each end of the arch. The same thickness is maintained thereafter until the ends of the arch. Seen from a distance, there was no conspicuous problem to be noticed from the effects of the restoration because the bridge had already been subjected to a repair project, although some areas, such as the side surface of each wheel guard for the floor system and the side surfaces of the arch ribs, appeared darkish.

The Salginatobel Bridge has an arch rise of 12.986 m with an arch-to-rise ratio of 1:6.9.

The arch rise of the Rossgraben Bridge is 9.67 m and the arch-to-rise ratio is 1:8.5. That is, the arch of the Rossgraben Bridge has a gentler curve than that of the Salginatobel Bridge. The construction of the Rossgraben Bridge was performed during the period from August 1932 to October of the same year, and the opening ceremony was held in November 19, 1932.

A monograph written in 2008 reports that the volume of vehicle and foot traffic passing over the bridge had increased for the previous 10 years, with 140 agricultural vehicle units crossing this bridge per day and residents in the neighborhood using it at least 5 times a day.

Professor Eugen Brühwiler said that the Rossgraben Bridge, together with the Schwandbach Bridge, which is located about 300 m upstream of this one, deserve to have respectful treatment for preservation because both bridges have great cultural value as well as contributing to the surrounding environment.

The refurbishment history of the Rossgraben Bridge is given in **Table 2**. The floor system was repaired during the period from 1978 to 79.

The Rossgraben Bridge was designated in 1984 as one of the structures in Switzerland that needs to be conserved by proper maintenance and refurbishment (registration No.485.4.2). In 1991 and 2001, the Rossgraben Bridge was investigated with a focus placed on the state of the concrete. The results showed that although corrosion of the steel reinforcement and spalling of the concrete were found in some areas, the entire arch was in a good condition except the crown, which had water leaks at the hinge. The floor system's waterproofness was good. The load-carrying capacity was assessed to be a maximum of 10 tons. It was considered that this figure was high enough to withstand the traffic volumes to be anticipated in the future.

In 2002, the Rossgraben Bridge together with the Schwandbach Bridge were repaired using a conventional approach to restoration. However, the refurbishment of the two bridges cost 200 million Swiss Francs (232.55 million yen). Therefore, it was not really successful from a cost-wise perspective.

As mentioned above, Professor Eugen Brühwiler said in 2004 that the Rossgraben Bridge and the Schwandbach

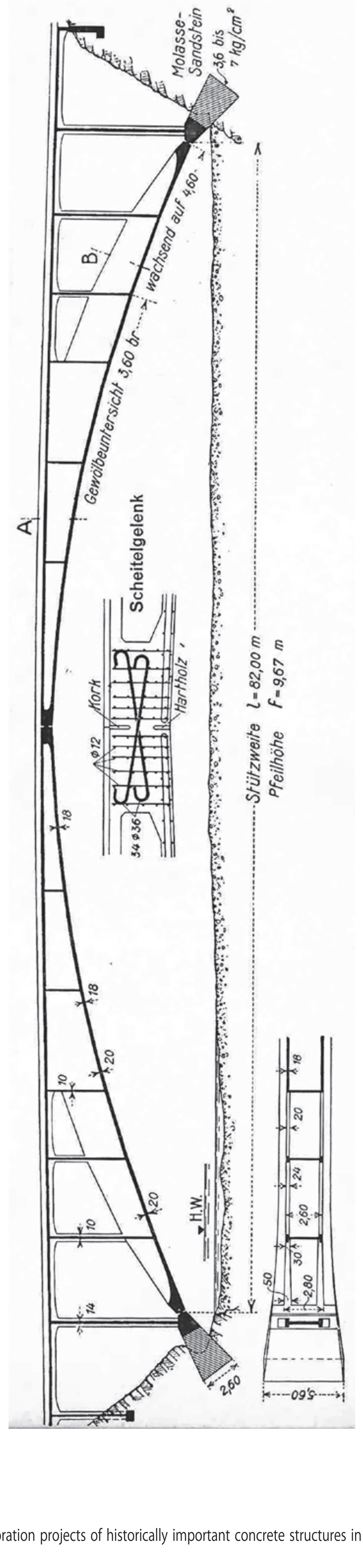


figure 1 General structural diagram of the Rossgraben Bridge [2]

Bridge deserve to have respectful treatment because both bridges have great cultural value as well as contributing to the surrounding environment. He made a plan for the conservation and restoration of the Rossgraben Bridge under his guidance, arguing that the extension of its service life should be performed cost-efficiently under the principle of sustainable development and that structural repairs should be carefully conducted while at the least retaining its original colors. His approach is important, in particular, when it comes to its application to conservation and restoration projects involving historic concrete structures in Japan.

The Rossgraben Bridge refurbishment project was performed during the period from March to September of 2005. Bridge refurbishment included improving the bridge's water drainage system (**Photos 3**, **4** and **Figure 2**), waterproofing the floor slab, renewing the roadway pavement, repairing areas that had concrete spalling and/or reinforcement bar corrosion, and impregnating exposed concrete surfaces with a water repellent (to a depth of 10 mm) for preventing water infiltration into concrete (**Figure 3** and **Photo 5**). In particular, due caution was taken to faithfully replicate the original surface pattern left by the timber formwork on the concrete surfaces. When this concrete bridge was constructed, concrete was poured into wide plank forms. The pattern made by the wood grains

photo 3 Water drainage system on the bridge surface (a catch-basin was provided at the center of the road at each end of the bridge) and newly installed steel railings

photo 4 Three drainpipes were provided at the bottom center of the arch ring.

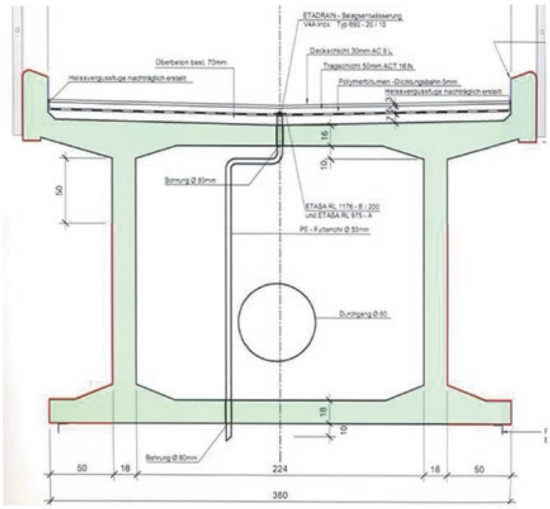


figure 2 Drainage system: Rainwater is run through the drainpipe from the catch-basin on the bridge surface to flow away underneath the arch.(photo provided by Prof. Eugen Brühwiler, Swiss Federal Institute of Technology in Lausanne)

table 2 Refurbishment history of the Rossgraben Bridge[3]

Month / Year	Problems and refurbishment history
Nobember 1932	Rossgraben Bridge was completed.
1978 ~ 1979	The floor slab was repaired.
1984	The bridge was selected as a structure to be conserved by proper maintenance and refurbishment. (No.485.4.2)
1991, 2001	The bridge was investigated with a focus on the condition of the concrete. Results: corrosion of the steel reinforcement and spalling of the concrete were found in some areas. Some steel railings were corroded and the floor slab's sealing was peeling off. The load-carrying capacity was assessed to be a maximum of 10 tons (design live load capacity = 7 tons). It was reported that this figure was high enough to withstand the traffic volumes to be anticipated in the future.
2002	As a refurbishment measure, a chemical reaction inhibitor was applied, but without good results.
2004	Professor Eugen Brühwiler said that the Rossgraben Bridge and the Schwandbach Bridge deserve respectful treatment because both bridges have great cultural value as well as contributing to the surrounding environment.
March ~ September 2005	Bridge refurbishment included improving the bridge's water drainage system, waterproofing the floor slab, renewing the roadway pavement, repairing areas that had concrete spalling and/or reinforcement bar corrosion, and impregnating exposed concrete surfaces with a water repellent (to a depth of about 20 mm) for preventing water infiltration into concrete. In particular, due caution was taken to faithfully replicate the original surface pattern left on the concrete surfaces by the timber formwork. When this concrete bridge was constructed, concrete was poured into wide plank forms. The pattern made by the wide plank forms was left on the surfaces of the concrete. The refurbishment project cost 556 thousand Swiss Francs (64.6 million yen).

of the wide plank forms was left on the surfaces of the concrete. This has been recognized as one of the identifying features of Maillart's concrete structures.

The replication of the original surface pattern left by the timber formwork was also applied in the conservation and refurbishment project of the Felsegg Bridge, another bridge designed by Maillart. In the Rossgraben Bridge refurbishment project, the steel railings used for maintenance purposes were also replaced with new ones (**photo 3**).

Figure 4 shows the details of the original center hinge part. The hinge consists of hard cork at the top and a

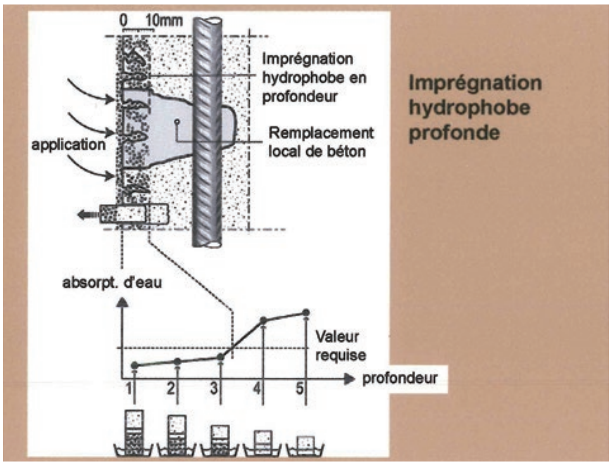


Figure 3 Concrete cover: A water repellent was impregnated into the covering concrete to a depth of 10 mm (of the total thickness of 25 mm) to create a waterproof layer, followed by an application of sprayed mortar. (photo provided by Prof. Eugen Brühwiler, Swiss Federal Institute of Technology in Lausanne)

photo 5 A water repellent was applied to the surfaces of the concrete balustrade and wheel guard.

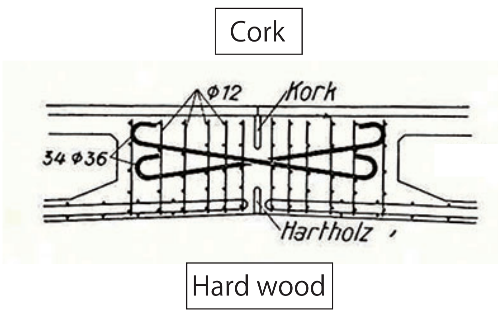


figure 4 Details of the original center hinge section (photo provided by: Prof. Eugen Brühwiler)

piece of hard wood at the bottom of the mid-point. 74 years have passed since the construction of this bridge and these components as well as the concrete have come to show deterioration. They were thus replaced during the refurbishment project. The two hinges at the ends of the arch ring were also repaired at the same time.

The following four points were noticed concerning the Rossgraben Bridge:

a)The concrete covering the steel bars

It seemed to me that the concrete covering the rebar was not very thick. Although I did not get to study the drawing of the Rossgraben Bridge's rebar arrangement myself, the thickness of the concrete covering the Rossgraben Bridge steel was estimated to be about 25 mm, a figure derived from those given for the Schwandbach Bridge and the Salginatobel Bridge. Specifications for Highway Bridges in Japan (published in 2017) require a minimum of 30 mm of concrete over road bridge steel. Perhaps in Robert Maillart's time the emphasis on the importance of the thickness of the concrete covering rebar was not as great as it is today. Therefore, it does seem that the corrosion of the steel reinforcement and spalling of the concrete that were found in many areas was due to this thin concrete cover. The result was that, during the conservation and refurbishment project, focus had to be placed on the repair of corroded steel bars and the spalling of concrete (**photos 6** and **7**).

b)The arch's water drainage system

A 3-hinge box-girder bridge with an arch rib, like the Rossgraben Bridge, is liable to have pools of rainwater accumulate in the areas enclosed by the spandrel walls and arch rings. For example, on the Salginatobel Bridge, which has the same arrangement of 3-hinge box-girder with arch rib as the Rossgraben Bridge, holes were made at the bottom of the spandrel wall to let rainwater escape easily. The Rossgraben Bridge has water drainage pipes arranged in areas enclosed by spandrel walls.

c)Vegetation

About 80 years have passed since construction. All around the Rossgraben Bridge, many trees have taken root and flourished. In areas near the base of the arch ribs, plants are growing so thickly that the arch rib is constantly in contact with moisture, blackening the concrete that makes up these parts (**photos 8, 9** and **10**).

The vegetation growing thickly around the bridge will tend to accelerate the deterioration of the concrete. It is necessary to prune back the plants around the bridge at regular intervals.

d)Differences in color between the original and repaired areas

In drafting a conservation plan, if it is expected that the difference between the original color of areas to be repaired and the color after repair is so noticeable, the surface patching repairs should be made in regular and especially rectangular shapes, instead of random or irregular shapes.

(2)The Schwandbach Bridge

The Schwandbach Bridge is a stiffened-deck reinforced concrete arch bridge near Bern in Switzerland, designed by Robert Maillart and completed in 1933. The bridge has a main span of 37.40 m and a total length of 44.65 m. As a structural feature, the highway deck is curved in design with a radius ranging from 20 meters to 22 meters.

To create this form, the arch ring itself is arranged as a straight run under the floor system at the outer curve of the bridge, while the inner curve is divided by vertical spandrel columns following the curve of the highway deck. This cleverly gives the viewer the illusion that the arch itself follows the curve of the bridge, when viewed from its inner curved side (**photo 11**). On the other hand, the arch rib is installed straight against the floor system on the outer curved side of the bridge, so that the viewer is led to think that the arch rib overhangs, outside the curve (**photo 12**). To make the unique design of this bridge easier to understand, a plan for this bridge is given, as **figure 5**.

The Schwandbach Bridge was completed in November 1933. It was studied in June 1935 by Professor Mirko Ros of the EHT Zurich for testing the structural integrity of the curved stiffened arch. The investigation was performed by applying live loads on the bridge and measuring the stress applied to the bridge at the inside and outside of the curved floor slab and the inside and outside of the arch, using

photo 6 The bottom surface of the arch ring was repaired (The traces of annual tree rings left by the timber formwork were reproduced on the surface of the repaired concrete.)

photo 7 Repaired spandrel wall (There is not much difference in color between the concrete used for the repair and the original structure.)

photo 8 Repaired arch ring (There is not much difference in color between the concrete used for the repair and the original structure. Water dams were installed on the side edges of the arch ring.)

photo 9 Repaired hinge section

photo 10 Repaired hinge part of springing

sensors. The results confirmed that the bridge was a sound structure that had the perfect stress-wise elasticity for a curved bridge (**table 3**).

The Schwandbach Bridge has a 3% gradient in the centerline direction of the bridge (that is, the roadbed is banked by 2% as it goes around this curve) and a 2% gradient or rise of the roadbed as it runs from the centerline toward both ends. Therefore, only one catch-basin is provided, and

photo 11 View of the inner surface of the curved side

photo 12 View of the outer surface of the curved side

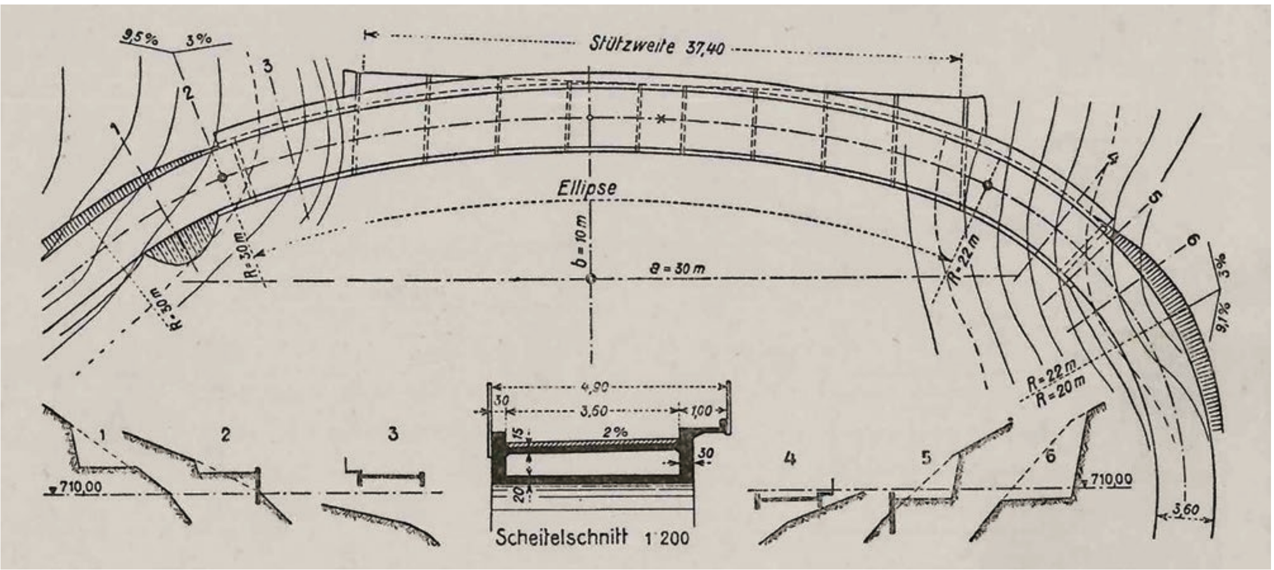


figure 5 Plan of the Schwandbach Bridge[2]

table 3 Refurbishment history of the Schwandbach Bridge [3]

Month / Year	Problems and refurbishment history
April 1905	Schwandbach bridge was completed
June 19 - 22, October 19 - 22, 1935	The EMPA (Swiss Federal Laboratories for Materials Science and Technology) studied the integrity of the bridge by applying a load of 12.5 tons at 28 points of the bridge and measured the stress applied to the bridge using 82 sensors). Professor Mirko Ros of the EHT Zurich confirmed that the Schwandbach was a sound structure that had the perfect stress-relief elasticity for a curved bridge and that the effect of the curved main girder was so small as to be negligible.
August ~ September 1978	The floor slab was repaired
1984	The bridge was selected as a national heritage to be conserved as a cultural property.（No.485.4.1)
2002	As a refurbishment measure, a chemical reaction inhibitor was applied, but without good results.
2004	Professor Eugen Brühwiler said that the Rossgraben Bridge and the Schwandbach Bridge deserve respectful treatment because both bridges have great cultural value as well as contributing to the surrounding environment.
March ~ September 2005	Bridge refurbishment included improving the bridge's water drainage system, waterproofing the floor slab, repairing the drainage channels in the floor slab, renewing the railings, repairing areas that had concrete spalling and/or reinforcement bar corrosion, and impregnating exposed concrete surfaces with a water repellent (to a depth of about 20 mm). In particular, due caution was taken to faithfully replicate the original surface pattern on the concrete surfaces left by the timber formwork. When this concrete bridge was constructed, concrete was poured into wide plank forms. The pattern made by the wide plank forms was left on the surfaces of the concrete. The refurbishment project cost 374 thousand Swiss Francs.

it is located on the edge of the inner curved side near the center of the bridge (**photo 13**).

In the same manner as for other areas of the Schwandbach Bridge's arch ring, rainwater runs down through a triangular hole provided at the bottom edge of the wall along the arch ring (**photo 14**). However, as with the Rossgraben Bridge, plants proliferated near the bridge and moss was found growing on the outer surfaces of the concrete arch (**photo 14**). If a bridge is affected by its natural environment in such a manner, it is necessary to prune the plants to reduce the impact of vegetation as much as possible. In the conservation and refurbishment project for the Schwandbach Bridge, focus was placed on the repair of its spandrel walls (**photo 15**). A close look at the previously repaired areas will reveal that the color of the concrete used for repair appears slightly brighter than the color of the original structure. However, when seen from a distance, there should be little or no distinguishable difference in color between the newer and older parts. It is supposed that those areas had also been repaired because of rebar corrosion and spalled concrete.

The steel railings were replaced with new ones because their surfaces were corroded (**photo 16**).

photo 13 Catch-basin of the Schwandbach Bridge (at the edge of the inner curved side near the center of the bridge)

photo 14 Drainage system running from the arch rib

Table 3 shows the history of the Schwandbach Bridge's refurbishment projects. The history of this bridge's refurbishment is almost the same as that of the Rossgraben Bridge. It was repaired under the guidance of Professor Eugen Brühwiler of Ecole Polytechnique Fédérale de Lausane (EPFL) during the period from March to September of 2005. A signboard attached to the baluster railing of this bridge says that both the Rossgraben Bridge and the Schwandbach Bridge were designated as historic structures in the canton of Bern in 1984 and comprehensively repaired in 2005 by Rüeggisberg and Wahlern, using budgets provided by the Swiss government and the canton of Bern (**photo 17**).

Ultra-high-strength-fiber-reinforced concrete was used for the refurbishments of both the Rossgraben and the Schwandbach Bridges. Professor Eugen Brühwiler reports4) that the concrete has the following strength characteristics:

photo 15 Repaired spandrel wall

photo 16 Replacement of steel railings

compressive strength greater than 150 N/mm^2 and tensile strength greater than 10N/mm^2. When this concrete is used, the covering over the rebar can be reduced to as little as 25 mm thick. Therefore, it may be possible to conclude that this high-performance concrete is suitable for refurbishing historic concrete structures, at least up to the present moment.

According to its name plate, the Schwandbach Bridge was constructed in 1933 by Losinger & Cie AG and Ernst & Albert Binggeli under the supervision of R. Maillart Engineur, Bern. The bridge can carry a live load of up to 7 tons (**photo 18**).

(3)The Felsegg Bridge

The Felsegg Bridge is a 3-hinged box-girder arch bridge with twin arch ribs, which spans the Thur at Felsegg in St. Gallen canton (**photos 19** and **20**). The bridge was completed in 1933. Since this bridge was intended to span over a highway, it was necessary to raise the girder height more than usual. Maillart for the first time adopted a pointed arch design, in which the inner arch is polygonal rather than curved. The girder height was thereby raised in the area running a quarter of the total arch length away from the crown (**table 4**).

The Felsegg Bridge has a total length of 132.4 m with a single span of 72 m.

The bridge supports a two-lane road, 6.5 m wide, with a 1.5 m wide footway on each side. The effective width of the bridge is 9.5 m (**Figure 6**). The arch rise f of the Felsegg Bridge from the base hinges to the mid-span hinge is 8.53

photo 17 Signboard saying that Rossgraben Bridge was refurbished in 2005 (cited from a photograph of a signboard installed on site).

photo 19 Felsegg Bridge

photo 18 Schwandbach Bridge Nameplate

photo 20 Twin arches of the Felsegg Bridge

table 4 Refurbishment history of the Felsegg Bridge[3]

Month / Year	Problems and refurbishment history
1933	Felsegg Bridge was completed
March, 1936	The bridge was studied by Professor Mirko Ros of the EHT Zurich (EMPA) using sensors. The results of the measurements were positive. He said that this bridge, spanning over the Thur, was structurally interesting, unique in design and cost-effectively maintained.
Late 1960s	This bridge had been used as a main roadway connecting Wil and St.Gallen until Autobahn 1 (E60) was opened. It was decided that the bridge should be conserved as a historic structure.
February. 2014	It was decided that Felsenau Bridge should be reinforced and completely refurbished. The refurbishment project was started in 2014.

m. Thus the arch-to-rise ratio of the Felsegg Bridge is 1:8.53 while the Salginatobel Bridge has an arch-to-rise ratio of 1:7.2 and the Rossgraben Bridge, 1: 8.27. Therefore, the Felsegg Bridge has the steepest arch curve of the three. The spandrel walls installed near the base hinges are 14 cm thick and the other three are spaced at a pitch of 6.8 m toward the crown on each side and are 10 cm thick. This is, of course, quite thin.

The two arches were constructed as follows: First, one arch was constructed and then the formwork and timbers were moved to the parallel location that was a distance of 1.6 m from the first arch. The second arch was then constructed in place by filling the forms again with concrete.

It is supposed, from noting that the bridge's drainage systems were retrofitted at later times, that not so much emphasis was placed on how to drain rainwater at the time when Maillart's bridges were designed (**photos 21** and **22**).

At present, a drainpipe protrudes from the wall balustrade to drain rainwater that accumulates on the floor slab (**photo 23**). This is the sole drainage system for carrying water away from the bridge's surface.

The hinges at the ends of the arch are sealed to prevent the entry of rainwater (**photo 24**).

The Guidelines1 require that the original wood grain surface pattern left by the timber formwork be replicated faithfully on the concrete surfaces. Such a replication can be

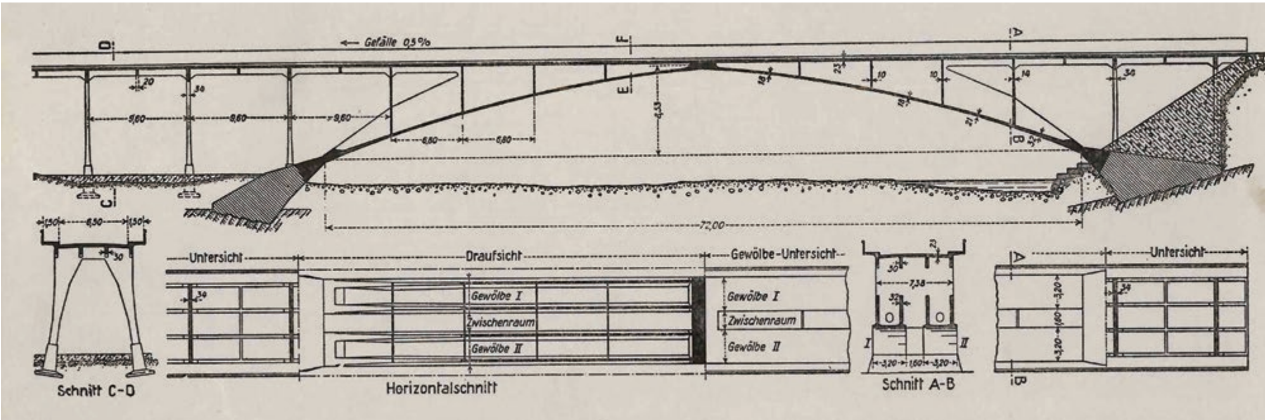


figure 6 General structural diagram of the Felsegg Bridge [2]

photo 21 Retrofitted drainpipe (1)

photo 23 Drainpipe protruding from wall balustrade

photo 22 Retrofitted drainpipe (2)

photo 24 Repaired hinge

observed on the piers (**photo 25**) and concrete balustrades (**photo 26**). However, it seems that the color of the concrete in these areas is too light for concrete that is 80 years old.

(4) The Töss Footbridge (a pedestrian bridge)

The Töss Footbridge is a pedestrian bridge that spans the Töss River in Winterthur, Zurich, which was completed in 1934. This bridge has a total length of 48 m and an arch span of 38 m, with the bridge width at 2.4 m (effective width = 2.0 m) and wall balustrade 54 cm high and 20 cm wide. The arch ring is 14 cm thick and the floor slab is 9 cm thick. The arch and the floor slab are joined in the center, making the total thickness there 23 cm (**figure 7**). The arch-to-rise ratio of this pedestrian bridge is 1:10.34, making it the flattest arch among the bridges designed by Maillart. It is unknown when the Töss footbridge was repaired last, but it seems that the color of the concrete is too light for its age (**photos 27** and **28**).

The floor system of the Töss footbridge is shown in **photos 29** and **30**. Deteriorating reinforced concrete was repaired

photo 25 Replication of the original surface pattern left by timber formwork on pier concrete surfaces

photo 26 Replication of the original surface pattern left by timber formwork on balustrade concrete surfaces

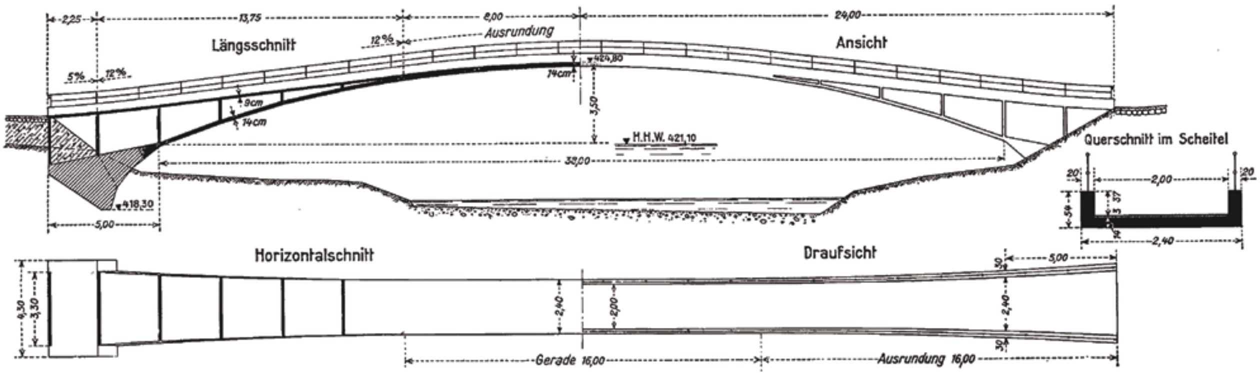


figure 7 General structural diagram of Töss Footbridge[2]

photo 27 Overall view of the Töss Footbridge

photo 28 Springing

and the railings were replaced with new ones. New concrete was sprayed on, but it would have been better to reproduce the color of the old concrete (in this case, 80 years old) to the extent possible.

(5)The Salginatobel Bridge

The Salginatobel Bridge (**photo 31**) is regarded to be a masterpiece among Maillart's 3-hinged reinforced concrete arch bridges. This bridge has the longest arch span among the bridges he designed. The Salginatobel Bridge was built in 1930. It runs 80 m above the bottom of the Salgina ravine in Schiers, in the Graubünden canton of eastern Switzerland (**photo 32**). The timber scaffolding for the center ring, which supported the arch while under construction, was devised by Richard Coray (the Richard Coray Scaffolding Company). The arch span of the bridge is 90.04 m, the arch rise is 12.986 m and the effective width is 3.5 m. During the original design process, consideration was given to withstanding a live load of 8 tons (3 tons for front-wheel loads and 5 tons for rear wheel loads), and to allowing for the application of an unexpected load of 350 kg/cm^2. On August 21, 1991, the American Society of Civil Engineering (ASCE) designated the bridge an International Historic Civil Engineering Landmark. This marked a turning point, and from that time the maintenance and refurbishment of Maillart's reinforced concrete bridges became more and more widely considered and discussed.

In most cases, old bridges are usually conserved while they are still in service. Therefore, it is necessary to repair them at low cost and without making drastic changes to their appearance.

Figure 8 shows a general structural diagram for the Salginatobel Bridge. The original design for this bridge included a plan to drain rainwater that accumulated on the floor slab outside the arch through semicircular holes made in the lower area of the wall balustrade (**photo 33**). However, rainwater that flowed out through these semicircular holes splashed over the spandrel walls and arch ring concrete, causing the concrete to deteriorate. At that time, it does not seem to have occurred to Maillart that rainwater that accumulated on the floor slab could be drained away from the bridge efficiently by installing gutters or something similar in the lower areas of the concrete wall balustrades.

The solution that exists at present, instead of the installation of gutters, is a series of catch-basins that are provided on both sides on the bridge surface to drain away

photo 29 Condition of the bridge's surface

photo 31 Salginatobel Bridge

photo 30 General view of the floor slab

photo 32 Salgina Ravine (view from the bridge)

the rainwater that accumulates on the floor slab. All the semicircular holes have been closed to prevent the rainwater that accumulates on the floor slab from flowing out through them. (**photo 33**: drain holes viewed from outside the bridge and **photo 34**: Catch-basin.)

Photo 35 shows how the drain pipes are arranged in the bridge girders. The inside of the arch ring has openings through the spandrel walls to allow the passage of personnel and to drain rainwater (**photo 36**). One of the characteristics of Maillart's design is its design strength. The strength of a cubic specimen of reinforced concrete is 333 kg/cm^2. In addition, the spandrel walls are very thin. For example, the thickness at the center of the spandrel walls of the span (**figure 8**), except for the left-side piers, is 12 cm (spandrel walls ⑦、⑧, ⑨ and ⑩) and 14 cm (for number ⑪). These are thinner than the minimum thickness for spandrel walls specified in the present Guidelines. The thickness of the bases of the spandrel walls under the arch is 20 cm at the ends of the arch and becomes thinner approaching the crown, (i.e., 14 cm, 12 cm, 10 cm, 10 cm, 10 cm and 10 cm, respectively). The refurbishment history of the Salginatobel Bridge is given in **Table 5**. As can be seen in the table, the

photo 33 Drainage holes viewed from off the bridge

photo 35 Arrangement of drainpipes inside the girder

photo 34 Drainage system on the bridge surface (provision of catch-basins)

photo 36 Drainage system inside the arch ring

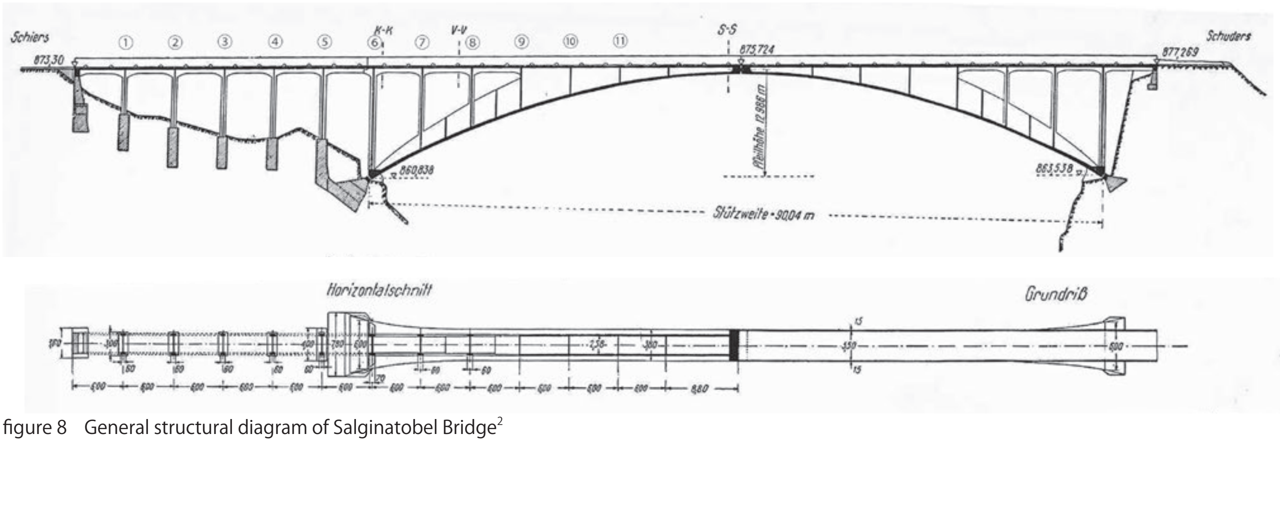


figure 8 General structural diagram of Salginatobel Bridge[2]

bridge was refurbished extensively in 1995, 1996 and 1997. The concrete balustrades that had been severely damaged due to rainwater were completely replaced.

The former balustrades were 150 mm thick and 1.1 m high. However, the new ones are more heavily reinforced and a little larger, at 180 mm thick and 1.35 m high.

The surfaces of the arch and the lateral and transverse walls were planed to a depth of 10-20 mm, using high-pressure water jets. They were refinished with a 30 mm layer of shotcrete (sprayed concrete). It seems that high-pressure water was used for fear of damaging sound parts, if the damaged areas were cut away by hand. Sprayed concrete was selected because the concrete to be repaired was so thin that it was deemed to be inappropriate to use concrete containing coarse aggregate.

However, the technical development of sprayed concrete has undergone very significant advances since 1994, when that refurbishment project was carried out. A better sprayed concrete method could be used if such a repair were to be made today.

Photo 37 shows the difference between the arch ring on the north side of the bridge and the one on the south side. The arch ring on the south side is always exposed to daylight. Consequently, moisture evaporates from it swiftly and the concrete has retained its light tone, whereas the arch ring on the north side often retains moisture, so the concrete has darkened (**photo 38**). **Photo 39** also shows the appearance of the arch ring concrete on the south side. **Photo 40** shows a piece of the timber formwork that was actually used to hold the concrete when the bridge was originally constructed. Annual tree rings can be clearly seen, left on the formwork by the imprint of the planking. It is understood that in Switzerland when conserving historic concrete structures, they place emphasis on the replication of the original surface pattern left by the formwork timbers.

In the case of Salginatobel Bridge, as with others, information about the designer of the bridge, Robert Maillart, is provided on a signboard posted near the bridge,

photo 37 Arch rings on the north and south sides

photo 38 Discoloration of the north-side arch ring's concrete

table 5 Refurbishment history of the Salginatobel Bridge[3]

Month / Year	Problems and refurbishment history
August, 1930	Salginatobel Bridge was completed
June, 1973	The bridge's concrete had deteriorated because of an inadequate drainage system and the use of anti-icing salt in the winter. The bottoms of the semicircular holes were elevated by filling in the lower section with concrete to keep rainwater from splashing over the concrete arches. The hinges at the side of Schuders were repaired. Carbonated concrete and concrete spalling were repaired across the whole bridge. The cracked floor slab was repaired by removing the original concrete to a depth of 60 mm and placing 80 mm of new concrete on it. As a result the structural members of the floor slab became 180 to 220 mm thick. In addition, the floor slab was paved further to a thickness of 30 to 40 mm with asphalt.
2nd August, 1991	The American Society of Civil Engineering (ASCE) designated the bridge an International Historic Civil Engineering Landmark. ASCE President James E. Sawer said that the Salginatobel Bridge is an elegant, serviceable, and important structure. At that time, a total of 13 structures had been designated international historic civil engineering landmarks, among which only seven bridges were included.
1995 and 1997 ~ 98	Salginatobel Bridge was comprehensively refurbished. The shoes installed on the west end of the bridge in 1994 were removed and new shoes were installed to reduce the effect of ground pressure upon the bridge. In particular, attention was paid to reducing the possibility of damage to the concrete due to rainwater and corrosion of the reinforcement. The expansion joints were protected to prevent the entry of rainwater. The waterproof materials for the floor slab installed in 1976 were replaced with new ones. All damaged concrete railings were replaced with new ones. However, at 180 mm thick and 1.35 m high, the new ones are more heavily reinforced and a little larger. The surfaces of the arch and the lateral and transverse walls were planed to a depth of 10 - 20 mm, using high pressure water jets, followed by refinishing with a 30 mm layer of shotcrete (sprayed concrete). The original surface patterns left by thick timber formwork on the concrete were faithfully reproduced, relying on historic photographs. Refurbishment cost 2.1 million Swiss Francs, of which 300,000 Swiss Francs was used for the application of shotcrete and the installation of new railings.

although it is not clear when this was put in place. It provides information about the life of Robert Maillart, who was a pioneer of the construction of reinforced concrete bridges in Switzerland, the locations of Mallart's bridges in Graubünden, and technical data on the Salginatobel Bridge. It is recommended that historic concrete structures in Japan also have similar signboards that provide these types of information.

In spite of due care, it seems that the repaired areas of the Salginatobel Bridge now look too light. This is probably because the waterproofing agent that was painted on the surface of the concrete during refurbishment contained too much white pigment. It is preferable that the difference between the appearance of repaired areas and the original concrete, in service for about 90 years, is not conspicuous.

(6)The Valtschiel Bridge

The Valtschiel Bridge is a deck-stiffened arch bridge (**photos 41** and **42**), located in Donath, Graubünden. It was completed in 1925. This bridge was Maillart's third arch bridge, constructed after the Flienglibach Bridge (arch span: 28.8 m) and the Schrähbach Bridge (arch span: 38.7 m). This bridge has an arch span of 43.2 m, making it the longest of his deck-stiffened arch bridges.

The Valtschiel Bridge's general structural diagram is shown in **Figure 9**. One of the characteristics of this bridge is that thin arches are used to stiffen the deck. This design contributed greatly to reducing the cost of timber scaffoldings.

Another road arch bridge was constructed downstream of this bridge in 1980 and the ownership of the Valtschiel Bridge was then transferred to the municipality of Donath. Since then, the bridge has only been used for pedestrian and bicycle traffic. Because the area where the Valtschiel Bridge is located is always exposed to moisture, the bridge has numerous rust spots and chipped concrete resulting from being exposed to repeated freeze-thaw cycles. On the other hand, the concrete did not become as severely deteriorated as the other bridges discussed in this report. This is because anti-icing agents had not been used on the bridge. Although the Donath community itself was not very active in the maintenance and refurbishment of the Valtschiel Bridge, a sports club advocated refurbishing this technically and historically important bridge. A marathon race had been conducted every year, using Scham in Transviamala as the starting point. In 2009, the sponsor of the race proposed

photo 39 South-side arch ring concrete

photo 40 Timber formwork used for the construction of the Salginatobel Bridge

photo 41 Valtschiel Bridge

photo 42 Valtschiel Bridge (close view) (cited from a photograph of a signboard installed on site)

refurbishing the Robert Maillart-designed Valtschiel Bridge on their own, under the slogan "Maillart's Valtsiel Bridge". The bridge was inspected and a refurbishment plan for the bridge was discussed. During the course of that discussion, it was decided to include the Helbeltobel Bridge in Urzach in the canton of Graubünden in the refurbishment plan.

Photo 42 shows the state of the deterioration of the Valtschiel Bridge's concrete at that time. The refurbishment project for the Valtschiel Bridge was started in 2013, based on the results of the inspection of the bridge in 2009. The refurbishment history of the bridge is shown in **Table 6**. Three major refurbishments were carried out during this project. First, two layers of ultra-high-performance concrete (UHPRFC) were placed on the deck to improve its waterproofness (**photo 43** and **figure 10**). Second, the bottoms of the semicircular holes were elevated by filling in

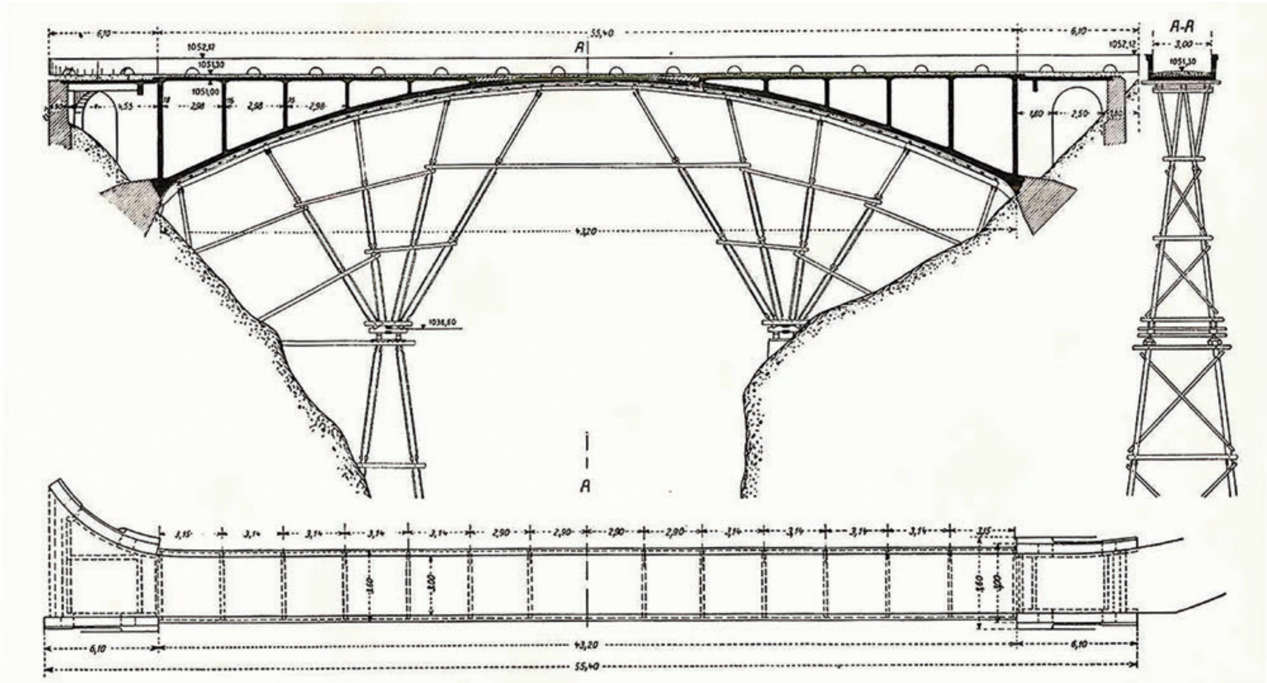


figure 9 General structural diagram of the Valtschiel Bridge[2]

table 6 Refurbishment history of the Valtschiel Bridge3[3]

Month / Year	Problems and refurbishment history
1925	The Valtschiel Bridge was completed. This was Maillart's third arch bridge, constructed after the Flienglibach and Schräh-bach Bridges.
September, 1926	The bridge was studied by Professor Mirko Ros of the EHT Zurich (EMPA) using sensors. The results of measurement were considered satisfactory. The cube strength of the concrete used for the construction of the Valtschiel Bridge was 50 N/mm2 (500 kg/cm2) and the modulus of elasticity was 50,000N/mm2. That is, the strength of the concrete used is comparable to that of concrete being used at present.
2013	Two layers of ultra-high-performance concrete (UHPRFC) were placed on the deck to improve its waterproofness. The bottoms of the semicircular holes made in the lower edge of the concrete balustrade were elevated by filling in the lower section with concrete to keep rainwater away from the openings in the balustrade and prevent it from splashing over the outside of the bridge.

photo 43 Deteriorated Valtschiel Bridge before restoration (cited from a photograph of a signboard installed on site)

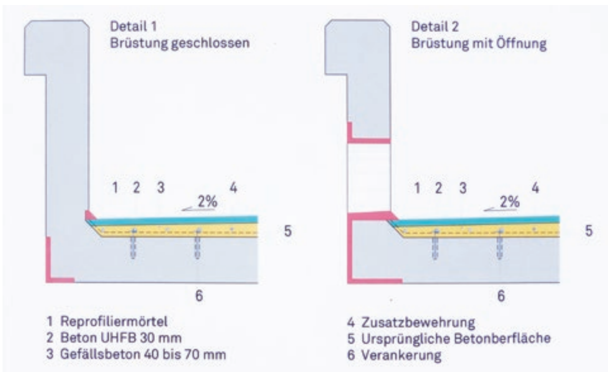


figure 10 Cross sectional view of UHPRFC (cited from a photograph of a signboard installed on site)

the lower section with concrete. This kept rainwater away from the openings in the balustrade and prevented it from splashing over the concrete arches. In addition, drainage channels, running along the centerline of the bridge, were placed under the new level of the semicircular holes (**photos 44** and **45**). Third, deteriorated concrete was removed by spraying water under pressure on those areas and repairs were made using sprayed concrete. The concrete in the repaired areas is conspicuously lighter in color than the surrounding concrete. Color matching is also an important factor to be considered in such a refurbishment project (**photos 46, 47, 48** and **49**).

2.2 Concrete shells

The Swiss engineer, Heinz Isler (1926 - 2009), is regarded around the world as the most famous designer of concrete shell structures. In this paper, some of his reinforced concrete structures are investigated to determine whether

photo 44 Waterproofing using 2 layers of UHPRFC (cited from a photograph of a signboard installed on site)

photo 45 Preventing rainwater from splashing over the outside of the bridge

photo 46 Preventing rainwater that accumulates on the bridge surface from flowing out of the bridge

photo 47 Repaired spandrel wall base

photo 48 Repaired bottom arch ring surface

photo 49 Repaired spandrel wall bottom surface

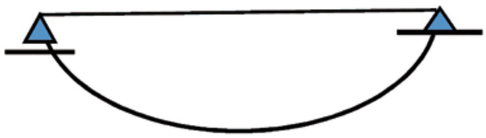
there is a difference between Maillart's concrete bridges and Isler's concrete shells, as related to the conservation and refurbishment of reinforced concrete structures. First, let's take a look at the structural differences between concrete bridges and concrete shells. Bridges, if they consist of a single span and have an arch, usually do not suffer very much from cracks because compressive force is applied inside the main girder. A simple girder bridge works as a beam, with the upper side of the girder receiving the compressive force while the lower side receives tensile force. That is, the lower center part of the girder sustains a large tensile force, which can cause cracks there. Bridges with two or three spans have negative bending moment applied to their intermediate piers, so the upper side of each girder receives tensile force and the lower side receives compressive force. That is, the areas where cracks are expected to occur on a bridge with multiple spans are the reverse of those on a single span bridge (**figure 11**).

Concrete shell structures often form a curved roof, with prestressed tendons bonded to the ends of the concrete shell. This arrangement means that compressive force is always acting inside the concrete shell. This probably has contributed to the fact that there is less need for the large-scale refurbishment of concrete shell structures (**figure 12**).

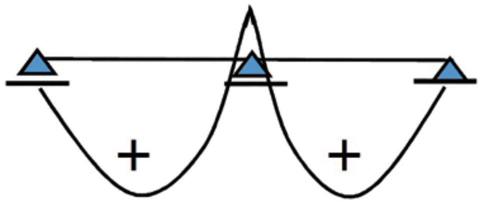
(1)The Tennis Hall in Grenchen

The Tennishalle Grenchen AG (**photos 50** and **51**) is a sports hall with a concrete shell roof covering six tennis courts. It was completed in the 1970s.

According to a caretaker at the facility, no large-scale refurbishment of this concrete shell structure has been performed since its construction (**photos 52, 53** and **54**), except for sealing carried out to repair rainwater leaks at the joints between roof sections. It was supposed that the concrete shell was always being subjected to compressive force, so the concrete making up the shell would deteriorate less than that of bridges. The exterior of the concrete shell had moss growing on the lower parts of the shell arches,



Distribution of bending moment of a single span



Distribution of bending moment of two spans

figure 11 The bending moment of a beam

figure 12 Axial forces on a shell (compressive force)

photo 50 Tennis center in Grenchen

photo 51 A structure consisting of 6 connected shell roofs

probably supported by the presence of rainwater.

When a concrete shell structure is designed, the strength of the concrete and the shape and thickness of the shell are key factors to be considered according to the use of the structure being planned. In order to conserve this historically important facility, it will be necessary to investigate the shell's dimensions in detail.

(2)Deitingen South Service Station

The Deitingen Service Station is topped by two concrete cupola roofs with three-dimensional triangular shapes, with the bases of the two triangles arranged in parallel to each other. It was completed in 1968 (**photos 55** and **56**). The concrete shell roofs protect shops and restaurants. The total length of the two triangular shapes is 69.45 m, with each triangle measuring 34 m long, 26 m wide and 11.5 m high. The apex of each triangle is anchored to the ground, and the other two vertexes are anchored to the building.

During refurbishment, snow guards were installed on the roofs as a new feature, to prevent masses of snow from sliding down onto the ground when snow accumulates on the roofs (**photos 57, 58** and **59**). This shell roof structure, consisting of two triangles, was designed on the basis of the Mövenpick logo. Heinz Isler created concrete shell structures in a variety of shapes to suit the purposes and intentions of their owners. His engineering sense is spectacular.

2.3 Pedestrian bridge leading to a swimming pool in Belinzona

This paragraph discusses a refurbishment project for a concrete pedestrian bridge leading to a swimming pool in Belinzona. **Photo 60** shows the pedestrian bridge in question.

photo 52 Interior view of the shell roof design

photo 53 Formwork scaffoldings being fabricated (cited from a photograph of a signboard installed on site)

photo 54 Concrete shell under construction (cited from a photograph of a signboard installed on site)

photo 55 Deitingen south service station concrete shell roofs

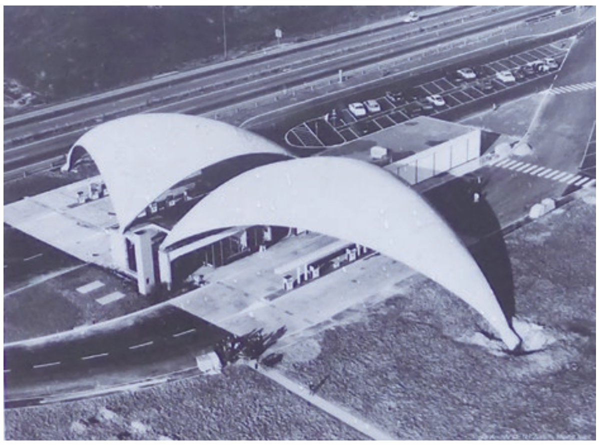


photo 56 Two-triangular concrete cupola roofs (cited from a photograph of a signboard installed on site)

Here, two types of refurbishment projects performed in the past under the guidance of Professor Eugen Brühwiler are discussed.

One included the installation of a water-resistant layer by spraying concrete over the surface of a concrete wall balustrade. The newly installed water-resistant layer appears natural in color and is not noticeably different from the color of the original concrete around it (**photo 61**).

The other refurbishment project was performed by repairing rusted rebar and then spraying concrete over the reinforcement. The color of the concrete repaired in the second refurbishment project appears clearly brighter than the color of the original structure. It is necessary to take color matching into account in advance so that the color of repaired areas goes well with the color of the original structure as much as possible. As shown in **photo 62**, when

photo 57 Installed snow guards

photo 60 Pedestrian bridge leading to a swimming pool

photo 58 The apex of each triangular concrete shell anchored to the ground

photo 61 Installation of a water-resistant layer made by spraying concrete over the surface of the concrete wall balustrade (the color of the repaired areas goes well with the color of the surroundings)

photo 59 Anchor of concrete shells

photo 62 Repaired concrete balustrade wall (the color of the concrete repair is conspicuously lighter)

sprayed concrete is immersed into the original structure, considerations should be taken to make the color of the concrete in these areas almost the same as that of the original concrete that is decades old.

As shown in **photo 63**, if it is expected in advance the difference in color between the original color of areas to be repaired and the color after repair is so noticeable, it may be advisable to make repairs in regular and especially rectangular shapes. (**Photos 64, 65, 66, 67** and **68**).

3. Lessons learned from examining some projects to refurbish concrete structures in Switzerland

The service life of concrete structures is given in the Specifications as 100 years. This long span of time suggest, therefore, that the conservation and restoration of concrete

photo 63 Repaired concrete balustrade wall (the color of the concrete repair is conspicuously lighter)

photo 64 Repaired concrete balustrade wall

photo 65 The color of the repaired areas is close to the color of the original structure, making them look more natural.)

photo 66 Corroded steel bars (1)

photo 67 Corroded steel bars (2)

photo 68 Corroded steel bars (3)

structures must be ongoing throughout that lifetime. In reality, however, the Specifications require that concrete structures should have a close visual inspection every five years, although no specific methods or procedures for restoration have yet been established. Some ideas advocated by Professor Eugen Brühwiler of the Ecole Polytechnique Fédérale de Lausane (EPFL) about the conservation and restoration of concrete structures are provided below for reference. First, concrete structures need to be maintained and refurbished at regular intervals. Second, such maintenances and refurbishments should be performed in such a way that appearance and esthetic value, economy, and technology are taken into full considerations. The cost of the Rossgraben Bridge and the Schwandbach Bridge refurbishment projects performed in 2002, during the years in which Professor Eugen Brühwiler had not yet participated, was 400 thousand yen /m^2 (bridge length x allover width). The criticism was offered that the refurbishment cost was too high, and more cost-effectiveness was strongly demanded. The costs of later refurbishment projects performed under the guidance of Professor Eugen Brühwiler were reduced to almost half of those in the past: 175 thousand yen/m^2 (bridge length x allover width) for the Rossgraben Bridge and 200 thousand yen/m^2 for the Schwandbach Bridge. These costs may be used as guides for the cost of concrete bridge refurbishment projects in Japan.

In many cases the color of the concrete used for repairs was lighter than that of the original structure. It is preferable to make traces of repairs inconspicuous, by – for example – making repairs in regular shapes such as rectangles. Third, refurbishment techniques are important, but new ones are not always better. It is necessary to examine at regular intervals the appropriateness of the materials and work methods, whether old or new, used for refurbishment. In particular, new materials and work methods need to be checked for their appropriateness over a span of 10 to 20 years. The specifications for the construction of concrete structures, such as the thickness of the covering concrete, differ between those in the norms at the time when the structure was constructed and the norms in effect at the present time. This is a difficult problem faced by many people involved in a project to refurbish a concrete structure. The Guidelines for the Preservation of Built Heritage in Switzerland established in March 2006 state that it is not necessarily required to conform with present norms. However, historic concrete structures are often conserved and restored while still in service. It is thus necessary to examine whether an old bridge can withstand an increased load that may well be applied in the present day. For example, the replacement of supporting bridge cables is an especially urgent issue to be considered.

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Chapter 5

A case study report on the conservation and restoration of concrete constructions

A case study report on the conservation and restoration of concrete constructions

Ishida Shin-ya *

Modern Cultural Heritage Section
Center for Conservation Science
Tokyo National Research Institute for Cultural Properties

* Current affiliation: Kagawa Prefectural Board of Education / Lifelong Learning and Cultural Assets Division

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*Photographs and charts without references in this chapter are by the author.

1.Introduction

1.1 This report's background and objectives

The Japanese Government led the way in the production of cement within the country in 1872. That is when the Ministry of Finance's Civil Engineering Division within the Construction Bureau built the Cement Manufacturing Factory in Tokyo. The first privately-managed cement company, the Cement Manufacturing Company (later renamed Onoda Cement Co., Ltd. and now called Taiheiyo Cement Corporation), was founded in 1881 in Onoda in Yamaguchi Prefecture. The first reinforced concrete (RC) civil engineering structure in Japan is said to be the Melan-type arch girder bridge over the Biwako Canal completed in 1895. It is believed that the first RC building in Japan was a pump shed built in 1904 on the premises of Sasebo Heavy Industries Co., Ltd. in Nagasaki Prefecture.

The Former Yamamura Family Residence (the Yodoko Guest House), which was designated as an Important Cultural Property in 1974, was subjected to a conservation and refurbishment project during the period from July 1985 to February 1989. This was the first time an RC nationally designated cultural property was the object of such a project in Japan. The number of RC structures designated as cultural properties in Japan started to increase after the Agency for Cultural Affairs initiated the Comprehensive Research into the Heritage of Modernization Project in 1990. The construction of brick, steel, and concrete artifacts is one outcome of modernization. Concrete structures, among these three types, is the structural type most frequently designated as historically important cultural properties (Supplement 1). However, fewer conservation and refurbishment projects have been initiated for concrete cultural properties than for brick or steel ones. It thus seems reasonable that more attention should be paid to the conservation of culturally important concrete constructions, including the methods used to repair them.

The Modern Cultural Properties Section of the Tokyo National Research Institute for Cultural Properties consulted experts and gathered a group for a conference to address these issues. On the basis of the results of the discussions at this conference, we will review in this case study the following four points that were identified as issues common to the conservation and restoration of many historic concrete constructions (**table 1-1**).

(1) the reproduction of the work methods and specifications used for the original construction; (2) the selection of repair materials and methods; (3) the selection of structural reinforcement methods; and (4) concrete construction maintenance.

This will provide useful information to the owners of cultural properties and to architectural conservators about how to maintain and repair the items entrusted to them. In addition,

table 1-1: Research themes concerning the conservation and restoration of concrete constructions and issues to be addressed

	Research theme	Issue to be addressed	Conservation project related to the addressed issue
1	Reproduction of work methods and specifications	Rapidly advancing construction technology may make obsolete, it also often means that the technology used to construct a concrete construction designated as a cultural property is no longer part of the current skill set. This makes it necessary to keep alive the construction technologies that were used in the past. ① To what extent can the original materials be reproduced or re-used? ② How can the work methods used for the construction of the original object in question be reproduced?	① Former Mitani Reservoir Waterworks Facilities ① Former Shime Coal Mine Shaft Tower ② Hiroshima Peace Memorial Museum ② Hiroshima Memorial Cathedral for World Peace
2	Selection of repair materials and methods	Concrete constructions are usually quite solid. If any partial deterioration or damage occurs, it is difficult to identify exactly the areas that require repair. In many cases you may be forced to select an irreversible repair method. ① Why were these particular repair materials and methods selected? ② How is it best to use the repair materials and methods for the different areas to be repaired? ③ How should the original materials and those used for the repairs be made identifiable? ④ How do we define and achieve "minimum interventions?	① Marunuma Dam ① Former Shime Coal Mine Shaft Tower ② Hiroshima Memorial Cathedral for World Peace ③ Former Shime Coal Mine Shaft Tower ④ Hiroshima Peace Memorial Museum
3	Selection of structural reinforcement methods	Many concrete constructions designated as cultural properties also have excellent designs with great esthetic value. The addition of new stiffeners may impair the design value of the structure. ① How do we select the best structural reinforcement methods to meet these two needs: for structural integrity and fidelity to design? ② How can we improve structural rigidity?	① Hiroshima Peace Memorial Museum ② Hiroshima Memorial Cathedral for World Peace
4	Maintenance	Each structure has areas that need to be repaired regularly (such as to prevent the ingress of water). The repaired areas of some structures need to be inspected regularly. ① What refurbishment methods allow for periodic repairs? ② How do we monitor for changes in repaired areas?	① Former Yamamura Family Residence (Yodoko Guest House) ② Umekoji Locomotive House

we will present some cases of conservation and refurbishment projects that address these issues.

1.2 Investigative methods

(1)Field surveys

While preparing to make this report, we performed field surveys of concrete structures, referred to in Supplement 3. We selected concrete constructions for our survey that exhibited the most marked restoration cases executed according the state of concrete deterioration and damage that had been repaired or reinforced using methods suitable for addressing the issues given in Table 1-1 and the List of Conservation and Refurbishment Project Reports (Supplement 3). Each field survey tour included, if at all possible, the engineers who had been responsible for the repair of the concrete construction being examined.

(2)Field survey interviews

During each field survey tour, we interviewed the engineers and others involved in the repair of that structure and the maintenance personnel as well, focusing on the four points given in **table 1-1**.

(3)Literature surveys

We studied the Conservation and Refurbishment Project Reports and investigative reports about each of the concrete constructions, as well as technical papers about the conservation and restoration of concrete constructions.

1.3 Organization of this report

Chapter 1 discusses this report's background and objectives and the investigating methods used. Then, Chapter 2 deals with the mechanisms of concrete deterioration and damage. Chapter 3 takes up the current issues to be addressed concerning culturally valuable concrete constructions. Finally Chapter 4 discusses the details of the conservation and restoration of concrete constructions, focusing on the current issues, using some of the designated cultural properties mentioned in the previous chapter.

2. Deterioration of and damage to concrete constructions

Some of the historically important concrete constructions that are now extant are so severely deteriorated or damaged that they are taken out of service due to concerns about their safety. Given below are typical causes of deterioration found in those concrete constructions, examples of remedial measures and an overview of the work methods used to repair deterioration by type of cause.

Professor Imamoto Ken-ichi discusses methods of repairing progressive cracks in concrete in detail in Chapter 1 of this book (starting on page 26). He cites major causes of progressive cracks, such as reactive aggregate, chlorides contained in concrete, lack of thickness in the concrete covering rebar, repeated cycles of freezing and thawing, the chemical action of acids and salts, the corrosion of rebars due to concrete carbonation, and the corrosion of rebars due to the infiltration of chlorides.

2.1 Types of material deterioration and damage

Concrete deterioration is chiefly caused by two basic processes: chemical and physical ones. Chemical factors include chloride attack, carbonation, chemical erosion, and alkali aggregate reaction. Repeated cycles of freezing and thawing as well as wear are the predominant physical factors. In actual fact, however, deterioration often progresses through a combination of multiple factors. Typical causes of deterioration of and damage to concrete are given in **table 2-1**.

The Japan Concrete Institute states that it is especially important to pay attention to the following two points when seeking to understand the deterioration of concrete constructions.

① Various chemical reactions, including cement hydration reaction, continue to progress within the concrete over a long period of time after the concrete has been put in place. The reaction processes and products are affected by many factors, such as the type and quantity of chemical substances contained in the concrete, the type and quantity of chemical substances that came from outside, and the environment under which the concrete exists.

② Hardened concrete is a porous material with fine continuous voids, through which gases (e.g. sulfur, carbon dioxide), ions (e.g. chloride ions, alkali metal ions, sulfate ions), and moisture penetrate into or move out of the concrete.

2.2 Methods for repairing deterioration or damage

Table 2-2 shows examples of repair methods grouped by the cause of the deterioration and damage listed in **table 2-1**. In addition, the overview of each repair method is given in **tables 2-3, 2-4**, and **2-5**.

3. Current issues related to the conservation and restoration of historically valuable concrete constructions

This chapter discusses the current issues to be addressed that are listed in **table 1-1**.

3.1 Issues related to the reproduction of the work methods and materials specified

The construction methods and materials of structures that were built after the beginning of the modern era often vary greatly, even if their construction periods are only slightly different.This is because the development of new technology promoted the replacement of older work methods and materials by newer ones, at a rapid pace. Construction methods and specifications used for only a brief period reveal the technological level prevalent at the time when they were used. This is why we recognize such construction methods and specifications as being historically valuable. However, it is not easy to reproduce in conservation and restoration projects those technologies that have been frequently updated or replaced. In addition, it can also be difficult to obtain materials that are the same as those used for the construction of the original structures.

Furthermore, concrete constructions are often completed in such a way that their concrete surfaces are exposed to view when finished. If the surface of a concrete construction is deteriorated or partially damaged, it is usually repaired by placing sealant into the deteriorated or damaged areas, such as cracks. However, if deterioration or damage extends over a wide area, the replacement of some concrete may be found to be necessary. The problem arises that it is difficult to reproduce accurately the original color and texture of the finished surface of these historic concrete constructions and there is concern that the use of repair materials may impair the appearance of the structure.

table 2-1: Causes and details of deterioration affecting concrete constructions (reference : bibliograpphy 4,5,6)

Cause of deterioration or damage	Details of deterioration and damage
Chloride attack	Chloride ions present in the concrete cause corrosion of the contained rebars, resulting in damage, such as cracks, to the concrete. Excessive amounts of chloride ions contained in the concrete promote the disruption of the passive layer, making the steel reinforcement more likely to corrode. Chloride within the concrete comes about in the following two ways: ① There were chloride ions originally included in gravel from the sea, chemical admixtures, the cement itself, or water used for mixing the cement; ② Chloride molecules infiltrated the mixture, carried on the air (as from a nearby seacoast), or there was an ingress of chloride ions from de-icing agents.
Carbonation	Carbon dioxide in air can infiltrate into concrete to form calcium carbonate, reducing the alkalinity of the concrete. Reduction in the pH of concrete below 11 causes the disruption of the passive film on concrete surfaces, exposing the steel reinforcement to a corrosive environment. Carbonation is usually promoted where one or more of the following characterizes the environment: ① High concentration of carbon dioxide; ② High humidity; ③ High temperature.
Chemical erosion	This type of deterioration can occur due to a chemical reaction, such as between chemical substances supplied from the external environment and the concrete. The chemical erosion of the concrete is caused by one of the following three factors: ① Change in the nature of the cement hydration products, from being water insoluble to soluble, due to a chemical reaction between them and a chemical substance (e.g. acid, animal oils, minerals, corrosive gases, the action of microorganisms that cause the generation of sulfuric acid). This makes the concrete porous or decomposes it; ② The generation of a new expansive compound due to a chemical reaction between cement hydration products and a chemical substance (e.g. animal oils, sulfates, sea water, a concentrated alkaline solution). The expansion of this compound forces apart component particles of the concrete; ③ Long-term contact of the concrete with water. In this case, cement hydration products inside the concrete leach out, making the concrete porous.
Alkali aggregate reaction	In a wide sense, alkali aggregate reaction refers to chemical reaction between alkali hydroxides (KOH and NaOH) in the capillary water within the concrete, or a solution that is absorbed into the concrete's capillaries, and alkali-reactive minerals in the aggregate. It generally refers to a phenomenon in which the generation of cracks in the concrete is caused by the formation of a reaction product such as alkali or silica gel or internal swelling from water absorption.
Repeated cycles of freezing and thawing	Water in the concrete freezes to ice and then expands (by about 9%) within the pores of the cement, either between the aggregate material particles or at the interface of the cement and aggregate, causing damage to the concrete.
Dry shrinkage	After concrete is poured, the concrete mixture contracts during hardening due to the loss of water through capillary action. This shrinkage causes an increase in tensile stress, which may lead to cracking, internal warping and external deflection when it exceeds the specified tensile strength level.
Fire	Fire causes rapid temperature rises in some parts of the concrete, creating unequal expansion and resulting in spalling or cracking of the concrete.
Wear or cracking	Repeated application of force to the same location on the concrete surface causes the concrete to spall or the aggregates to separate and fall off. In other cases, concrete can crack when subjected to one or a few strong impacts.
Fatigue	Repeated application of stress may lead to sudden damage to or destruction of the concrete. The main causes of fatigue damage include: concrete fatigue, rebar fatigue, and the fatigue of the interface between the concrete and rebars.
Contamination	Concrete can be contaminated by the growth of lichen and algae or the occurrence of free lime or efflorescence.

3.2 Issues related to the selection of repair materials and methods

Since concrete constructions are usually built in such a way that the material becomes an integrated and continuous whole, it is difficult to select a repair method that replaces only certain structural members with new ones or particular parts of the structure with new sections. In addition, when determining the range of the repair, the boundary between a deteriorated or damaged area and a sound area is not so clear; it is hard to identify the area requiring repair precisely. Furthermore, a repair method that integrates a repaired part with an existing sound part often seems to be selected resulting in an irreversible procedure which contradicts a basic principle in architectural conservation. And also, a repaired part may again prematurely deteriorate or become damaged due to the environment surrounding the concrete construction. That is, there are situations when sufficient consideration is not given to the surrounding environment when the selection of repair materials or methods is made.

table 2-2: Examples of repair methods grouped by the cause of deterioration and damage（reference : bibliography 4,5,6）

Cause of deterioration or damage	Details of remedial measures	Repair method	Purpose of repair
Chloride attack	① Removal of substances that cause corrosion ② Suppression of substances that cause corrosion from infiltrating or permeating into the concrete covering the rebar ③ Prevention of the infiltration of substances that cause corrosion to reach the surface of the rebar ④ Use of non-corroding rebars ⑤ Control of the electrical potential of the rebar inside the concrete ⑥ Use of rust-preventives	Patching	Removing chloride ions
		Surface coating	Suppressing infiltration of causative substances
		Desalination	Discharging chloride ions
		Cathodic protection	Controlling the rebar's electrical potential
Carbonation	① Suppression of the progress of carbonation ② Suppression of the progress of rebar corrosion	Patching	Removing areas of carbonation
		Surface coating	Suppressing infiltration of water and carbon dioxide
		Re-alkalization	Recovery of corrosion resistant effect
Chemical erosion	① Planning of preventive measures during the design stage that consider the design service life of concrete constructions, or installation at the time of construction of provisions that will allow for periodic repairs ② Application of. Concrete surface coating to protect against acids or sulfates ③ Use of sulfate-resisting Portland cement, moderate-heat Portland cement, Portland blast-furnace slag cement, and Portland fly-ash cement, which are all relatively resistant to sea water ④ Protection of rebar against erosion by such things as sea water, by securing a sufficiently thick concrete over the reinforcement or using concrete with a high degree of water-impermeability, or a small water/cement ratio	Patching	Removing deteriorated areas
		Surface coating	Suppressing the infiltration of causative substances
Alkali aggregate reaction	① Reducing the total amount of alkali in the concrete ② Use of blended cement that inhibits alkali-silica reactions ③ Use of less reactive aggregates	Repairing cracks	Suppressing the ingress of water
		Surface coating	Suppressing the supply of alkali
Repeated cycles of freezing and thawing	① Use of aggregates that have high resistance to the effects of freezing ② Use of an appropriate amount of entrained air by using AEA, AEW, or high-performance AEW (about 3 - 6% according to the environment or the maximum size of coarse aggregate) ③ Use of denser concrete by making the w/c ratio lower, to change the characteristics of the air-void system (AVS) of the concrete, including the spaces. ④ Creasing or draining slopes, and waterproofing concrete constructions to prevent the infiltration of snowmelt into the concrete	Patch repair	Removing deteriorated areas
		Crack repair	Suppressing infiltration of causative substances ①
		Surface coating	Suppressing infiltration of causative substances ②
Wear	① Using concrete with a small w/c ratio and increasing the compressive strength of the concrete by providing a sufficient wet-curing period ② Smoothing the concrete surface and using aggregate with high abrasion resistance to prevent the formation of cavities.	Patch repair method	Restoration to a sound concrete surface
Contamination	Removal of contaminants	Cleaning	Removing contaminants

3.3 Issues related to the selection of structural reinforcement methods

The monolithic designs of concrete constructions enable a relatively high degree of freedom for variation. For this reason, when we are required to reinforce concrete constructions, special consideration must be given to both the aspects of structure and appearance. The installation of base isolation or vibration control devices is sometimes selected as a method of protecting structural integrity, but the cost of installing seismic isolators is usually so great that it would be difficult to use this method to protect and restore all historically important concrete constructions at the present time. In addition, when a seismic isolator is installed, it is necessary to remove part of the foundation, such as some of the pilings. In such a case, the materials and methods used for the foundation need to be conserved as technologically valuable items. Moreover, owing to the high level of freedom in the design of concrete constructions, the design chosen may have produced areas with concentrated stress. For this reason, some historically important concrete constructions have problems in terms of

table 2-3: Overview of methods used to repair deterioration or damage (reference : bibliography 4,5,6)

Work method		Overview of work method
Crack repair	Injection	Injecting repair material (e.g. resin or cement) into the cracks of the concrete.
	Routing and filling	Routing (to widen or deepen cracks to make filling easier) and filling these enlarged cracks with an appropriate joint sealant. Suitable for repairing cracks that are 0.5 mm or more wide.
	Sealing surfaces	Forcing a permeable waterproof agent into cracks, generally 0.2 mm or less wide.
Surface coating		Coating concrete surfaces with paint. Paint, concrete wall panels and/or buried formworks may be used.
Patching		Applying concrete patches over damaged or deteriorated concrete to repair concrete constructions that have suffered loss of concrete.
Electro-chemical approach	Desalination	Removing salt from the concrete by passing electric current through the concrete: Specifically, installing a temporary anode containing an electrolytic solution on the concrete surface and supplying DC current to the rebars (serving as the cathode) inside the concrete from the temporary anode to make chloride ions migrate to the surface of the concrete, thus removing the salt from the concrete.
	Re-alkalization	Installing a temporary anode containing an alkaline solution on the concrete surface and supplying DC current to cause the alkaline solution to move toward the rebars (serving as the cathode) embedded inside the concrete.
Cathodic protection process		Installing an anode on the concrete surface and supplying a weak DC current to the rebars (serving as the cathode) inside the concrete to lower the electrical potential of the steel to below that at which it will corrode, thus preventing the ionization of the rebar.
Cleaning		Removing contaminants using water or hot water under pressure. Chemicals may be used, depending on the nature of the contaminants.

table 2-4: Repairs of cracks due to dry shrinkage (reference : bibliography 4,5,6)

Degree of deterioration	Nature of the cracks	Repair method used
1	0.2mm or less wide	Surface coating (using elastic waterproof coating materials)
2	0.2~1.0mm	Injection (using epoxy resin, acrylic resin, polymer cement, etc.)
3	1.0mm or more wide	Routing and filling (using sealants (urethane resin, silicone resin), flexible epoxy resin)

table 2-5: Repairs of cracks due to repeated cycles of freezing and thawing (reference : bibliography 4,5,6)

Degree of deterioration	Nature of the cracks	Repair method used
1	Minor cracks on the concrete surface only, or scaling	Provision of a protective layer using a surface coating method, surface impregnation method, metal plates, or waterproofing
2	Fine cracks on the concrete surface (about 0.3 mm wide), pop-outs or scaling (up to medium sized -- about 10 mm deep)	Repair techniques, such as routing and filling, injection of resin, or partial replacement and then providing a protective layer using metal plates or waterproofing
3	Wide cracks (0.3 mm or more) or very severe scaling (up to about 20 mm deep)	Repairing by partial replacement and then providing a protective layer using metal plates or waterproofing
4	Cracks, spalling or flaking nearly reaching the rebar, or extremely severe scaling (up to about 30 mm deep)	Repairing by partial replacement and then providing a protective layer using metal plates or waterproofing.
5	Severe spalling or flaking of the concrete. The fragile layer is deep (30 mm or more) and some loss of rebar material has occurred.	Repairing by partial replacement and then providing a protective layer using metal plates or waterproofing.

seismic vulnerability. Mr. Satoshi Nishioka, senior specialist in the Cultural Resources Utilization Division of the Agency for Cultural Affairs, discusses structural reinforcement projects in detail in Chapter 3 of this book (page 45 and thereafter).

3.4 Issues related to maintenance

Concrete constructions need to be repaired regularly to prevent deterioration and damage. In particular, the penetration of water into the concrete material may lead to serious deterioration or damage, making periodic repairs, including waterproofing, indispensable. However, it should be noted that such periodic repairs may involve repeated removal of, sound materials or areas which may result in additional damage. It is therefore also necessary to perform some preventive maintenance, make periodic inspections, and do post-repair monitoring in order to maintain historic concrete constructions.

4. Case studies related to the conservation and restoration of historically important concrete constructions[1]

4.1 Former Yamamura Family Residence（Yodoko Guest House）

(1)Issues related to maintenance (Repair measures taken in consideration of what might be done in subsequent conservation and restoration projects)

[Background]

Since its designation as a cultural property in 1974, the Former Yamamura Family Residence (Yodoko Guest House) (**photo 1-1**) underwent two major repair projects: the first one was a large-scale conservation and refurbishment project, including underpinning, performed during the period from 1985 to 1988; and the second one was a rehabilitation project that was performed during the period from 1995 to 1997 to repair damage due to the 1995 Great Hanshin Awaji Earthquake Earthquake. After that, a third refurbishment project was performed during the period from June 2016 to December 2018, with the main focus placed on improvement of the waterproof layers of the house. When this refurbishment project was performed, the following measures were taken, in consideration of what might be done in subsequent conservation and restoration projects:

① Reduction of the structural load; ② Repair of some artificial-stone ornaments; ③ Provision of joints between ornaments and their base stones.

Below is a discussion of these three measures.

[Overview]

Measure ① : In order to get rid of the layers of deteriorated asphalt waterproofing on the rooftop, the protective mortar on those waterproof layers and the Oya stone paving stones, 232 rectangular Oya stone stones, and the protective mortar around the base of each artificial stone ornament were temporarily removed. After the removal of the asphalt waterproofing layers, it was found that the roof slabs on the south balcony, directly connected to the dining room on the fourth floor and the east balcony had many surface cracks. Therefore, with a view to alleviating structural loading, the following measures were taken. The use of thick protective mortar was discontinued on the south balcony. The steel frames under the slab were cross-connected using beam-like members. Artificial wooden decks were placed over these to alleviate the application of a heavy load imposed by a new concrete slab. Furthermore, restrictions were imposed on the number of visitors who are allowed to go out onto the balcony at one time. At the same time, the east balcony was left closed to the public, partly because there were no railings provided making safety measures insufficient. It was decided to not open the east balcony to the public even after the end of this refurbishment project which enabled removal of the protective mortar layer to reduce the load on the slab.

Measures ②：Two design types (**Figs. 1-1** and **1-2**) of artificial-stone ornaments were refurbished using the in-situ plastering method and the formwork molding method, depending on the state of deterioration.

It was found from examining relevant literature that in relatively many cases the type A artificial-stone ornaments tended to retain their original integrity. It was also found from a preliminary investigation that these were constructed using hard mortar to fill the center of the mold as a core, and then the outer part was covered with relatively soft artificial mortar. A piece of type A artificial-stone ornament was broken apart for examination. After examination, the ornament was restored by treating it as three parts. One part was repaired with in-situ concrete and two parts with precast concrete, and then the three parts were reassembled (**photo 1-2**).

The state of conservation of the artificial-stone ornaments depended on the extent to which they were exposed to rainfall. The type A ornaments, which retained relatively large amounts of the original materials, were refurbished by installing a Galvlume steel sheet on top of each ornament to serve as a form of eaves (**photo 1-3**).

On the other hand, not even one element of the type B artificial-stone ornaments was found remaining on the building in an investigation performed in 1983 preceding the earlier restoration. It was therefore not clear what the original specifications of the type B artificial-stone ornaments had been. New type B artificial-stone ornaments were fabricated by dividing the design into five separate parts and installing the replacements during the conservation and restoration project performed between 1985 and 1988 (**photo 1-4**).

However, some of the newly fabricated type B artificial-stone ornaments broke because rainwater made its way into the ornament through the joints of the parts and corroded the rebar inside. For this reason, new type B artificial-stone ornaments were refabricated as one-piece items, instead of five pieces, for this refurbishment project.

In addition, to prevent the ornaments from breaking, no rebar was used inside them. The type B ones were more severely deteriorated than the type A ones, but the cause of deterioration was not clearly identified. Finally, restoration of the detailed design of this type was temporarily abandoned (**photo 1-5**). Complete restoration of the type B artificial-stone ornaments will be performed after durable repair materials to be used for the project are identified.

The major materials used for repairing the artificial-stone ornaments at the Former Yamamura Family Residence included: white cement, cement, crushed granite, and finely crushed Oya stone. This stone was in the 0.6 to 1.2 mm particle range. It was obtained using a sifter with a 0.5 mm mesh to remove the red-brown clay that was included in the original crushed stone. The colors of the repair materials were selected from among various samples fabricated by varying the amount of admixed white cement. It is quite likely that river sand from the Ashiya River, which runs near the Yodoko Guest House, had been used as an aggregate when the original ornaments were made. Granite sand that was found from Okayama Prefecture was selected to use as the aggregate, for its similarity in color and composition. The strength of the concrete used for the repair was examined before placement, by performing a standard strength test --- 20 cycles of thermal cycling --- according to JIS 6909 7.11.

Measure ③：Considering the design of the building, it was anticipated that the waterproofing layers would need repeated repairs in the future. Therefore, expansion joints were made between the artificial-stone ornaments and the Oya stone base stones, because the ornaments would need to be removed to repair the waterproofing layers in subsequent refurbishment projects (**figure 1-3**).

[Findings]

The Former Yamamura Family Residence (the Yodoko Guest House) was designated as an Important Cultural Property in 1974. Since then, it was subjected to a total of three conservation and refurbishment projects including this one. The patterns of damage to and deterioration of many structural members and materials were clarified to some extent during these projects. Various measures were taken during this conservation and refurbishment project, in consideration of what might need to be done in subsequent conservation and refurbishment projects: restrictions on the use of the balconies that are vulnerable to heavy loads, an in-situ strength test of the concrete used for repair, changes in the specifications of structural members to reduce deterioration, and provision of joints between the ornaments and base stones to allow for possible waterproofing in the future.

[Construction information]

Name of the Property: Former Yamamura Family Residence (Yodoko guest House)

Classification: Residence

Completed in: 1924

Structure and Classification: 4 story reinforced concrete (RC) building with a flat roof.

Building Area: 359.1 m^2

Cultural Property Classification: Important Cultural Property

photo 1-1: Facade of the Former Yamamura Family Residence (the Yodoko Guest House)
(photo taken by：フォトスユー笠原恭太郎)

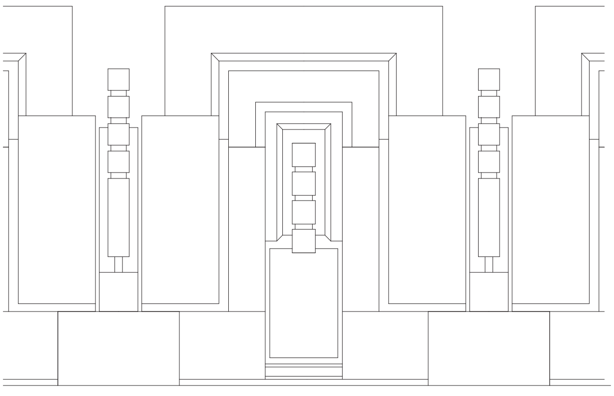

figure 1-1：Type A artificial-stone ornaments
(figure provided by：Architerctural Reserch Association)

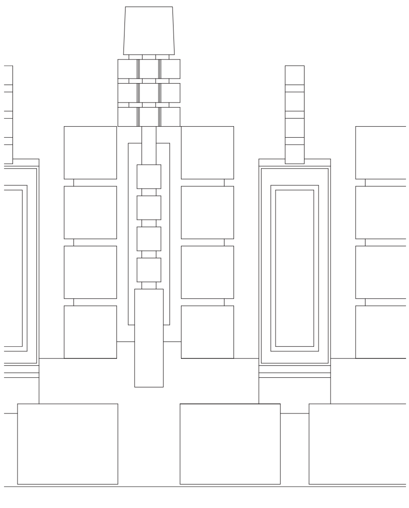

figure 1-2：Type B artificial-stone ornaments
(figure provided by：Architerctural Reserch Association)

Date of Designation: 21 May, 1974
Location: 173, Yamatecho, Ashiya City, Hyogo
Owner: Yodogawa Steel Works, Ltd.

4.2 The Former Shime Coal Mine Shaft Tower

(1)Issues related to the reproduction of work methods and specifications – matching the textures used and the colors of the repair materials to the originals

[Background]

The Former Shime Coal Mine Shaft Tower (hereinafter called the "Shaft Tower") (**photo 2-1**) is a representative building that contributes to the unique scenery of Shime Town, Fukuoka Prefecture, and is also valuable as part of Japan's industrial heritage. This Shaft Tower was completed in 1943. After more than 75 years since its completion, the whole structure had undergone notable deterioration and damage,

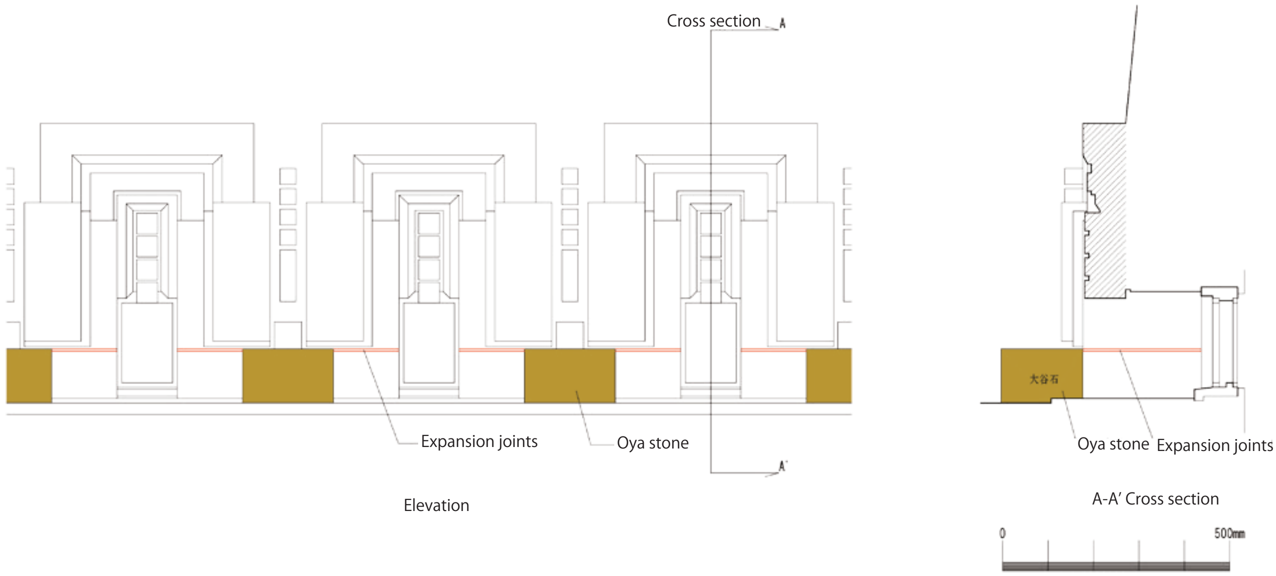

figure 1-3：Provision of joints between ornaments and their base stones (type A) (red parts were joints of provision) (figure provided by：Architerctural Reserch Association)

photo 1-2: Type A artificial-stone ornaments (with three parts reassembled) (red parts were newly placed in-situ)
(photo provided by：Yodogawa Steel Works, Ltd.)

photo 1-4：All five separate parts of a type B artificial-stone ornament were reassembled (They are color-coded)
(photo provided by：Architerctural Reserch Association)

photo 1-3: Galvlume steel sheets on top of ornaments to serve as a form of eaves.

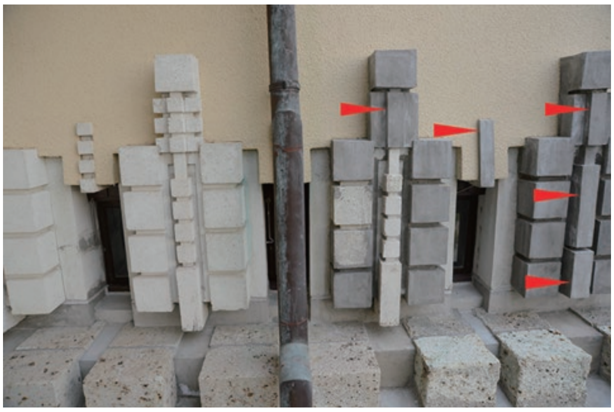

photo 1-5: Type B artificial-stone ornament whose restoration of detailed design was abandoned (indicated by red arrows)

such as the flaking off of the concrete and exposure of rebar. Therefore, during the period from September 2018 to October 2020, a conservation and restoration project was performed to repair the Shaft Tower with the focus on suppressing the progress of deterioration and damage as well as preventing the actual collapse of the structure. In this conservation and restoration project, due considerations were given to the work methods and repair materials to be used. There was a concern that apparent differences in texture and colors between the original and the repaired areas would impair the appearance and scenic value of the structure.

[Overview]

After scaffolding had been installed to facilitate this conservation and restoration project, the structure's entire concrete surface was cleaned with high-pressure steam (**photo 2-2**) to remove contaminants. Then the textures and colors of the concrete surfaces revealed after cleaning were examined carefully. This pre-repair cleaning process was carried out by utilizing the experience of the conservation and repair project performed on the Hiroshima Memorial Cathedral for World Peace.

photo 2-1: Exterior view of the Former Shime Coal Mine Shaft Tower before restoration

photo 2-2: Cleaning of the concrete surfaces
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

The deteriorated and damaged areas of the Shaft Tower were repaired using both the injection method and the plastering method. For the injection method, non-shrink grout was used, and polymer cement mortar containing a rust-inhibitor (hereafter referred to as the polymer cement mortar) was used for the plastering method. Various types of non-shrink grouts were commercially available. From among nine brands, one non-shrink grout product was selected because it was similar in color to the original concrete. It was considered likely that color irregularities and reductions in performance might occur if the polymer cement mortar was mixed in the field using pigments and white cement. Therefore, the mortar was mixed at the factory during this project (**photo 2-3**). At one time a plan was submitted to the Repair Investigation Committee for color-matching the original and repaired areas using paint after refurbishment, but that plan was turned down because it was not certain if the appropriate materials and techniques would be available.

To reduce the possibility of changes in appearance, some measures were taken when performing the injection method which are discussed below. At the time when the Shaft Tower was originally constructed, the placement of concrete was made by filling formworks that had been fastened tightly together using annealing wire. Today's placement of concrete using standard separators will usually leave small round

photo 2-3: Color-matching repair samples are being compared
(photo provided by : The Japanese Association for Conservation of Architectural Monuments

photo 2-4: Mini-cones installed in areas to be repaired
(photo provided by : The Japanese Association for Conservation of Architectural Monuments

holes (known as tie holes) with a diameter of 30 mm on the concrete surfaces. To avoid this inconsistency in appearance, the same concrete placement method could have been used as for the original construction. That is, the use of formworks tightened together using annealing wires had actually been proposed, but this was turned down because it was judged that annealing wires could not withstand the grout injection pressure (estimated to be as high as 41.4 kN/m^2). In the end, the use of formworks fastened together using separators was adopted for putting the concrete in place during this conservation and restoration project. To make the tie holes less conspicuous, however, mini-cones (**photo 2-4**) and separator-pulling devices with spacers (**photo 2-5**) were used, depending upon the thickness of the concrete covering the rebar. (The mini-cones used were commercially available ones that leave 17-mm diameter. tie holes in the concrete surface after removal. They were used where the concrete covering the rebar was less than 30 mm in thickness. The separator-pulling devices with spacers were customized items that leave 8-mm diameter, tie holes in the concrete surface. They were used where the concrete covering the rebar was 30 mm or more in thickness.)

In addition, wooden sheathing was also arranged in as close as possible to the same way that the forms had been placed to pour the original concrete, to reduce the difference in appearance between the original and repaired areas. Furthermore, keeping in mind that this structure is a mining facility, the refurbishment was carefully completed with due attention to avoiding impairment of the engineering integrity, including the accuracy and quality, of the original construction.

[Findings]

Generally, the surfaces of concrete constructions become contaminated due to deterioration caused by aging. It is therefore preferable to clean the surfaces before determining what work methods to use, because this can contribute to reducing the possibility of differences in color between the original and repaired areas. For this conservation and restoration project, various steps such as using mini-cones and separator-pulling devices with spacers, were taken to reduce the possibility of differences in appearance between original and repaired areas due to refurbishment, including the placement of new concrete.

(2) Issues related to the selection of repair materials and methods

The patch repair method and increasing the thickness of the concrete covering the rebar

photo 2-5: Separator-pulling devices with spacers installed on a test specimen
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 2-6: Corroded rebar

photo 2-7: Addition of a splint (indicated by a red arrow) alongside the corroded bar (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

[Background]

The policy for repairing the Shaft Tower was recorded in the Conservation and Utilization Plan established in 2013 as follows:

*This refurbishment project was aimed at preventing the Shaft Tower from falling by: (1) suppressing the progress of deterioration by making appropriate repairs where necessary; and (2) returning the concrete to a sound state.

*After refurbishment, the public was to be allowed to view the Shaft Tower only from behind fences. Therefore, reinforcement of the structure against large earthquakes or other natural disasters was not considered to be executed at that time.

After the refurbishment project was started, the concrete in some parts of the Shaft Tower was chipped away to investigate its interior state. It was found that on the whole the concrete under the main reinforcement was dense and sound. It was reported at the meeting of the Repair Investigation Committee held in January 2019 that it would be best to keep chipping of the internal concrete to a minimum, to maintain the structure's sound condition. In response to this report, the Repair Investigation Committee adopted a new repair policy that said: "It is preferable to reexamine the refurbishment method, giving priority to maintaining the current structural integrity of the Shaft Tower to the extent possible". The refurbishment method was reviewed thereafter. In particular, the methods for repairing the concrete and the main and hoop rebar were changed to ones considered most suitable for conserving the structural integrity of the existing concrete. These are discussed in detail, below.

[Overview]

Before the review, it had been planned that major pieces of the main rebar would be replaced with new ones whenever a steel bar showed a greater than 20% loss of its original cross-sectional area and its size had dropped by one level or more. After the review, it was decided that main rebar should be replaced on the basis of the state of corrosion of all the steel bars embedded inside a given pole or beam, not the corrosion level of each piece of steel bar. That is, it was decided that main rebar should be replaced or repaired appropriately if the combined reduction of cross-sectional area of all the steel bars embedded inside a column or beam had been lowered by more than 20% (**photo 2-6**).

The cross-section of the rebar was measured at the thinnest part using slide calipers. If the rebar was thinner than the allowable limit, the restorers avoided as much as possible cutting and replacing the corroded rebar with new. Instead, they added a splint (consisting of lap-spliced short steel bars) alongside the corroded bar (**photo 2-7**).

This approach conforms to the afore-mentioned repair policy of: "maintaining the current structural integrity of the Shaft Tower as much as possible" as well as the principle of preserving original structural members to the extent possible. When splinting the corroded rebar with new rebar, position and length were determined in the same way as in the case when a splint is lap-spliced to the sound part of existing rebar. The lap length of each joint was set at 40 d (40 x 25 = 1 m if the main rebar inside the column base was 25 mm in diameter) according to the Standard Specifications for Construction Work (JASS5 Reinforced Concrete Projects) published by the Architectural Institute of Japan (AIJ). If it was difficult to add a new steel bar into the rebar system as a splint (for example, if there was no space for a new steel bar), the thinned part of the corroded steel bar was cut away and then a new piece of steel bar was inserted into the section of existing rebar where the old piece was cut away, using enclosed arc welding (**photo 2-8**).

If a splint bar was used at a column's base or on the end of a beam, a post-construction anchor was provided at the joint. If a new steel bar was joined to existing rebar by enclosed arc welding, ultrasonic testing was conducted to check for any defect in the joint. The hoop rebar was repaired by moving aside the corroded steel bar and adding a new piece, instead

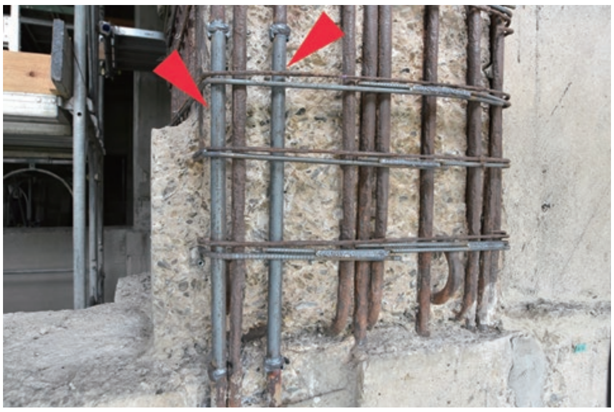

photo 2-8: A new piece of steel bar inserted using enclosed arc welding (steel bars indicated by red arrows) (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 2-9: New concrete was placed to areas whose thickness of covering concrete was insufficient (increased thickness indicated by a red arrow) (photo provided by : The Japanese Association for Conservation of Architectural Monuments

of replacing the corroded and reduced rebar with a new one. Furthermore, the following conditions were also observed when patch repairing was performed on areas where the concrete covering the rebar was too thin. Generally during restoration, it is necessary to increase the covering concrete's thickness so as to slow down the progress of deterioration. However, in some repaired areas, if this project's covering concrete were to be increased to 40 mm, the value specified in JASS5, it would have created a big difference in thickness between repaired and non-repaired areas, significantly impairing the structure's appearance. Therefore, the plan discussed below was used to determine the thickness of the covering concrete in the areas to be repaired, to minimize the difference in appearance between repaired and non-repaired areas while assuring that the resistance of the repaired areas to carbonation was adequate. A guideline on the design of concrete constructions published by the AIJ states that the magnitude of concrete corrosion factors should be determined when carbonation reaches the depth of the rebar. Therefore, during this conservation and restoration project, it was assumed that rebar corrosion started when the difference between the thickness of the concrete covering the rebar and the depth of carbonation became equal. In the meantime, on the assumption that cultural properties need to be refurbished every 50 years, the thickness of the original covering of concrete that would allow a time span of 50 years until the carbonation depth reached the rebars was calculated from the rate of carbonation for each type of concrete material. On the basis of the results of these calculations, the restorers determined the minimum thicknesses of covering concrete necessary for the various areas to be repaired. Different thickness of covering concrete were established for the different areas to be repaired and the work methods to be used: 18 mm (with the injection method) or 14 mm (with the plastering method) for areas of repair exposed to rainfall; and 10 mm (injection) and 6 mm (plastering) for other areas (**photo 2-9**).

[Findings]

In this case study, rebar was repaired by splinting corroded steel bars or replacing the corroded portions of steel bars with new ones using enclosed arc welding, while giving priority to maintaining the current structural integrity of the cultural property to the extent possible. Areas where there was an insufficient thickness of concrete covering the rebar, including those exposed to rainfall, were patch-repaired while assuring there was the minimum thickness of covering concrete specified in the AIJ's guideline. That is, this project was performed with an emphasis on the conservation of original materials and techniques used for the construction of this structure.

(3)Issues related to the selection of repair materials and work methods - Selection of surface protection agents

[Background]

With more than 75 years having passed after the Shaft Tower was completed, the whole structure underwent notable deterioration and damage, including flaking off of concrete and exposure of rebar. Therefore, a conservation and restoration project was undertaken to repair the concrete structure's deteriorated and damaged areas, with a focus on suppressing the progress of deterioration and damage as well as preventing the actual collapse of the structure. This section describes the discussions held during the planning stage of the project about the best means for conserving the concrete parts of the cultural property which suffered from carbonation.

[Overview]

The entire Shaft Tower structure had suffered notable deterioration and damage. Therefore, it was considered necessary to take appropriate measures to preserve the whole of it, including areas where deterioration or damage was not yet conspicuous. However, patch-repairs of some areas were left for subsequent projects. Specifically, for this conservation project, the possibility of using surface protection agents was discussed, in order to prevent the ingress of water into the concrete and suppress the progress of carbonation, which were two major causes of rusted rebar. A preliminary investigation was conducted during the period from 2014 to 2016. During this preliminary investigation, one type of rust-inhibiting coating and three types of surface penetrant (silicate-based, lithium nitrite, and silane-based) were subjected to a field test. As a result, a combination of the rust-inhibiting coating and a silane-siloxane-based water repelling agent were selected as candidates to protect the surface, because this combination did not result in efflorescence on the concrete's surface.

After the repair materials to be used for patch repairing had been selected, the type of surface protection to use in this project was reexamined, taking into account the afore-mentioned purpose of suppressing the corrosion and carbonation of rebar even in areas where corrosion or carbonation was not yet conspicuous.

These three conditions were identified as critical:

① Keep to a minimum any changes in appearance, such as color and texture, due to the application of the surface protection agents
② Assure compatibility between the surface protection agents and the concrete repair material. The development of efflorescence or discoloration was not to be accepted.
③ Make sure the repairs were reversible. The surface protection agent applied must be removable or the concrete surface must be able to return to its original state within a certain period of time.

Keeping these three conditions in mind, three types of surface protection agents were examined for suitability, using various tests. First, each surface protection agent was applied to an area on the Shaft Tower's concrete surface, to determine the amount of agent that penetrated into the concrete. Second, a weathering test was performed over a few months, to check for any changes in the appearance of the concrete coated with each type of surface protection agent. A weathering test was also conducted by applying each surface protection agent to test specimens fabricated with the type of concrete repair material that was to actually be used (**photo 2-11**). The following three types of surface protection agent were tested:

1. Liquid water-based hydrophobic agent: A transparent organic-inorganic hybrid paint forms hydrophobic layers, both on the surface of the concrete and inside it. It prevents the entry of water into the concrete. It must also have a certain level of moisture-permeability (permeability by water vapor) that does not inhibit the discharge of moisture from inside the concrete (Advantages: It has been reported that a surface protection agent of this type will maintain water repellence for 18 years after application. Thus long-term durability can be expected. Disadvantages: The concrete surface has a slightly different texture after application. In terms of the reversibility of repair, it is necessary to apply a release agent to remove the agent from the concrete surface and scaffoldings must be used.)
   Test results: There was no efflorescence either on the existing concrete surface or on the surface of concrete used as a repair material.
2. Combination of a surface penetrant and a rust-inhibiting coating (silicate-based surface penetrant + nitrite-based permeable rust-inhibitor):The rust-inhibitor permeates right through the concrete to form a passive film on the surface of the rebar. The silicate-based penetrant provides alkalinity, which makes the concrete denser. (Advantages: A protective layer is formed on the surface of rebar to suppress corrosion without causing any conspicuous change in the appearance of the concrete. Disadvantages: Some types of concrete repair material might develop efflorescence over time. The water repellence only last a rather short time, about five to seven years.
   Test results: Both the existing concrete surface and the surface of the concrete used as a repair material developed efflorescence (**photo 2-10**).
3. Combination of a permeable water-repellant and a rust-inhibiting coating (silane-siloxane-based surface penetrant + nitrite-based permeable rust-inhibitor):
   The rust-inhibitor permeated through the concrete as expected, to form a passive film on the surface of rebar. The silane-siloxane-based surface penetrant formed a water-repellent film on the concrete's surface. (Advantages: Almost no change in the concrete's appearance was observed after application. The effect lasts for about 15 years. Disadvantages: High cost. It is possible that efflorescence might occur at some time or in some place.)
   Test results: A slight amount of efflorescence occurred on the surface of concrete used as a repair material.

The three types of surface protection were tested according to plan. The water-based hydrophobic agent was selected on the basis of the test results, because it had a strong anti-efflorescent effect on the concrete repair material and was

photo 2-10: Development of efflorescence: after the application of nitrite-based permeable rust-inhibitor+ silane-siloxane-based surface penetrant)
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

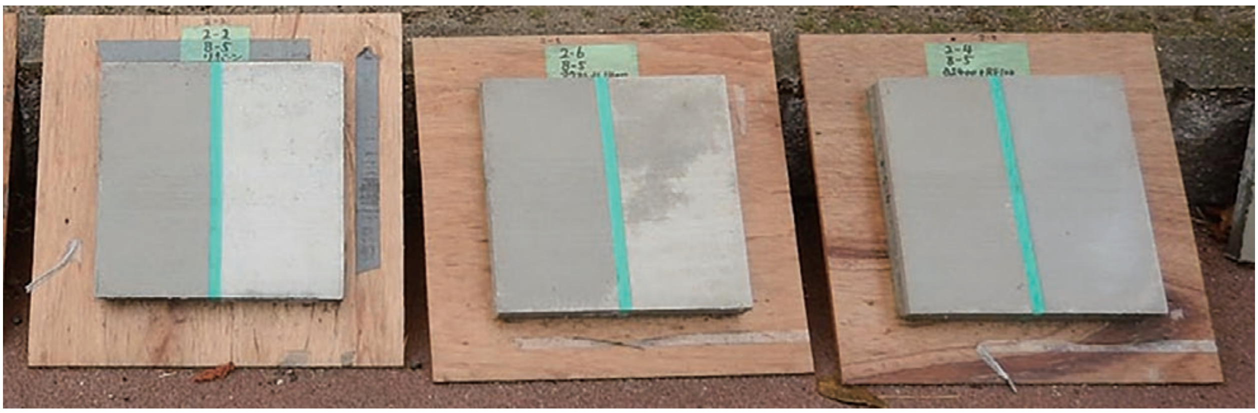

photo 2-11: Test specimens made of a repair material coated with three different types of surface protection agents (from left: liquid water-based hydrophobic agent, silane-siloxane-based surface penetrant + nitrite-based permeable rust-inhibitor and silicate-based surface penetrant + nitrite-based permeable rust-inhibitor) (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

quite durable. There were no significant differences in terms of water permeability. It was also found that all three types of surface protection agent had some degree of reversibility, although there were differences in degree among them.

[Findings]

Three types of surface protection agent were examined to learn about the effects of suppressing carbonation of the concrete. Of the three, an agent was selected which had a track record of more than 15 years in terms of durability and an excellent anti-efflorescence effect. However, considering the 50-year refurbishment interval proposed for cultural properties, a concern still remains about the agent's durability. Therefore, after the conservation and refurbishment project is completed, it will be preferable to monitor continuously the state of surface protection agents applied and review the refurbishment interval on the basis of these monitoring results.

[Construction information]
Type of Structure: Reinforced concrete construction, with eight stories above and one below ground, and a tower.

[Construction information]
Name of the Property: Former Shime Coal Mine Shaft Tower
Type of Structure: industrial facility, transportation, engineering work
Completed in: 1943
Building Area: 270.71 m^2
Type of Structure: Reinforced concrete construction, with eight stories above and one below ground, and a tower.
Cultural Property Classification: Important Cultural Property
Date of Designation: 8 December, 2009
Location: Shime, Shime Town, Fukuoka
Owner: Shime Town
Conservation Project Period: September 2018 to October 2020

4.3 The Marunuma Dam

(1)Issues related to the selection of repair materials and methods
- Monitoring of over several years repair materials and methods used

[Background]

Marunuma Dam (**photo 3-1**) was repaired in 2001 by applying a protective coating (polyurethane resin) to the dam's upstream face (concrete core wall) in order to prevent deterioration of the concrete due to repeated cycles of freezing and thawing. However, rainwater made its way underneath the coating film, which led to about 460 m2 of coating peeling away (**photo 3-2**).

Two of the buttresses that had been repaired during the preceding repair project became severely deteriorated due to freeze-thaw cycles that affected the upper rear part of the dam on the right bank side (**photo 3-3**).

A refurbishment project was planned to prevent further deterioration due to freeze-thaw cycles. A field investigation of what type of repair methods and materials should be used was performed at the site, lasting several years.

[Overview]

Prior to a full-fledged refurbishment project that was to be carried out during the period from October to December 2018, a preliminary field investigation was performed during the period from 2013 to 2017 to find out why the protective coating applied to the upstream face had peeled off and also to select the most suitable repair methods and materials for performing the refurbishment. The investigation included several years spent monitoring various types of repair methods and materials that had been used on a trial basis (P**hoto 3-4**).

The investigation of repair methods and materials was carried out as follows.

The main causes of the peeling off of the protective coating applied to the upstream face were thought to have been: First, rainwater made inroads into the concrete through cracks at the crest of the dam. It then passed through cracks inside the upstream face and reached the boundary between the protective coating and that wall, thus weakening the bond of the coating to the concrete, and resulting in deterioration of the concrete. On the basis of these assumptions, it was planned to provide a new protective coating that would waterproof the crest of the upstream face and to fill the cracks on the upstream face using an appropriate material.

While studying what waterproofing to use on the crest of the upstream face, three types of elastic waterproofing coating (polyurethane resin, epoxy resin, and inorganic glass) were applied to the existing concrete surface at the site, on a trial basis (**Photo 3-4**). During the same period, these were also subjected to laboratory tests including an accelerated degrading test, to compare their bond strengths and durability. On the basis of the test results, as well as evaluations of workability and cost-effectiveness, it was decided to use the epoxy-resin to make repairs during this refurbishment project.

The specific work methods for cracks repairs had to be selected according to the nature of cracks, such as their width, that were found on the upstream face of the dam. Three different crack-repair methods were tried at the site, which were based on different materials and relied on different crack-filling methods. After trial use on the existing dam concrete, a core concrete sample was taken from each repaired area. The routing and filling method using low-viscosity epoxy resin was selected from among these three, because with this method the resin traveled most deeply into the concrete. In addition to the above refurbishment, it was also decided to coat the upstream face with a silane-based surface penetrant to protect the concrete.

The planned refurbishment project of the Marunuma Dam was finally undertaken as follows:

The crest of the dam through which rainwater had made its way to the boundary between the upstream face concrete surface and the protective coating was repaired by: (1) removing all the protective film applied on the existing concrete of the crest surface; (2) coating deteriorated concrete surfaces with polymer cement mortar; then applying epoxy resin-based protective film over the whole concrete surface of the crest (**photo 3-5**).

The upstream face itself was repaired in the following manner. First, the primer which had been used to repair the peeled-off protective film in the past was removed and the exposed surface of the concrete was cleaned. Then, a low-viscosity epoxy resin waterproofing agent was injected from the surface into the cracks (**photo 3-6**). Finally, the whole surface of the upstream face was coated with a silane-based surface protective agent (**photo 3-7**).

The two severely deteriorated buttresses were repaired as follows: The layer of concrete that had deteriorated due to repeated cycles of freezing and thawing, 150 mm to 200 mm deep, was chipped off the surface of each buttress; the buttress's newly exposed concrete was cleaned (**photo 3-8**); and steel tie-bars were installed over the areas where deteriorated concrete had been chipped away (**photo 3-9**), followed by the creation of a framework of steel bars, the installation of forms and placement of concrete.

[Findings]

Prior to the start of this conservation and refurbishment project, a preliminary investigation was performed over several years to discover the cause of the damage to the protective coating applied in the previous repair project and select the most suitable repair method and material. The repair methods and materials examined were selected from ones that were being widely used for the refurbishment of general concrete constructions, not for exclusive use during the refurbishment of concrete constructions designated as cultural properties. This meant that the repair methods and materials used for this project were ones that could be performed easily, even by repair workers only familiar with general construction skills.

The effectiveness of the repair methods and materials used in this refurbishment project will be verified by checking the repaired areas for changes over time.

[Construction information]
Name of the Property: Marunuma Dam

photo 3-1：Marunuma Dam

photo 3-2: The protective coating of the dam's upstream face peeling away (photo provided by : Tokyo Electric Power Company Holdings, Incorporated

photo 3-3: A buttress deteriorated due to freeze-thaw cycles (the surface coating provided in the past repair project peeled off) (photo provided by : Tokyo Electric Power Company Holdings, Incorporated

photo 3-4: Monitoring of the protective coating applied on a trial basis (photo provided by : Tokyo Electric Power Company Holdings, Incorporated)

Type of Structure: industrial facility, transportation, engineering work
Completed in: 1931
Type of Structure: Reinforced concrete construction, with eight stories above and one below ground, and a tower.
Cultural Property Classification: Important Cultural Property
Date of Designation: 25 December, 2003
Location: Katashina Village, Gunma

photo 3-5: Protective film applied over the whole concrete surface of the crest (photo provided by : Tokyo Electric Power Company Holdings, Incorporated)

photo 3-6: Part of the protective film peeling off from the dam's upstream face (photo provided by : Tokyo Electric Power Company Holdings, Incorporated)

photo 3-7：buttress frost damaged
(photo provided by : Tokyo Electric Power Company Holdings, Incorporated)

Owner: Tokyo Electric Power Company Holdings, Inc.
Conservation Project Period: October to December 2018

4.4 The Former Mitani Reservoir Dam Water Supply Facility

(1)Refurbishment of deteriorated and damaged sheds - Criteria for the reproduction of the original specifications

[Background]

The intake water control gate sheds at the Former Mitani Reservoir Dam Water Supply Facility are historically valuable steel-framed buildings whose exterior walls were finished by mortar applied over a steel wire mesh (**photo 4-1**). They are still in existence, looking much as they did in the past (**photo 4-2**).

A wall constructed using a combination of wire mesh and mortar is likely to contain voids. In the case of this facility, too, many of the sheds had undergone deterioration and damage, including rusted steel frames and wire mesh; and spalling, cracks, and mortar flaking from the walls (**photo 4-3**).

In planning the refurbishment of these sheds, discussion was held concerning the level of seismic resistance to be achieved by refurbishment. It was determined that the sheds should be sufficiently robust to meet the "Standards for possible restoration" established by the Agency for Cultural Affairs.

photo 3-8 : Deteriorated concrete chipped off and the exposed concrete surface cleaned (photo provided by : Tokyo Electric Power Company Holdings, Incorporated)

photo 3-9: Creation of framework of steel bars (photo provided by : Tokyo Electric Power Company Holdings, Incorporated)

This means that although there might be a danger of some collapse during a major earthquake, the buildings can be sufficiently restored as cultural properties.

It was decided not to perform seismic reinforcement of these sheds because it was assumed that people did not spend long periods of time inside them. Therefore, during the refurbishment project, only repairs on the deteriorated and damaged areas of the sheds were undertaken.

[Overview]

The refurbishment of the intake water control gate sheds at the Former Mitani Reservoir Dam Water Supply Facility was conducted during the period from 2013 to 2018.

With partial refurbishment as the operating principle, the project was carried out according to the repair policies outlined in **tables 4-1** and **4-2**, on condition that each building's original design and architectural method be conserved to the extent possible without changing them in essence. **Table 4-1** also gives criteria for repairing damaged areas due to deterioration caused by age.

In this project, structural members that could not be reused were replaced with new ones or repaired, in principle, using the same repair materials and methods as those used when the sheds were originally built.

However, the proportions of mortar and concrete and the place of origin and composition of the cement and aggregate were selected with a priority placed on strength, stiffness, and durability. That is, the restorers did not have to stick to the original materials and conditions, except if it was proved they were especially intended for use on these particular buildings during the original construction (such as the materials and mix proportion of the oil paint used for this refurbishment project) (**photos 4-4** to **4-7**). The analysis of the original mortar and concrete used for the sheds showed that they were almost the same as those widely used at present, meaning that they had not been specifically chosen for that project.

Furthermore, the areas that had lost structural strength due to problems with the design and construction method of the original buildings and that posed problems in terms of managing their preservation were investigated to determine how to repair them according to the extent of damage and conditions for repairing and measures listed in **table 4-2**.

Table 4-3 shows the comparison of specifications and repair policies regarding the refurbishment of the intake water control gate sheds.

No.2 shed seemed to be especially severely damaged, as compared with the other sheds. Therefore, from the beginning of a preliminary investigation performed prior to the full-fledge refurbishment project, there was a great deal of concern about what repair methods to use, including whether it could be repaired and conserved at all. After reviewing the refurbishment plan and considering the entire situation, repair work was initiated, starting with No.3 shed, followed by Nos. 4, 1, and 5 sheds, in that order. In the course of the repair project, it was found that except for the clearly damaged areas, the concrete structure of each shed as a whole, including the steel structural members, was in sound condition. Therefore, even the No.2 shed that had appeared to be severely damaged could be repaired in the same way as the other sheds.

The patch-repair method (equivalent to the "Refrete system") widely used at present for the refurbishment of reinforced concrete constructions, was adopted.

photo 4-1: Steel-framed building whose exterior walls were finished by mortar applied over a steel wire mesh (reference :『重要文化財　旧美歎水源地水道施設　保存修理工事報告書』、p.87)

photo 4-2: Intake water control gate sheds

photo 4-3: Deteriorated and damaged internal walls of No.2 intake water control gate shed　(reference : 『重要文化財　旧美歎水源地水道施設　保存修理工事報告書』、p.95)

Specifically, each shed's spandrel wall was repaired by installing forms and pouring non-shrink grout concrete. Areas other than the spandrel walls were repaired by troweling on polymer cement mortar. Prior to starting the repairs, damaged areas were checked for the extent of spalling and deformation of the wall concrete to determine how much concrete should be removed. The wall concrete was removed from some areas where spalling and deformation were conspicuous, to check for the amount of corrosion on the rebar embedded in the wall. Then, the wall was repaired, while the amount of concrete being removed was under constant review. It had been decided to review the repair policy if it was anticipated that the original structural members might lose more material than expected, but in the end all the sheds could be repaired satisfactorily without having to resort to major replacement of structural rebars. Areas with minor cracks or spalling of the wall concrete were repaired by injecting cement slurry to fill voids in the wall concrete, to rustproof the rebar as well as to provide continuity between the concrete and the rebar. Cracks that were 0.2 mm or more wide and not filled with efflorescence inside were repaired using the crack-repair method (low-pressure injection of an ultra-fine polymer cement).

[Findings]

During this refurbishment project, repairs were made in keeping with the state of deterioration of and damage to the sheds' concrete. The materials and mix proportion of mortar and concrete originally used for these were analyzed prior

photos 4-4 to 4-7: Intake water control gate No.1 shed: ① before repair ② surface concrete was chipped away ③ rust-prevention of wire mesh and preparation of substrate ④ patch-repairing using mortar (reference :『重要文化財　旧美歎水源地水道施設　保存修理工事報告書』、p.89)

table 4-1: Repair policies（reference:『重要文化財旧美歎水源地水道施設保存活用計画』、p.55。）

1		Areas that are slightly damaged should be left as they are after necessary conservation measures are taken.
2		Mortar flakes that had peeled off the walls and that are valuable from a design perspective should be re-used.
3		When structural members that cannot be reused are replaced with new ones or repaired, the repair materials and methods should, in principle, be the same as those used when they were originally constructed.
4		If the same type of industrial products are not available as those used originally, the following approaches should be taken.
	a	Damaged items made of industrial goods, such as bricks and tiles, manufactured in almost the same way now as in the past and relatively easily available, should be repaired without causing a big difference in appearance, such as by using supportive members that resemble the original damaged items, to the extent possible.
	b	Steel plates and bars should be repaired using similar products that are available at present, if exactly the same products are difficult to obtain. Items that are valuable in decorative terms may be reproduced by changing the manufacturing methods from the originals (such as by reproducing the shape of a metallic part using milling instead of casting or forging).
	c	The mix proportions of mortar and concrete and the place of origin and composition of the cement and aggregate should be selected with a priority placed on strength, stiffness, and durability. That is, the restorers do not have to stick to the original materials and conditions, except if it is proved they were especially intended for use on these particular buildings during the original construction.
5		If an entire building is severely damaged and the range of refurbishment will extend over a wide area, the preservation of the original structural members of this particular building should be taken into consideration separately.

table 4-2: Repair conditions to be observed and measures to be taken regarding areas with loss of structural strength, and management of their preservation（reference:『重要文化財旧美歎水源地水道施設保存活用計画』、p.55。）

1	The minimum amount of structural reinforcement, if any, should be made, using reversible work methods and giving due consideration to avoiding impairing the design value of the items being repaired.
2	Any changes in work methods and specifications that are required to improve durability should be made after due consideration to avoiding impairing the design value of the items being repaired.

to making patch-repairs of the damaged walls. It was concluded that the selection and mix proportion of the mortar and concrete used for the original construction were almost the same as those being widely used at present and were not specifically chosen for this project. Keeping all these points in mind, the walls of each shed were refurbished with a clear eye on improving durability, using suitable repair methods and materials to conserve the building, while paying attention to retaining the original concrete to the extent possible. However, it was decided that the preservation of original structural members must be discussed separately, as stated in **table 4-1** (5) if it was anticipated that there would be an extensive range of refurbishment because the entire building was severely damaged, and most of the original structural members might be lost.

[Construction information]
Name of the Property: Former Mitani Reservoir Waterwork Facilities
Classification: industrial facility, transportation, engineering work
Period of Construction: early 20th century
Type of Structure: Brick and concrete construction
Cultural Property Classification: Important Cultural Property
Date of Designation: 18 June, 2007
Location: Kokufusho, Tottori City, Tottori
Owner: Tottori City

table 4-3: Comparison of specifications and repair policies applied regarding the refurbishment of intake water control gate sheds
(reference:『重要文化財旧美歎水源地水道施設保存修理工事報告書』p.45)

Item	Former specifications	Specifications for repairs during this refurbishment project		Discussions of the specifications	
		Replacement	Re-use	Repair policies referred to	Overview of discussion
Steel frame (material)	Angles, flats, etc.	Same as before	Left as they were, except for some rebars that were rustproofed after being exposed by chipped concrete.	Table 4-1 (1) Table 4-1 (3)	It was decided to use commercially-available rolled steel in the same shapes as the originals
Steel frame (work method)	Riveting	Welding	Left as they were.	Table 4-1 (1) Table 4-1 (4) (b) Table 4-1 (4) (c) Table 4-2 (2)	The wall concrete was partially chipped away so that it was difficult to rivet the steel frames in the repaired areas. It was decided not to rivet the frames because the sound concrete might be damaged from the impact of riveting and because the design value of the wall would not be impaired if riveting was not used. They decided to join the frames using welding.
Wall	Mortar and concrete	Patch repairing (or the "Refrete" system)	Left as they were after cracks were repaired.	Table 4-1 (1) Table 4-1 (4) (c)	It seemed that the mortar and concrete mix proportion used for the original construction was not a special technique. It was concluded that the wall should be refurbished to improve durability using a new work method, preserving the remaining original concrete to the extent possible.
Wall (lath)	Rhomboid steel lath	Hexagonal SUS lath	Left as they were.	Table 4-1 (1) Table 4-1 (4) (b)	Rhomboid steel lath was not available. It was decided to use steel lath of a similar shape (hexagonal).
Wall finish	Cement wash (original) and mortar coating (subsequent repair projects)	Finish	Not re-used.	Table 4-1 (1) Table 4-2 (2)	It was decided to apply rust-preventive paste over the entire external wall surface, to suppress the carbonation of sound wall concrete that had not been chipped away and eliminate making a difference in thickness between the repaired and original areas. It was also decided to finish the wall using a water-repellent agent with a similar color to that of the original cement.
Roof finish	Cement wash except the No.5 shed (roofing)	Finish	Not re-used.	Table 4-1 (1) Table 4-2 (2)	The roof was also waterproofed, as discussed above. The No. 5 shed roof had been finished with roofing material, not with cement wash as specified for the other sheds (Nos. 1-4). It had undergone the most severe damage. It was decided that No. 5 shed roof should be repaired using the same specification as for the other sheds.

4.5 Hiroshima Memorial Cathedral for World Peace

(1)Issues related to the selection of repair materials and methods - Selection of crack-repair methods

[Background]

Hiroshima Memorial Cathedral for World Peace (hereafter referred to as the "Cathedral") (**Photo 5-1**) was subjected to large-scale external wall refurbishments at two different times in the past (1983 and 2001). The Cathedral was designated as an important cultural property by the Japanese government in 2006. After that, in response to a report that the building was deteriorating and considerably damaged, a conservation and refurbishment project for this reinforced concrete construction was planned. This was the first one since its designation as an important cultural property. The details of the project are given in **figure 5-1**.

Most of the cracks on the surface of the walls of the Cathedral were caused by drying shrinkage of the concrete. Cracks were also found in the concrete at the meeting points between the window frames and the brick walls, due to deformation or cracks that had recurred after a repair made in the past. For this reason, suitable repair methods were selected according to the specific states and types of cracks.

[Overview]

The refurbishment of this important cultural property was conducted during the period from November 2016 to September 2019, with a view to slowing down the progress of cracks as well as improving the appearance of the building. The repair methods used were selected from among those that are presently widely used for repairing cracks in various concrete constructions. In addition, when the repair materials were chosen, their similarity to the original ones and the possibility of the refurbishment's being reversed at some future time were both taken into account. Specifically, most of the cracks were repaired by injecting cement slurry into them under low pressure. Wide cracks in internal walls that required strength (i.e., bearing walls) were repaired by injecting epoxy resin while those in areas that require waterproofness and were covered by some finish were repaired using routing (enlarging

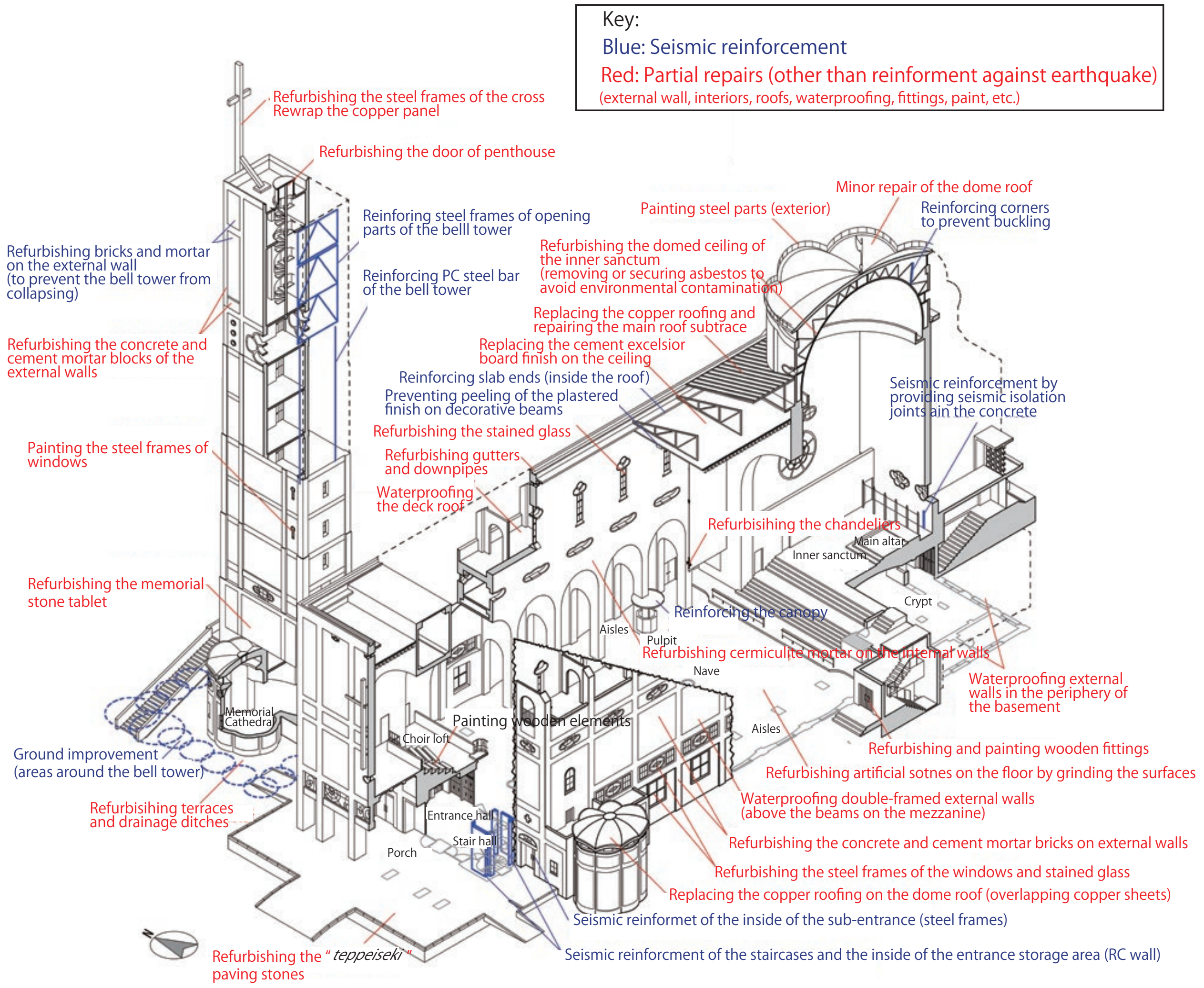

figure 5-1: Details of the refurbishment. Isometric projection of the Cathedral. (figure provided by : The Japanese Association for Conservation of Architectural Monuments)

the cracks and making them U-shaped) and filling them. That is, the propriate repair methods and materials were used in some areas according to the location and purpose of the repairs (**table 5-1**).

At the beginning of this project, it was planned that cracks on the internal walls would be repaired by chipping away the finishing coating around the cracks, or enlarging the cracks into a U-shape, and pressing repair materials into the enlarged grooves made in the substrate or concrete. However, it was found at an early stage of the project that there was almost no difference in the amount of repair materials that could be put into the grooves, whether or not the finishing coating was removed. Therefore, after that realization, the repair project was carried out without removing the finishing coating around the cracks.

The cracks in the external walls of the Cathedral were repaired by injecting cement slurry into them under low pressure, as was done for the repair of most of the cracks in the Cathedral. This was partly because: 1) these external walls were double thickness (**photo 5-2**), with cement mortar bricks. laid in front of an inner layer of concrete; and 2) partly because the cracks were on the whole relatively shallow. On the other hand, the routing and sealing method (enlarging cracks, making them U-shaped and then filling with sealant) was selected as the method for repairing the cracks on the roof slabs beneath the copper sheet roofing. This was because those cracks were wide and with this method they could fill in the cracks almost completely, making it also work well as a waterproofing measure. However, the routing and sealing method requires removing some of existing structural material along the cracks and could lead to the loss of the resemblance of the repaired areas to the original material. This method was therefore only used to repair cracks on the roof slabs in the exterior refurbishment of the Cathedral.

In this refurbishment project, the chief method used to repair cracks was the injection method, in which cement slurry is injected into cracks under low pressure. However, the repair methods and/or materials were changed according to the widths of the cracks, as stated in **table 5-2**. Cracks with a width of 1.0 mm or more were repaired by injecting epoxy resin, with a priority placed on securing strength. Those 0.2 mm or more and less than 1.0 mm wide were repaired by injecting polymer cement slurry.

In addition, cracks in the mortar finish over the metal lath

photo 5-1: HiroshimaMemorial Cathedral for World Peace, Front appearance

photo 5-2: External wall with double thickness (part of external wall mortared bricks removed) (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

table 5-1: Use, utilization and range of crack-repair methods

Work method	Details of method	Reason for use	Area where the method was used
Injection	Injecting cement slurry under low pressure	Cement slurry can be slowly injected into cracks at low pressure using a bond applicator. It makes it possible to inject the repair material deep into cracks.	Most areas of the building
	Injecting ultra-fine polymer cement	Polymer cement can be injected into cracks on concrete surfaces using a sealing gun. The operation is relatively easy and traces of the repair are not very conspicuous. The use of this method is restricted to repairing cracks on the surface of the concrete. Not suitable if the finish layer is thick or the rebar requires strengthening repairs.	Cathedral: Ceiling lath of the inner sanctum (Repaired using mortar)
Routing and sealing	Routing (enlarging cracks and making them U-shaped) and filling with sealant	Cracks are enlarged into the U shape along their exposed faces using a router and a suitable joint sealant is placed in the grooves. This technique leaves conspicuous repair traces. Suitable for areas that can be hidden by finishing or painting after repair.	Areas where waterproofing is needed or the structural members move

of the inner sanctum's ceiling were repaired using three different methods (injecting epoxy resin under lower pressure, injecting ultra-fine polymer cement, and routing and sealing). These are different in their respective characteristics, including strength, the ability to follow structural movements and workability. This was because it was highly likely that cracks might occur later along the rebar inside the concrete after the repairs, but the repaired areas could be made invisible by finishing and they might later be neglected.

It was decided to observe the results of the use of these techniques carefully for a while (**photos 5-3** to **5-7**). In a preliminary investigation performed prior to this refurbishment project, it was noticed that traces of the repairs made in the past using epoxy resin or resin mortar became discolored over time, causing differences in color from unrepaired areas. Therefore, the use of epoxy resin and resin mortar was limited during this refurbishment project to areas that were not exposed directly to ultraviolet rays such as the inner walls. This was done because ultraviolet rays are an important cause of resin discoloration.

[Findings]

Various crack-repair methods and materials were used appropriately during this refurbishment project to suit the specific states of the cracks, in order to slow down the progress of cracks and maintain the appearance of the building. There are many points to be learned from this project, including the effectiveness of the three different crack-repair methods that were put under observation.

(2)Issues related to the selection of repair materials and methods - matching the textures used and the colors of the repair materials with the originals

[Background]

It seems that for the most part the loss and spalling of the concrete that were found on the Cathedral had been caused by rebar corrosion. The loss or spalling of concrete often occurred in such areas as: where the concrete covering the rebar was thin: on beam-column connections, over concrete joints, and where repairs had been made in the past. Moreover, some areas had lost or spalled concrete that seemed to have been caused by improper concrete pouring during the original construction. Some of the Cathedral's external walls were made of undressed concrete. To avoid impairing the design value of these areas, the patch-repair method was used, while due consideration was given to replicate the texture and color of the existing concrete.

[Overview]

Loss and spalling of the Cathedral’s concrete were repaired using both the plastering and injection techniques. The plastering method was used to repair deteriorated areas that were less than 30 mm deep and the injection method for deteriorated areas that were 30 mm or deeper. The repair materials used for each method are given in **table 5-3**.

The plastering method involves the use of polymer cement-based mortar as the repair material. This technique was used for repairing deterioration at depths equivalent to or less than the thickness of the concrete covering the rebar underneath, when the area to be repaired was relatively small.

Table 5-4 shows the work processes and details of each process in the plastering technique.

The existing concrete surfaces of the Cathedral in some areas had a strong yellowish color. These variations in the color of the concrete surface were color matched to the surrounding areas using either of the following two methods: admixing a coloring agent into the repair materials or applying a concrete decorative agent onto the concrete surface after repairing the cracks (**photo 5-8**).

When repairing the Cathedral’s precast concrete and cement mortar bricks, consideration was given to harmonizing the texture of the repaired areas with that of the original areas by adjusting the type, quantity and size of the aggregate (sand) to match the original (**photos 5-9** and **5-10**).

Areas repaired using the plastering method posed the following problems: There was a difference in the concrete surface textures between repaired and original concrete areas, because the aggregate contained in the patch-repaired material used was far smaller than that contained in the concrete used for the original construction; color matching was difficult because the emulsion resin contained in the repair materials tended to make the color darker as it was troweled on repeatedly; and it was necessary to color-match again after cleaning if efflorescence occurred after repair.

The injection technique was used for repairing deterioration extending deeper than the covering concrete's thickness and when the areas to be repaired were relatively wide (**table 5-5**).

table 5-2: Cracks repaired using the injection method

Types of cracks	Repair specification	Remarks
Less than 0.2 mm wide	No repair made	
0.2 mm to less than 0.5 mm wide	Injection of slurry (gray)	Finishing coat was not removed.
0.5 mm to less than 1.0 mm wide	Injection of slurry + rubbing cement onto the surface	Finishing coat was not removed.
1.0 mm or wider	Injection of epoxy resin + rubbing cement onto the surface	Some of the finishing coat was removed before injection. Area was refinish-coated after injection.

photo 5-3: Injecting epoxy resin under low pressure (Ceiling of the inner sanctum) (photo provided by : Shimizu Corporation Hiroshima Branch)

photo 5-4: Injecting ultra-fine polymer cement
(photo provided by : Shimizu Corporation Hiroshima Branch)

photo 5-5: Routing and sealing
(photo provided by : Shimizu Corporation Hiroshima Branch)

photo 5-6: Injecting cement slurry under low pressure (External wall)
(photo provided by : Shimizu Corporation Hiroshima Branch)

photo 5-7: Injecting cement slurry under low pressure (Internal wall)
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

table 5-3: Repair materials used

	Repair material	Name of repair material (supplier)
Plastering	Patch-repair material: Polymer cement-based mortar	MasterEmaco S990 (BASF Japan)
	Cement-based rust-inhibitor for steel bars	MasterEmaco S200 (BASF Japan)
	Pigment: Cement-plaster coloring agent	MAIN (brown and bright yellow)
	Inorganic concrete protection and decorative paint	Erewhon #400 Super (EREWHON SYNTHESIS INDUSTRY)
Injection under pressure	Non-shrink mortar	MasterFlow 870 Grout (BASF Japan)
	Forms	Cedar planks with roughened surfaces

To repair the Cathedral's deteriorated concrete, pouring a repair material into areas to be repaired was once discussed as a promising method and was actually used. However, it posed some problems, such as that the repair material could not be poured precisely onto the target area, cracks occurred after curing, and the wood grain of the timber forms did not show clearly on the concrete surface. It was therefore decided to inject repair material under pressure, instead of just pouring it.

In the injection method, the forms are installed with sheathing boards arranged to produce wood grain patterns resembling those left on the existing concrete. Cedar was selected to make the forms, because it would leave a clear wood grain imprint on the concrete surfaces in the repaired areas (**photo 5-11**). Separators or form ties were not used, in order to avoid leaving tie holes on the concrete surface. Forms were secured from outside, using only pipes or pipe supports to the extent possible, but reinforced using concrete screws when necessary (**photo 5-12**).

After refurbishment using the injection method, the following problems were reported (**photo 5-13**). (1) Leaking mortar: Irregularities on the existing concrete surface produced by small gaps between the formwork and the concrete surface sometimes caused leaks of the poured mortar; (2) Poor filling of mortar: In addition, maybe uneven between an area to be repaired and those surrounding it at the edges where deteriorated concrete has been chipped away. To prevent

table 5-4: Plastering technique work processes and process details

Work process		Process details
1	Visual and sounding inspection	Check for deterioration using a test hammer and mark the deteriorated areas.
2	Chipping away deteriorated concrete	Chip away deteriorated portions using an electric or pneumatic chipping hammer.
3	Applying rust-inhibitor to rebar	Clean rust off the rebar using a disc sander or wire brush. After cleaning, apply rust inhibitor.
4	Color matching ① (selective)	Add appropriate coloring agent to the repair material in advance.
5	Patch-repairing	Trowel repair material into the cracks to fill them. Replicate the original patterns left on the concrete surface by the timber formwork, using a ruler. Finally, finished the concrete surface to match the surrounding areas using a wooden trowel and brush.
6	Color matching ② (selective)	Apply concrete protective and decorative paint with a brush or pieces of sponge to make the repaired areas resemble the surrounding areas.

table 5-5: Injection technique work processes and the details of each process

Work process		Details of the process
1- 3: Same as those for the plastering technique		
4	Installing formwork	Install formwork securely and carefully to an area from which deteriorated concrete has been chipped away, using care to prevent it from coming off during the pouring of the concrete or from expanding inappropriately. Secure the formwork using pipe supports that are in turn tied to the external scaffolding.
5	Patch-repairing cracks	nject non-shrink mortar under pressure. Remove the forms after the cement cures.

photo 5-8: Decorative coat being applied to a repaired area of the concrete (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 5-9: Precast concrete area being repaired
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 5-10: Cement mortar bricks being repaired (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

mortar from leaking from gaps like that, created between the concrete surface and the formwork, at first non-shrink mortar was poured into the deteriorated areas, but the result was unsatisfactory and left some areas poorly filled; and (3) Traces of cement injection ports: The injection method also posed the problem that the traces of the cement injection port left in the repaired area needed to be removed after injection.

[Findings]

In the plastering method used during this refurbishment project, the color matching of concrete surfaces was performed using two methods - admixture of a coloring agent in the repair materials and application of a concrete decorative agent onto the concrete surface after the repair. The relative effectiveness of the two methods was subjected to ongoing observation. This case will provide useful information about the best procedure for color matching concrete when using the plastering method. During patch-repairing, the repaired concrete surface was finished to resemble the original concrete surface surrounding it to the extent possible, using a trowel and brush. The effectiveness of this procedure was also subjected to ongoing observation.

photo 5-11: Surface roughening (embossing) made on a trial basis
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 5-12: Refurbishment using the injection method
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 5-13: A concrete surface from which the form has been removed after refurbishment using the injection method (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

(3)Issues related to structural reinforcement - Provision of seismic isolation slits

[Background]

The seismic performance of the Cathedral was investigated in 2013 and 2014, and it was found that the whole building, including the bell tower, needed to have a seismic retrofit. As a result, a seismic retrofit project, as outlined in **table 5-6**, was conducted.

This project was the very first instance of seismic isolation slits being installed in a nationally designated Important Cultural Property in Japan. The overview and findings of this retrofit project are discussed below.

[Overview]

The west end of the Cathedral building has a piloti (pier-based) construction, which means the building is supported by pillars that leave an open space below the structure. That results in the situation that the Cathedral building is designed so that the volume of the retaining walls is smaller on the west end than on the east end where the inner sanctum is located. This difference in retaining wall volume results in an imbalance in the structural strength of the building and had been a big concern for a long time. Therefore, the west end of the building, including the staircase, entrance storage area,

table 5-6: Major areas which underwent seismic reinforcement

	Details of seismic reinforcement
Bell tower	① Foundation improvement (areas around the bell tower) ② Reinforcement of opening with steel frames ③ Reinforcement with PC steel bars ④ Reinforcement of external wall mortared bricks (to prevent from falling)
Basilica	① Seismic reinforcement of staircase and the inside of entrance storage area (RC walls) ② Seismic reinforcement of the inside of sub-entrance area (steel frames) ③ Reinforcement of canopy ④ Reinforcement of slab edges (attic space) ⑤ Prevention of flaking of plastered beams ⑥ Reinforcement of angles to prevent buckling ⑦ Reinforcement using seismic isolation joints

and sub-entrance, was reinforced to improve earthquake resistance (**photos 5-14, 5-15,** and **5-16**)

The walls and floors of the staircase and entrance storage area were partly dismantled and reinforced, by such steps as adding a new RC wall to the inner layer of the concrete wall behind the cement mortar bricks. The sub-entrance was reinforced by adding new steel reinforcing members to compensate for the wall's small total volume. At the east end of the building, the walls of the inner sanctum and the anteroom were provided with a total of six seismic isolation joints to correct the imbalance of structural strength between the east and west parts of the building (**photos 5-17** and **5-18**). The seismic isolation joint works as a shock absorber and is placed in areas between a column and a wall and above and underneath a beam. Generally, these are provided in order to prevent the columns or beams of a building from being damaged during an earthquake by the side walls, either hanging or spandrel. In this refurbishment project, however, they were mainly used to improve the balance of structural strength of the whole building by reducing the volume of retaining walls at the east side of the building.

During this project's planning stages, a plan had been discussed, as a seismic reinforcement method, to execute large-scale reinforcement of the west side of the building to im-

photo 5-14: RC wall of staircase after reinforcement
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 5-15: Completed rebar arrangement of the entrance storage area's RC wall (photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 5-16: Sub-entrance reinforced with steel frames
(photo provided by : The Japanese Association for Conservation of Architectural Monuments)

photo 5-17: A seismic isolation slits provided in an anteroom wall (indicated by a red arrow)

photo 5-18: Seismic isolation slits provided in the main altar (The slits are now being mortared. They will be finally finished so the installation will not be exposed to view.)

prove the balance of structural strength of the whole building. But this plan was turned down due to a fear of substantially impairing the appearance of the building, and instead the provision of seismic isolation joints was adopted. This was because it was thought this method would minimize changes in appearance while effectively correcting the imbalance of the structural strength of the building.

[Findings]

To redress the imbalance of structural strength of the building, seismic reinforcement was provided using seismic isolation joints, or by reducing the volume of one of the buildings walls, in addition to the conventional reinforcement method of adding to a wall's volume.

The seismic isolation joint method requires removal of some of the sound concrete. Therefore, when refurbishing cultural properties, it is necessary to hold a careful discussion about the use of this method, in order to avoid as much as possible impairing the appearance and value of the structural design and materials.

[Construction information]

Name of the Property: Hiroshima Memorial Cathedral for World Peace
Classification: Religious facility
Completed in: 1954
Type of Structure: Roman basilica with a central nave and two aisles. Reinforced concrete (RC) building with 3 stories above and one below ground, and a bell tower. Copper roofed. With main and sub gates attached.
Building Area: 1,227.67 m^2
Cultural Property Classification: Important Cultural Property
Date of Designation: 5 July, 2006
Location: Naka ward, Hiroshima City, Hiroshima
Owner: Catholic Hiroshima Diocese
Conservation Project Period: Nobember 2016 to September 2019

4.6 Hiroshima Peace Memorial Museum

(1)Issues related to the reproduction of work methods and specifications - Reproduction of work methods

[Background]

The Hiroshima Peace Memorial Museum (hereafter called the "Museum") (Photo 6-1) was completed and opened in 1955, although some of the interior and exterior were not completely finished and the lighting system was insufficient due to a lack of funds. After the opening, most of the portions that had not been fully completed, such as the interior and fixtures, were gradually finished. However, the building was not finished according to the original design. Therefore, a large-scale refurbishment project was conducted in 1990 under the leadership of architect Kenzo Tange. In this refurbishment project, the finishing material applied to the concrete surface of the building during the supplementary construction project that had been performed after the opening of the Museum was removed, at the designer's earnest request, and a new polymer cement finish using a method (hereafter referred to as the "quasi-undressed concrete finish method") in which the wood grain and board patterns of solid wood board formworks were replicated on the original surface of the undressed concrete, using the monolithic technique. In 2006, the quasi-undressed concrete finish coating performed in the 1990 refurbishment project was repaired by the application of a final coat (**photos 6-2**, **6-3**).

In January 2007, the Hiroshima Peace Memorial Museum Refurbishment Plan was announced. It stated the condition of the structure before restoration as: "There are no cracks that threaten the structural integrity of the building or that seriously mar its appearance. Nevertheless, it appears that carbonation has nearly reached the rebar inside the concrete in some areas of this building. At present, the specified and required standard design strength of reinforced concrete constructions is 210 kg/cm^2. However, this building's design strength is 180 kg/cm^2, which was the standard design strength value required at the time when this building was constructed, causing concern about the structural integrity of this building." (The original version of the quoted description has been modified slightly by the author of this present work.) Therefore, during this refurbishment project, the structural resistance of the Museum building was reinforced using base-isolating technology, and deteriorated and damaged concrete in some areas of the building was also repaired. While repairing these parts of the building, the need arose to remove part of the existing quasi-undressed concrete finish from the concrete surface. After the completion of the repair, the quasi-undressed concrete finish was restored. Here is an overview of the removal and restoration processes applied to the existing quasi-undressed concrete finish.

[Overview]

The quasi-undressed concrete finish was removed (**photo 6-4**) and restored in the procedure outlined in **table 6-1**. (These data were prepared on the basis of the results of a field interview survey.)

The removal and restoration of the quasi-undressed concrete finish was carried out by the same restoration company that performed the quasi-undressed concrete finishing during the 1990 refurbishment project, allowing them to keep this finishing technique alive for younger restorers.

The main purpose of applying a quasi-undressed concrete finish during this refurbishment project was to transfer the wood grain design to the surface of the finishing material, i.e., the polymer cement applied over the concrete surface. That is, a wood grain design was transferred to the surface of the polymer cement by pressing three-dimensionally configured wood-grain patterned sheets over the surface of polymer cement that was applied to the concrete surface. Each of these sheets was about 97 mm wide, with a wood grain pattern about 800 mm long, repeated lengthwise over the entire sheet (**photo 6-5**). After removal, such a sheet can be reused about three times if it is washed with water.

Various polymer cement colors were considered before the project to replicate the color of the finished concrete surface. The polymer cement color finally adopted, however, showed changes from row to row of the tiled patterns on the concrete surface. These changes varied according to the number of days that the wood design sheet was left on the concrete surface before being peeled off, and also according to the season in which the polymer cement was applied. Any big changes in color between the tiled patterns on the concrete surface therefore needed to be and were corrected.

[Findings]

The finishing material removed from the concrete surfaces during this refurbishment project was applied when a supplementary construction project was executed after the initial completion of this building. That is, it was not the finishing material used during the building's original construction. This is why that finishing material was removed, with a priority given to the conservation of the original concrete. However, even if this finishing material had been applied originally, there is still a possibility that a different refurbishment method or preservation procedure, at least in terms of this finishing material, would have been used in this refurbishment project.

The Museum designer, Kenzo Tange, had requested the use of the quasi-undressed concrete finish method for the 1990 refurbishment. The question of whether to remove that finishing material posed a very difficult choice for the restorer,

table 6-1: Removal and restoration of a quasi-undressed concrete finish

Removal	1	Roughly chip the finish from the concrete surface using a gouge.
	2	Remove any finish remained on the concrete surface using a sander.
	3	Clean the exposed concrete surface using water under low pressure.
Restoration	4	Apply two coats of a rust inhibitor over the entire concrete surface.
	5	Apply a coat of sealant.
	6	Drive pins into the concrete with a spacing of 500 mm (the "pin-net method" (outer wall improvement system).
	7	Apply polymer cement mortar over the concrete surface.
	8	Apply wood grain patterned sheets over the mortar on the concrete surface.
	9	After the mortar dries, remove the sheets.
	10	Apply a single layer of top coat.


photo 6-1：Exterior, Hiroshima Peace Memorial Museum


photo 6-3: Concrete pillar with a quasi-undressed finish, showing deterioration and damage


photo 6-2: Quasi-undressed concrete finished surface (which received its final coat in 2006)


photo 6-4: Some of the finishing material was removed. (This view shows both the finishing material and the concrete underneath.)

in view of the high value placed on preserving historically important materials to the extent possible. The quasi-undressed concrete finish method has only been used in Japan for the refurbishment of this Museum's concrete. Therefore, one may say that using this refurbishment method for this project was most necessary for achieving the purpose of handing it down to the generations to come, in terms of the preservation and succession of technology.

(2)Issues related to the selection of repair materials and methods – Making the minimal repair necessary

[Background]

This refurbishment project was planned with a priority placed on the preservation of the Museum's original concrete. Prior to the project, a preliminary investigation was performed to investigate the building's state of deterioration and the damage to the concrete by removing the finishing material on the surface. It was found that the concrete was suffering from various levels of deterioration and damage, as well as incorrect placement of concrete. Suitable repair methods were selected for this refurbishment project according to the location and state of deterioration and damage.

[Overview]

When the patch-repair method was used, the concrete deterioration and damage were classified into four levels (shown below) and the minimum amount of patch-repair was performed on these areas, selected according to their classification level.

Levels of concrete deterioration and damage:

① Deteriorated and damaged areas and areas where concrete was placed incorrectly, so as to pose problems with earthquake-resistance
② Some rebar has been lost
③ Some other material has been lost
④ Some rebar is exposed

photo 6-5: Completed quasi-undressed concrete finish

Any deteriorated or damaged concrete within the areas to be finished using the quasi-undressed concrete technique were repaired by pouring concrete or filling with grout using a filling port (**photo 6-6**) if the deterioration or damage was extensive enough to warrant this, or by using the plastering method if the problem was not so extensive.

If a defective area is repaired by re-pouring concrete into a formwork, sufficient ready-mix concrete may not be put into the formwork because there is not enough pressure near the form's concrete filling inlet. To prevent this problem, an overhang is usually provided on the filling inlet and then removed when the formwork is removed. Injection ports were provided in some areas to be repaired for cases where a pump was used to inject concrete into the formwork. The use of a pump to inject concrete was minimized because the volume to be poured in was relatively small and there was a concern that the formwork could be damaged by the pump's pressure.

Areas where rebar was exposed in the lower parts of beams were repaired by installing formwork and then placing grout in the form.

Some areas where the concrete was deteriorated and damaged to the extent that rebar was slightly exposed, and repaired portions that could be hidden later by the application of finishing material were repaired simply by applying a rust inhibitor (**photo 6-7**).

The areas where a rust inhibitor needed to be applied were basically limited to those that were exposed to view. Never-

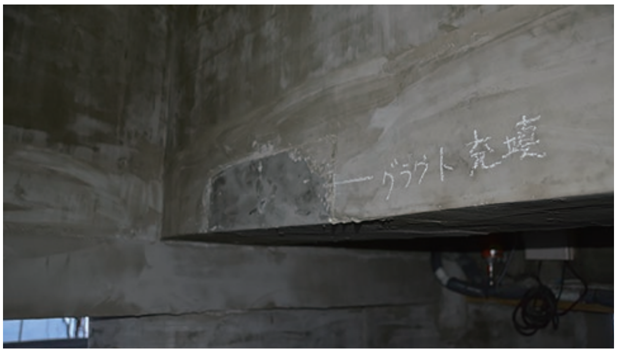

photo 6-6: Beam repaired by filling grout

photo 6-7: Areas where repaired parts could be hidden using a finishing material were treated in such a way that the repaired area could be clearly identified

theless, some areas deemed to substantially affect the structural integrity of the building were repaired using a special rust inhibitor (DS-400: Taiheiyo Techno Corporation) designed for use with the Chipping Refrete system.

The concrete in the lavatories was extensively deteriorated and damaged, and it also was not thick enough to assure structural integrity. These areas were repaired without the installation of new concrete, as follows: The original slab was left as is and was not removed; new steel plates were installed underneath that slab; and then grout was filled in the space between those steel plates and existing concrete (**photo 6-8**).

[Findings]

The Museum building's concrete was suffering from various levels of deterioration and damage.

The minimum amount of repair was performed, depending upon the location and state of deterioration and damage in order to conserve the existing concrete to the extent possible. In particular, areas where repaired parts could be hidden using a finishing material were repaired simply by applying a rust inhibitor in an effort to minimize the amount of intervention as much as possible. That is, even when the degree of deterioration and damage was the same, areas exposed to view and those that could be hidden by a finishing material were repaired using different methods. For this reason, the application of the idea of selecting different repair methods depending upon the location and state of deterioration and damage may make this project a good reference for future cultural property conservation and restoration projects.

photo 6-8: The space between the steel plates and the existing concrete was filled with grout

(3)Issues related to structural reinforcement - Selection of reinforcement methods and conservation of removed structural members

[Background]

The site in which the Museum is located is vulnerable to liquefaction. The seismic resistance of the building, including the individual floors' lack of horizontal load-carrying capacity, had been pointed out long since now, even dating back to the construction of the Museum. In 2011, four structural reinforcement plans (**table 6-2**) were suggested in order to improve the Museum's seismic resistance. In 2012, discussions of the four plans were instituted, to determine which plan was most suited to improving the seismic resistance of the Museum building effectively, in view of the fact that it is such an important cultural property, (**table 6-3**).

[Overview]

The method of reinforcing the structural resistance of the Museum building was discussed, while keeping two points in mind. Those were, it was important to not mar the landscape around the piloti-supported first floor, which is mentioned as one of the reasons for the designation of the building as an important cultural property, and also important to preserve the original concrete to the extent possible. Therefore, it was thought difficult to adopt either the first plan (in which steel braces used as new reinforcing members would be exposed

table 6-2: Details of the structural reinforcement plans

Plan	Method	Location		Features of the method
1st plan	Steel bracing	Upper framework	2nd floor	Additional concrete placed on the existing RC shear walls and the addition of shear walls (t = 200, Fc24), carbon fiber wound around girders and seismic isolation joints provided
			1st floor	Steel bracing with frames
		Lower framework		Addition of underground beams
2nd plan	RC replacement	Upper framework	2nd floor	After dismantling columns, girders and underground beams, new rebar is put in place and new concrete is poured to the same level as it had been (Fc 30).
			1st floor	
		Lower framework		
3rd plan	Seismic vibration control	Upper framework	2nd floor	Additional concrete placed on the existing RC shear walls and the addition of shear walls (t = 200, Fc24), carbon fiber wound around girders and seismic isolation joints provided
			1st floor	Addition of underground beams and provision of vibration control dampers
		Lower framework		
4th plan	Seismic base isolation	Upper framework	2nd floor	Addition of RC shear walls, reinforcement using carbon fibers (showroom and gallery floor) and provision of seismic isolation joints
			1st floor	Installation of new slab
		Lower framework		Addition of underground beams, installation of base isolators: 4 tin rubber bearing isolators, 8 natural rubber bearing isolators, 8 roller bearing isolators and 8 viscous mass dampers

to view on the first floor in the area of the pilotis) or the third plan (in which some of the vibration-control devices are also to be exposed. On the other hand, the second plan consisting of RC replacement requires chipping away the surface of the original concrete. This plan was judged to impair understanding of the original concrete placement technique and its historical value, and it was therefore turned down. More specifically, it was considered that chipping away the existing concrete of a building to enhance its seismic resistance was an inappropriate choice as a measure for reinforcing a monolithic RC building designated as an important cultural property, such as this Museum.

The fourth plan was reinforcement using seismic base-isolation devices. It was thought that this plan had various advantages over the other plans: it damps the force applied to the building during an earthquake; it conserves the pilotis used on

table 6-3: Discussion of structural reinforcement plans

		1st plan: steel bracing	2nd plan: RC replacement	3rd plan: Seismic vibration control	4th plan: Seismic base isolation
Historical value	Material	○	×	○	◎
		2nd floor: Reinforcement of RC shear walls 1st floor (piloti construction): Temporary steel bracing with existing concrete left as is.	Columns and girders are repaired by putting in new concrete so that the existing concrete is lost. The timber frame patterns left on the concrete surfaces are covered up.	2nd floor: Reinforcement of RC shear walls 1st floor (constructed using pilotis): Temporary steel bracing with existing concrete left as is.	2nd floor: Reinforcement of RC shear walls 1st floor: The reinforcement of the upper framework is performed as minimally as possible, with existing concrete left as is.
	Intended purpose of the design	△	△	△	△
		The piloti construction design is lost.	The RC construction technique used immediately after WWII is lost.	Some of the design features of the first floor using pilotis are lost.	The conception of the structural design used to bring this piloti construction to completion is lost.
Design value	Exterior	×	◎	×	◎
		The appearance of the exterior is greatly affected because rebars are exposed to view on the 1st floor.	No change in appearance	The appearance of the exterior is greatly affected because rebars are exposed to view on the 1st floor level.	No change in appearance
	Interior	○	◎	○	◎
		It is possible to perform reinforcement in a way that the appearance of the interior is not affected very much.	The seismic integrity of the building can be further improved by this than by the other plans.	It is possible to provide reinforcement that does not affect the appearance of the interior very much.	This plan mitigates seismic forces more than the other plans do. It minimizes the amount of reinforcement.
	Site and other	×	◎	×	△
		Affects the use of the site's landscape as a park: The integration of the building with surrounding areas and the sense of the openness of the first floor using pilotis are lost.	No particular effects on design value.	Affects the use of the site's landscape as a park: The integration of the building with surrounding areas and the sense of the openness of the first floor using pilotis are lost.	Expansion joints are needed at the connections between ground level and connecting corridors.
Reversibility of measures taken		○	×	○	○
		The reinforcement is installed on a temporary basis so that it can be removed without dismantling the building.	Original concrete is lost.	The reinforcement is installed on a temporary basis so that it can be removed without dismantling the building.	Additional reinforcing members on the ground level can be removed without dismantling the building.
Safety		△	△	△	◎
		During a major earthquake, there is a danger that the building may be somewhat damaged, but no danger of collapsing.	During a major earthquake, there is a danger that the building may be somewhat damaged, but no danger of collapsing.	During a major earthquake, there is a danger that the building may be somewhat damaged, but no danger of collapsing.	The building will suffer almost no damage during a major earthquake.
Total evaluation		×	×	×	○
		There is a problem with the preservation of design value.	There is a problem with the preservation of historical value.	There is a problem with the preservation of design value	This method has less impact on the design and historical value of the building than the other methods do. Sufficient safety is assured against earthquakes.

the first floor; the repair gives a priority to the conservation of the original concrete; the load on deteriorated areas inside the building which is difficult to identify is alleviated; and it conserves the original concrete (including the original concrete placement technique and material as well as the design).

It was originally planned that the quadruple foundation p**hoto 6-9**) underneath the lower edge of the staircase would be removed and discarded following the installation of base-isolation devices. However, it was decided to conserve them by reburying them underground outside the base-isolation areas for safekeeping their technological and material value. **Table 6-4** shows the recording and preservation processes performed in dismantling the building's foundation.

[Findings]

Four structural reinforcement plans for the Museum building were discussed for the purpose of improving the Museum's seismic resistance. Of the four plans, the seismic base-isolation method was selected on the basis of the thought that it was important to conserve the design value, including the piloti-construction, and to preserve the original concrete to the extent possible. Some parts of the foundation which were scheduled to be removed and discarded following the installation of base-isolation devices in the original plan were instead conserved separately in another place after they were studied and the results of the study were recorded.

This type of approach may be a helpful example of how to handle the structural members of a cultural property building that may need to be sacrificed during the performance of a structural reinforcement.

photo 6-9: The quadruple foundation elements were removed for underground preservation

[Construction information]
Name of the Property: Hiroshima Peace Memorial Museum
Classification: Cultural facility
Completed in: 1955
Building Area: 1,351.06 m^2
Type of Structure: Reinforced concrete (RC) building with 2 stories (and a small third story)
Cultural Property Classification: Important Cultural Property
Date of Designation: 5 July, 2006
Location: Naka ward, Hiroshima City, Hiroshima
Owner: Hiroshima City

4.7 Re-alkalization method

(1)Issues related to maintenance - Monitoring the re-alkalization method

[Background]

The re-alkalization method first came to be used in Japan in 1992. Among RC buildings designated or registered as cultural properties, the re-alkalization method was used to repair the main tower of Osaka Castle in 1993, Umekoji Locomotive House in 2015, and the Hiroshima Peace Memorial Museum in 2018. The re-alkalization method was used specifically to repair the carbonated concrete areas of these RC constructions, as reviewed here. The eaves and soffits and the external walls of the main tower of the Osaka Castle were repaired because harm could come to visitors from dislodged pieces of concrete. One column of the Umekoji Locomotive House was repaired using re-alkalization (on a trial basis) and two columns of the Hiroshima Peace Memorial Museum were repaired using the technique, also on a trial basis. At both the Umekoji Locomotive House and the Hiroshima Peace Memorial Museum where the method was tried, the repaired columns were subjected to regular observation to monitor the effects of re-alkalization, because there was a possibility the method might be used in subsequent refurbishment projects.

Here is an overview of the re-alkalization method and the progress of monitoring being performed at the Umekoji Locomotive House three years after the repair was undertaken.

[Overview]

Tables 7-1 and **7-2** show details of the preliminary investigation, pre-treatment and actual procedures of the re-alkalization method. The explanation of some processes is supplemented by photos (**photos 7-1** to **7-6**).

The column of the Umekoji Locomotive House that was

table 6-4: Recording and preservation of historically important information

1	After excavating the ground, the restorers investigated the state of the building and recorded their findings before and after dismantling the foundation and after reinforcement.
2	The concrete placement techniques used for the original construction of the Museum, such as the rebar arrangement method, were investigated and recorded.
3	Some of the concrete and rebar that would need to be removed were cut away and conserved. Material samples of the quadruple foundation were taken.

table 7-1: Preliminary investigation and pre-treatment performed before re-alkalization

Steps in the process	Details of the steps
1	Take a core sample from the area to be re-alkalized to determine the depth of carbonation.
2	Take another core sample from the area to be re-alkalized to measure the residual expansion of the concrete affected by AAR (the Canadian method) and ensure that there is no reactive aggregate in the core.
3	Set up scaffolds and a re-alkalization plant.
4	Make temporary electricity and water supply facilities available.
5	Remove finishing or coating, if any, from the concrete surface.
6	Patch-repair any deteriorated concrete, including any spalling, scaling, or rock pockets, using polymer mortar. * Use the patch-repair material that has been successfully used for the re-alkalization method in the past.
7	Repair cracks in the concrete (only those thought likely to impede the implementation of re-alkalization)
8	Prepare the concrete surface appropriately for the passage of electricity (i.e., removing foreign matter, insulation, and curing).

table 7-2: Re-alkalization process

1	Set up internal electrodes	
	-1	Locate the rebar inside the concrete using a rebar locator. (Use one internal electrode for each area of about 20 to 30 m2)
	-2	Chip away the concrete and expose the rebar in each area to be re-alkalized.
	-3	Polish the exposed rebar, wind lead wires around it to secure them in place.
	-4	After connecting the leads to the rebar, replace the previously removed concrete with polymer mortar.
	-5	If a number of internal electrodes are needed to serve the area to be re-alkalized, ensure that there is continuity among the electrodes. If the electrical resistance of the concrete is too high to energize some areas, increase the number of electrodes and check the continuity among them again. Keep installing electrodes until the whole area is electrified and continuity is assured.
2	Set up temporary anodes	
	-1	Arrange batten cleats on the surface of the concrete to be re-alkalized, maintaining the prescribed spacing, and secure them in place using plastic anchor bolts.
	-2	Attach external electrodes (in the form of steel mesh) onto the batten cleats.
	-3	Connect the external electrodes with wires that connect all the parts of each group to the same power supply unit and then connect them all to a single lead wire.
	-4	Connect the lead wires to the steel mesh (one wire for each area of about 10 m2)
3	Arrange the connection to the electrical supply	
	-1	Install a converter and a branch box in a specified place. Wire between the primary side, the converter and the branch box.
	-2	Connect the lead wire from the rebar inside the concrete to the negative output terminal of the converter.
	-3	Connect the lead wire from the external electrodes to the positive output terminal of the converter.
4	Spray cellulose fibers and electrolytic solution	
	-1	Prepare an electrolytic solution of the specified concentration using potassium carbonate and water.
	-2	Impregnate the cellulose fibers with an electrolytic solution of the specified concentration and spray the cellulose fibers impregnated with the electrolytic solution on the external electrodes using a sprayer.
5	Apply electric current and spray on the solution	
	-1	Apply about 1 A of direct current /m2 (of the concrete surface) for 14 days.
	-2	Throughout the period during which the direct current is being applied, spray the electrolytic solution over the concrete surface as needed to prevent the cellulose fibers from drying out. At the Umekoji Locomotive House, the electrolytic solution was sprayed once a day. Verify that the electric current continues to flow, and record the amount.
6	Check the effectiveness of the re-alkalization	
	-1	After the end of electrification period, take a core sample of the concrete from the areas subjected to re-alkalization and check whether the concrete has been sufficiently re-alkalized, using the phenolphthalein method, or otherwise verify that the carbonation depth is zero.
7	Remove the re-alkalization setup.	
	-1	Remove all temporary anodes and current application materials.
	-2	Clean away all adherents, including cellulose fibers, from the concrete surface, using an appropriate cleaning device such as a sander.
	-3	The temporary materials that are removed must be disposed of as industrial waste.

repaired using the re-alkalization method is being monitored with the spontaneous potential (SP) method, in which the potential of the rebar inside the concrete is checked to estimate the probability that the concrete around the rebar, including the concrete covering the rebar, has suffered from corrosion. Generally speaking, there are several methods for monitoring the effectiveness of re-alkalization, as shown in **table 7-3**. The spontaneous potential and polarization resistance measurement methods are the only available non-destructive ones. The spontaneous potential measurement method is usually selected because of the easy availability of the measurement device (**photos 7-7** to **7-9**).

The spontaneous potential method measures changes in the electrical potential of rebar inside concrete.

The potential of the rebar changes notably if the environment around the rebar becomes corrosive due to carbonation of or chloride attack upon the concrete. This method estimates the level of corrosion at measured areas, based on the degree of these changes in potential. The evaluation of rebar corrosion is performed according to established criteria published in ASTM C 876 (Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete) (**table 7-4**).

During the monitoring of the Umekoji Locomotive House project (**table 7-5**), the average potential values were -234 mV at 24 months after the end of re-alkalization and -239 mV at 36 months, meaning that the evaluation of rebar corrosion remained uncertain. The field restorer said that it is ideal for the average potential value to return to -200 mV or more positive; but, if the value levels off at around -230 mV, it is necessary to keep monitoring for changes in the corrosive environment in the concrete, using that value as the standard for comparison against later changes. It is now believed that, since there

photo 7-1: Internal electrode set up inside the concrete
(photo provided by : West Japan Railway Company)

photo 7-2: Temporary anodes installed on the concrete surface
(photo provided by : West Japan Railway Company)

photo 7-3: Sprayed-on cellulose fibers
(photo provided by : West Japan Railway Company)

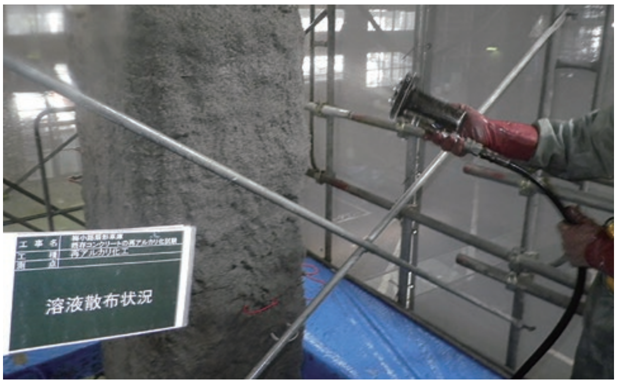

photo 7-4: Spraying on the electrolytic solution
(photo provided by : West Japan Railway Company)

photo 7-5: Appearance after removal of the re-alkalization setup
(photo provided by : West Japan Railway Company)

photo 7-6: Current appearance of a column undergoing re-alkalized in this project (photo provided by : West Japan Railway Company)

have been no big changes in average potential for some time, it can be concluded that the environment inside the concrete is being maintained in a non-corrosive state.

[Findings]

It is necessary to keep in mind the following points, when trying to re-alkalize RC buildings designated as cultural properties:

1. The technique requires making a hole, at least about 100 mm^2, for each area to be re-alkalized, which is used for installing an internal electrode.
2. Finishing material must be removed from the concrete surface before the implementation of re-alkalization.

photo 7-8: Spontaneous potential measurement
(photo provided by : West Japan Railway Company)

photo 7-7: Water being sprayed before monitoring
(photo provided by : West Japan Railway Company)

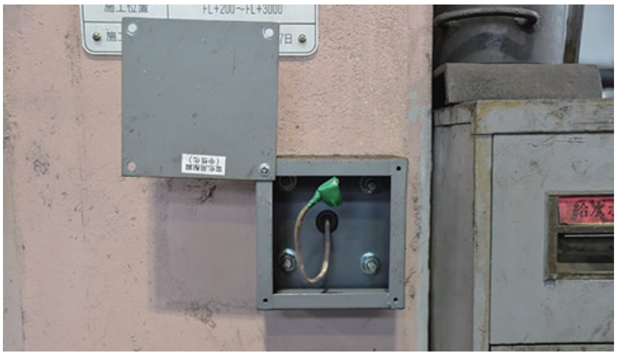

photo 7-9: Wiring for the internal electrodes left for monitoring purposes

table 7-3: Monitoring the re-alkalization method

Monitoring method		Details of the method	Suitability for monitoring
1	Phenolphthalein method	Break a core sample to measure the depth of carbonation by examining the color.	It is possible to measure the depth of carbonation directly, but this requires the collection of core samples. This phenolphthalein method was adopted for use only before and after a re-alkalization session, but not for monitoring.
2	Drilling method	Collect three core samples. Make a hole, 15 mm deep（ in a specified position for each core sample using a drill. Insert a PH meter into the hole and drip in pure water so you can measure the pH value of the water.	Not suitable: The collection of core samples is required.
3	Powder method	Collect three core samples. Make a hole, 15 mm deep, in a specified position for each core sample using a drill, as discussed above. Collect the concrete powder drilled out of the hole. Put the powder and pure water in a container. Leave it to stand for the specified length of time before measuring its pH.	Not suitable: The collection of core samples is required.
4	Measurement of potassium content	Collect three core samples. Measure the amount of potassium contained in each core sample.	Not suitable: The collection of core samples is required.
5	Spontaneous potential (SP) of the rebar	Measure the spontaneous potential (SP) of the rebar using the electrodes used for passing the electric current. Check the rebar's changes in resistance.	Suitable: It is possible to measure the potassium content without damaging the existing concrete.
6	Polarization resistance of the rebar	Measure the polarization resistance right above the rebar using the alternative current anodizing method.	Not suitable: The measuring device needed is not generally and easily available. It seems likely it will be difficult to obtain one dependably, even for years to come.
For the drilling and powder methods, refer to the following document: "Follow-up investigation of the re-alkalization method for about 10 years after the start of implementation" T. Nomura, S. Aramaki, et al.: Proceedings of the Repair, Reinforcement, and Upgrading of Concrete Structures, vol. 4. 2004.			

table 7-4: Evaluation of rebar corrosion according to ASTM C876

Spontaneous potential	Rebar corrosion evaluation
E ≧ -200mV	The probability of “no corrosion present” is 90% or greater
-200 ＞ E ≧ -350mV	Uncertain
-350mV ≧ E	The probability of “corrosion present” is 90% or greater

table 7-5：Average potential value of Umekoji Locomotive House

before re-alkalization	After re-alkalization	1 month after	3 months after	6 months after	12 months after	24 months after	36 months after
-100mv	-1344mV	-387mV	-307mV	-305mV	-278mV	-234mV	-239mV

3. It is necessary to take core samples before and after re-alkalization to check the condition of the concrete.
4. Re-alkalization can only be used in areas where the concrete covering the rebar is 150 mm in thickness, at the most.
5. Sufficient effectiveness of re-alkalization may not be obtained if the repair materials used are quite resistant to electrical current flow; this includes insulating materials.
6. The color and texture of re-alkalized concrete changes. The concrete surfaces of cultural property buildings subjected to re-alkalization up to this time have been coated with a finishing material, so changes in color and texture did not matter too much.

[Construction information]
Name of the Property: Main Tower of Osaka Castle
Category 1: Culture and Welfare
Category 2: Building
Type of Structure: Reinforced concrete construction, with 8 stories
Building Area: 1,199 m^2
Date on which Registration was Announced to the Public: 16 September, 1997
Date of Registration: 3 September, 1997
Location: Osakajo, Chuo Ward, Osaka City, Osaka
Owner: Osaka City

Name of the Property: Umekoji Locomotive House
Classification: industrial facility, transportation, engineering work
Type of Structure: Reinforced concrete construction with a fan-shaped garage, including an electric-powered overhead traveling crane and a siding
Cultural Property Classification: Important cultural property
Date of Designation: 10 December, 2004
Owner: West Japan Railway Company

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Former Yamamura Family Residence (Yodoko Guest House)
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佐々木明博氏（株式会社大林組広島支店広島平和記念資料館工事事務所）

Former Shime Coal Mine Shaft Tower
徳永博文氏（志免町社会教育課）
伊奈仁氏（公益財団法人文化財建造物保存技術協会事業部設計室設計課）

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Appendix - 1. List of Nationally Designated / Registered Concrete Structures

Name of Property	Name of Structure	Classification	Year of Construction	Structure and Classification	Date of Designation	Location
Important Cultural Property						
旧手宮鉄道施設 Former Temiya Railway Facilities	貯水槽 Water Tank	industrial facility, transportation, engineering work	before 1916	brick masonry and concrete	2001.11.14	Otaru City, Hokkaido
	転車台 Turntable	industrial facility, transportation, engineering work	1919	steel with concrete pit	2001.11.14	Otaru City, Hokkaido
大谷派本願寺函館別院 Otani-ha Branch Hongan-ji Temple Hakodate Branch Temple	本堂 Worship Hall	religious facility	1915	reinforced concrete	2007.12.4	Halodate City, Hokkaido
	鐘楼 Belfry	religious facility	early Taisho era	reinforced concrete	2007.9.12.4	Halodate City, Hokkaido
	正門 Main Gate	religious facility	early Taisho era	single-bay shikyaku-mon gate, reinforced concrete	2007.12.4	Halodate City, Hokkaido
小岩井農場施設 Koiwai Farm Facilities	第一号牛舎 Cattle Barn No. 1	industrial facility, transportation, engineering work	1934	wood frame, reinforced concrete and wood frame（with silo on north side）	2017.2.23	Shizukuishi Town, Iwate
	第二号牛舎 Cattle Barn No. 2	industrial facility, transportation, engineering work	1908	wood frame, reinforced concrete and wood frame（with silo on north side）	2017.2.23	Shizukuishi Town, Iwate
	第四号牛舎 Cattle Barn No. 4	industrial facility, transportation, engineering work	1908	wood frame, reinforced concrete and wood frame（with silo on north side）	2017.2.23	Shizukuishi Town, Iwate
藤倉水源地水道施設 Fujikura Reservoir Waterworks Facilities	堰堤 Dam	industrial facility, transportation, engineering work	1911	gravity concrete dam	1993.8.17	Akita City, Akita
	放水路 Floodway	industrial facility, transportation, engineering work	1911	concrete	1993.8.17	Akita City, Akita
旧池田家住宅洋館 Former Ikeda Family Residence Western-style Residence		residence	1922	reinforced concrete	2017.11.28	Daisen City, Akita
横利根閘門 Yokotone Lock		industrial facility, transportation, engineering work	1921	lock: stone masonry, brick masonry, and concrete lock, approach wall: brick masonry and concrete	2000.5.25	Inashiki City, Ibaraki
石岡第一発電所施設 Ishioka First Power Plant Facilities	取水堰堤 Intake Weir	industrial facility, transportation, engineering work	around Taisho era	reinforced concrete	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	沈砂池 Settling Basin	industrial facility, transportation, engineering work	1911	reinforced concrete	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	第一号水路橋 First Aqueduct	industrial facility, transportation, engineering work	1911	reinforced concrete single-arched bridge	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	第二号水路橋 Second Aqueduct	industrial facility, transportation, engineering work	1911	reinforced concrete single-arched bridge	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	水槽余水路 Cistern Spillway	industrial facility, transportation, engineering work	1911	stone masonry and reinforced concrete	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	調圧水槽 Pressure Controlling Cistern	industrial facility, transportation, engineering work	1911	reinforced concrete cylindrical cistern	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	本館発電機室 Main Building Dynamo Hall	industrial facility, transportation, engineering work	1911	reinforced concrete	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	本館旧変圧器室 Main Building Former Transformer Hall	industrial facility, transportation, engineering work	1911	reinforced concrete	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki
	本館変電室 Main Building Substation Hall	industrial facility, transportation, engineering work	1916	reinforced concrete	2008.12.2	Takahaghi City and Kitaibaraki City, Ibaraki

Name of Property	Name of Structure	Classification	Year of Construction	Structure and Classification	Date of Designation	Location
丸沼堰堤 Marunuma Dam		industrial facility, transportation, engineering work	1931	buttressed reinforced concrete dam, water conveyance channels, with concrete retaining wall upstream and stone masonry retaining wall on left bank downstream	2003.12.25	Katashina Village, Gunma
旧碓氷峠鉄道施設 Former Usui Pass Railway Facility	旧丸山変電所蓄電池室 Machine Room of Former Maruyama Substation	industrial facility, transportation, engineering work	1911	brick masonry, steel frame reinforced concrete（with subsidiary structure on back）	1994.12.27	Annaka City, Gunma
	熊ノ平変電所本屋 Kumanotaira Substation Main Building	industrial facility, transportation, engineering work	1937	reinforced concrete	2018.8.17	Annaka City, Gunma
旧遠山家住宅 Former Tōyama Family Residence	土蔵 Earthen Storehouse	residence	1934	reinforced concrete and earthen-walled, building area 67.12 ㎡, 2-stories with basement, concave and convex roof tiles	2018.8.17	Kawajima Town, Saitama
旧遠山家住宅 Former Tōyama Family Residence	裏門及び外塀 Back Gate and Outer Wall	residence	昭和 11 頃	reinforced concrete（to north and south of Back Gate and to east of nagaya-mon gate building）	2018.8.17	Kawajima Town, Saitama
明治生命保険相互会社本社本館 Meiji Life Insurance Company Main Building		commercial and business facility	1934	steel frame reinforced concrete	1997.5.29	Chiyoda Ward, Tokyo
三井本館 Mitsui Main Building		commercial and business facility	1929	steel frame reinforced concrete	1998.12.25	Chuo Ward, Tokyo
旧東京帝室博物館本館 Former Imperial Museum Main Building		cultural facility	1937	steel frame reinforced concrete	2001.6.15	Taito Ward, Tokyo
旧朝倉家住宅 Former Asakura Family Residence	土蔵 Earthen Storehouse	residence	ca. 1919	reinforced concrete and wood frame	2004.12.10	Shibuya Ward, Tokyo
旧渋沢家飛鳥山邸 Former Shibusawa Family Asukayama Residence	青淵文庫 Seien Bunko Library	residence	1925	brick masonry and reinforced concrete	2005.12.27	Kita Ward, Tokyo
清洲橋 Kiyosu-bashi Bridge		industrial facility, transportation, engineering work	1928	3-span steel stiffened suspension bridge, including 2 reinforced concrete bridge piers and 2 reinforced concrete bridge abutments	2007.6.18	Chuo Ward, Tokyo
永代橋 Eitai-bashi Bridge		industrial facility, transportation, engineering work	1926	3-span steel cantilevered tied-arch bridge, including 2 reinforced concrete bridge piers and 2 reinforced concrete bridge abutments	2007.6.18	Chuo Ward, Tokyo
勝鬨橋 Kachidoki-bashi Bridge		industrial facility, transportation, engineering work	1940	steel frame drawbridge, 2 reinforced concrete bridge piers（including 4 bridge pier towers）, 2 reinforced concrete bridge abutments	2007.6.18	Chuo Ward, Tokyo
早稲田大学大隈記念講堂 Waseda University Okuma Memorial Hall		educational facility	1927	steel frame reinforced concrete with reinforced concrete clock tower	2007.12.4	Shinjuku Ward, Tokyo
旧三河島汚水処分場喞筒場施設 Former Mikawajima Sewage Treatment Plant Pump Facilities	阻水扉室 East and West Sluice Gate Chambers	industrial facility, transportation, engineering work	1921	reinforced concrete, with reinforced concrete shed	2007.12.4	Arakawa Ward, Tokyo

Name of Property	Name of Structure	Classification	Year of Construction	Structure and Classification	Date of Designation	Location
旧三河島汚水処分場喞筒場施設 Former Mikawajima Sewage Treatment Plant Pump Facilities	沈砂池及び濾格室 East and West Grit Chambers and Screen Rooms	industrial facility, transportation, engineering work	1921	concrete	2007.12.4	Arakawa Ward, Tokyo
	濾格室上屋 Screen Room Shed	industrial facility, transportation, engineering work	1921	reinforced concrete	2007.12.4	Arakawa Ward, Tokyo
	量水器室及び喞筒室暗渠 Water Meter Chamber and Pump Chamber Culvert	industrial facility, transportation, engineering work	1921(Pump Chamber Culvert)、1923 (Water Meter Chamber)	reinforced concrete（Water Meter Chamber, Water Conveying Channel, Sluice Gate Chamber, Pump Pool and Culvert connecting to Pump Chamber）, reinforced concrete with cistern, steel cylindrical pipe and manhole	2007.12.4	Arakawa Ward, Tokyo
	喞筒室 Pump Chamber	industrial facility, transportation, engineering work	1921	steel frame and reinforced concrete, with 2 reinforced concrete girder bridges	2007.12.4	Arakawa Ward, Tokyo
国立西洋美術館本館 The National Museum of Western Art Main Building		cultural facility	1959	reinforced concrete	2007.12.21	Taito Ward, Tokyo
旧東京科学博物館本館 Former Tokyo National Museum of Nature and Science Main Building		cultural facility	1931	reinforced concrete, partially steel frame reinforced concrete	2008.6.9	Taito Ward, Tokyo
髙島屋東京店 Takashimaya Tokyo Department Store		commercial and business facility	1933 1954	steel frame reinforced concrete	2009.6.30	Chuo Ward, Tokyo
聖徳記念絵画館 Meiji Memorial Picture Gallery		cultural facility	1926	reinforced concrete	2011.6.20	Shinjuku Ward, Tokyo
明治神宮宝物殿 Meiji Jingu Homotsuden Treasure Museum	中倉 Middle Storehouse	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
	東西倉（2 棟） East and West Storehouses (2 structures)	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
	東西廊（2 棟） East and West Corridors (2 structures)	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
	東西橋廊（2 棟） East and West Bridge Corridors (2 structures)	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
	東西渡廊（2 棟） East and West Connecting Corridors（2 structures)	cultural facility	1921	stone masonry and reinforced concrete girder bridge	2011.6.20	Shibuya Ward, Tokyo
	北廊 North Corridor	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
	車寄 Car Portico	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
	事務所 Office	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
	正門 Main Gate	cultural facility	1921	reinforced concrete	2011.6.20	Shibuya Ward, Tokyo
旧前田家本邸 Former Maeda Family Main Residence	洋館 Western-style Residence	residence	1929	reinforced concrete	2013.8.7	Meguro Ward, Tokyo
	洋館渡廊下 Western-style Residence Connecting Corridor	residence	1930	reinforced concrete	2013.8.7	Meguro Ward, Tokyo
	門衛所 Guard House	residence	1929	reinforced concrete	2013.8.7	Meguro Ward, Tokyo
	正門及び塀 Main Gate and Wall	residence	1929	reinforced concrete	2013.8.7	Meguro Ward, Tokyo

Name of Propery	Name of Structure	Classification	Year of Construc-tion	Structuree and Classification	Date of Designa-tion	Location
尊經閣文庫 Sonkeikaku Library	図書閲覧所 Reading Hall	cultural facility	1928	reinforced concrete, partially wood frame and steel frame	2013.8.7	Meguro Ward, Tokyo
	書庫 Book Vault	cultural facility	1928	reinforced concrete	2013.8.7	Meguro Ward, Tokyo
	貴重庫 Treasure House	cultural facility	1928	reinforced concrete	2013.8.7	Meguro Ward, Tokyo
	門及び塀 Gate and Wall	cultural facility	1928	reinforced concrete	2013.8.7	Meguro Ward, Tokyo
築地本願寺本堂 Tsukiji Hongwan-ji Worship Hall		religious facility	1934	reinforced concrete, partially steel frame reinforced concrete	2014.12.10	Chuo Ward, Tokyo
旧朝香宮邸 Former Residence of Prince Asaka（Tokyo Metropolitan Teien Art Museum)	本館 Main Building	residence	1933	reinforced concrete	2015.7.8	Minato Ward, Tokyo
	倉庫 Storehouse	residence	1933	reinforced concrete	2015.7.8	Minato Ward, Tokyo
	自動車庫 Garage	residence	1933	reinforced concrete	2015.7.8	Minato Ward, Tokyo
	正門 Main Gate	residence	1933	reinforced concrete	2015.7.8	Minato Ward, Tokyo
三越日本橋本店 Mitsukoshi Nihonbashi Department Store		commercial and business facility	1927	steel frame reinforced concrete	2016.7.25	Chuo Ward, Tokyo
横浜市開港記念会館 Yokohama Port Opening Memorial Hall		cultural facility	1917	brick masonry・steel-frame brick masonry and reinforced con-crete	1989.9.2	Yokohama City, Kanagawa
旧横浜船渠株式会社第一号船渠（ドック） Yokohama Dock Company, Ltd. No. 1 Dock		industrial facility, transportation, engi-neering work	1898	stone masonry, brick masonry and concrete dry dock	2000.12.4	Yokohama City, Kanagawa
国道一号箱根湯本道路施設 National Highway Number One Ha-kone-Yumoto Roadway Facilities	函嶺洞門 Kanrei-Domon Tunnel	industrial facility, transportation, engi-neering work	1931	reinforced concrete	2015.7.8	Hakone Town, Kanagawa
	千歳橋 Chitose-bashi Bridge	industrial facility, transportation, engi-neering work	1930	reinforced concrete single-arched bridge	2015.7.8	Hakone Town, Kanagawa
	旭橋 Asahi-bashi Bridge	industrial facility, transportation, engi-neering work	1933	reinforced concrete single-arched bridge	2015.7.8	Hakone Town, Kanagawa
萬代橋 Bandai-bashi Bridge		industrial facility, transportation, engi-neering work	1929	reinforced concrete 6-arched bridge, rein-forced concrete side spans and newel posts and bridge railing	2014.7.6	Niigata City, Niigata
旧佐渡鉱山採鉱施設 Former Sado Mine Mining Facilities	大立竪坑櫓 Odate Vertical Shaft	industrial facility, transportation, engi-neering work	1940	steel shaft, with concrete foundation and openings for steel cables	2012.12.28	Sado City, Niigata
	大立竪坑捲揚機室 Odate Vertical Shaft Winch House	industrial facility, transportation, engi-neering work	1940	reinforced concrete, stone masonry with concrete shaft opening	2012.12.28	Sado City, Niigata
	道遊坑及び高任坑 Doyu and Takato Mine Tunnels	industrial facility, transportation, engi-neering work	明治開削、ca. 1940	stone masonry and concrete mine tunnels	2012.12.28	Sado City, Niigata
	高任粗砕場 Takato Crushing Plant	industrial facility, transportation, engi-neering work	1937	steel frame, with con-crete foundation	2012.12.28	Sado City, Niigata
	高任貯鉱舎及びベルトコンベアヤード Takato Ore Storage House and Belt Conveyer Yard	industrial facility, transportation, engi-neering work	1938	steel frame and rein-forced concrete（Ore Storage House）	2012.12.28	Sado City, Niigata
富岩運河水閘施設（中島閘門） Fugan Canal Lock Gate Facilities (Nakajima Lock Gate)	閘門 Lock Gate	industrial facility, transportation, engi-neering work	1934	concrete and reinforced concrete lock gate	1998.5.1	Toyama City, Toyama
	放水路 Floodway	industrial facility, transportation, engi-neering work	1934	stone masonry and reinforced concrete floodway	1998.5.1	Toyama City, Toyama

Name of Property	Name of Structure	Classification	Year of Construc-tion	Structure and Classification	Date of Designa-tion	Location
常願寺川砂防施設 Joganji-gawa River Erosion Control Facili-ties	白岩堰堤 Shiraiwa Dam	industrial facility, transportation, engi-neering work	ca.1919-1939	gravity concrete dam（main dam, subsidiary dam）, concrete bed sill, reinforced concrete latticed retaining wall	2009.6.30	Toyama City, Toyama
	本宮堰堤 Hongu Dam	industrial facility, transportation, engi-neering work	1936	gravity concrete dam（Main Dam, Former First Subsidiary Dam）	2017.11.28	Toyama City, Toyama
	泥谷堰堤 Dorodani Dam	industrial facility, transportation, engi-neering work	1931-1932	gravity concrete dam (First to Nineteenth Dam), concrete bed sill（First Bed Sill to Third Bed Sill）	2017.11.28	Toyama City, Toyama
永平寺 Eihei-ji Temple	大庫院 Priest's Quarter	religious facility	1929	reinforced concrete and wood frame	2019.9.30	Eiheiji town, Fukui
八ツ沢発電所施設 Yatsusawa Power Plant Facilities	取水堰堤 Intake Dam	industrial facility, transportation, engi-neering work	1912	stone masonry and concrete dam	2005.12.27	Otsuki City, Ya-manashi
	取水口制水門 Intake Control Gate	industrial facility, transportation, engi-neering work	1912	stone masonry, a series of 4 intake control gates of brick masonry and concrete	2005.12.27	Otsuki City, Ya-manashi
	取水口沈砂池 Intake Settling Basin	industrial facility, transportation, engi-neering work	1912	stone masonry, brick masonry, and concrete	2005.12.27	Otsuki City, Ya-manashi
	第一号隧道 First Tunnel	industrial facility, transportation, engi-neering work	1912	concrete tunnel	2005.12.27	Otsuki City, Ya-manashi
	第一号開渠 First Open Culvert	industrial facility, transportation, engi-neering work	1912	stone masonry, brick masonry, and concrete	2005.12.27	Otsuki City, Ya-manashi
	第二号隧道 Second Tunnel	industrial facility, transportation, engi-neering work	1912	concrete tunnel	2005.12.27	Otsuki City, Ya-manashi
	第一号水路橋 First Aqueduct	industrial facility, transportation, engi-neering work	1912	reinforced concrete single-arched bridge	2005.12.27	Otsuki City, Ya-manashi
	第三号隧道 Third Tunnel	industrial facility, transportation, engi-neering work	1912	concrete tunnel	2005.12.27	Otsuki City, Ya-manashi
	第二号水路橋 Second Aqueduct	industrial facility, transportation, engi-neering work	1912	brick masonry and con-crete 3-arched bridge	2005.12.27	Otsuki City, Ya-manashi
	第四号隧道 Fourth Tunnel	industrial facility, transportation, engi-neering work	1912	concrete tunnel	2005.12.27	Otsuki City, Ya-manashi
	第三号水路橋 Third Aqueduct	industrial facility, transportation, engi-neering work	1912	brick masonry and con-crete 5-arched bridge	2005.12.27	Otsuki City, Ya-manashi
	第五号隧道 Fifth Tunnel	industrial facility, transportation, engi-neering work	1912	concrete tunnel	2005.12.27	Otsuki City, Ya-manashi
八ツ沢発電所施設 Yatsusawa Power Plant Facilities	第四号水路橋 Fourth Aqueduct	industrial facility, transportation, engi-neering work	1912	brick masonry and concrete single-arched bridge	2005.12.27	Otsuki City, Ya-manashi
	第六・七・八・九・一〇及び一一号隧道 Sixth, Seventh, Eighth, Ninth, Tenth, and Elev-enth Tunnels	industrial facility, transportation, engi-neering work	1912	concrete tunnel	2005.12.27	Otsuki City, Ya-manashi
	大野調整池制水門 Ono Retention Basin Control Gate	industrial facility, transportation, engi-neering work	1914	stone masonry, a series of 7 intake control gates of brick masonry and concrete	2005.12.27	Otsuki City, Ya-manashi
	大野調整池余水路 Ono Retention Basin Spillway	industrial facility, transportation, engi-neering work	1914	stone masonry, brick masonry and concrete	2005.12.27	Otsuki City, Ya-manashi

Name of Property	Name of Structure	Classification	Year of Construction	Structure and Classification	Date of Designation	Location
八ツ沢発電所施設 Yatsusawa Power Plant Facilities	第一二・一三・一四・一五・一六・一七及び一八号隧道 Twelfth, Thirteenth, Fourteenth, Fifteenth, Sixteenth, Seventeenth, and Eighteenth Tunnels	industrial facility, transportation, engineering work	1912	concrete tunnel	2005.12.27	Otsuki City, Yamanashi
	水槽 Cistern	industrial facility, transportation, engineering work	1912	stone masonry, brick masonry and concrete	2005.12.27	Otsuki City, Yamanashi
	水槽余水路 Cistern Spillway	industrial facility, transportation, engineering work	1912	stone masonry, brick masonry and concrete	2005.12.27	Otsuki City, Yamanashi
読書発電所施設 Yomikaki Power Plant Facilities	発電所 Power Plant	industrial facility, transportation, engineering work	1923	reinforced concrete (main hall), concrete (cistern)	1994.12.27	Nagiso Town, Nagano
	柿其水路橋 Kakizore Aqueduct	industrial facility, transportation, engineering work	1923	reinforced concrete 2-arched bridge, reinforced concrete side spans on both sides	1994.12.27	Nagiso Town, Nagano
片倉館 Katakurakan	浴場 Bath House	cultural facility	1928	reinforced concrete	2011.6.20	Suwa City, Nagano
	会館 Assembly Hall	cultural facility	1928	wood frame, partially reinforced concrete	2011.6.20	Suwa City, Nagano
牛伏川本流水路（牛伏川階段工） Ushibuse-gawa River Main Stream Waterway (Ushibuse-gawa River Stepped Channel)		industrial facility, transportation, engineering work	1917	stone masonry and concrete	2012.7.9	Nagano City, Nagano
旧常田館製糸場施設 Former Tokidakan Silk Mill Facilities	五階鉄筋繭倉 Five-storied Reinforced Concrete Cocoon Warehouse 庫	industrial facility, transportation, engineering work	1926	reinforced concrete	2012.12.28	Ueda City, Nagano
旧八百津発電所施設 Former Yaotsu Power Plant Facilities	発電所本館 Power Plant Main Building	industrial facility, transportation, engineering work	1911	concrete (floodway)	1998.5.1	Yaotsu Town, Gifu
	放水口発電所 Water Outlet Power Plant	industrial facility, transportation, engineering work	1917	brick masonry（power plant building）, reinforced concrete（cistern）	1998.5.1	Yaotsu Town, Gifu
	水槽 Cistern	industrial facility, transportation, engineering work	1911	brick masonry and concrete, length 73m, depth 36m	2005.7.22	Yaotsu Town, Gifu
	余水路 Spillway	industrial facility, transportation, engineering work	1911	stone masonry and concrete	2005.7.22	Yaotsu Town, Gifu
美濃橋 Mino-bashi Bridge		industrial facility, transportation, engineering work	1916	steel stiffened suspension bridge, including 2concrete anchorage	2003.5.30	Mino City, Gifu
旧日向家熱海別邸地下室 Former Hyuga Family Atami Vacation Residence Basement		residence	1936	reinforced concrete	2006.7.5	Atami City, Shizuoka
旧名古屋控訴院地方裁判所区裁判所庁舎 Former Nagoya Court of Appeals Building		public facility	1936	brick masonry and reinforced concrete	1984.5.21	Nagoya City, Aichi
旧品川燈台 Former Shinagawa Lighthouse		industrial facility, transportation, engineering work	1870	brick masonry（altered to reinforced concrete）	1968.4.25	Inuyama City, Aichi
名古屋市庁舎 Nagoya City Hall		public facility	1933	steel frame reinforced concrete	2014.12.10	Nagoya City, Aichi
愛知県庁舎 Aichi Prefectural Hall		public facility	1938	steel frame reinforced concrete	2014.12.10	Nagoya City, Aichi
末広橋梁（旧四日市港駅鉄道橋） Suehiro Bridge (Former Yokkaichi-shi Minato Station Railroad Bridge)		industrial facility, transportation, engineering work	1931	4 steel plate girder bridges (including 1 drawbridge), 2 concrete bridge abutments (including embankment walls)・4 concrete bridge piers (including machine room)	1998.12.25	Yokkaichi Citiy, Mie

Name of Property	Name of Structure	Classificaton	Year of Construc-tion	Structure and Classification	Date of Designa-tion	Location
梅小路機関車庫 Umekoji Locomotive House		industrial facility, transportation, engineering work	1914	reinforced concrete fan-shaped locomotive house	2004.12.10	Kyoto City, Kyoto
舞鶴旧鎮守府水道施設 Maizuru Former Navy Base Waterworks Facilities	桂取水堰堤 Katsura Intake Weir	industrial facility, transportation, engineering work	1900	gravity concrete dam	2003.12.25	Maizuru City, Kyoto
	桂量水堰堤 Katsura Measuring Weir	industrial facility, transportation, engineering work	1900	concrete gravity dam	2003.12.25	Maizuru City, Kyoto
	旧岸谷川上流本流取水堰堤 Former Kishitani River Upper Stream Mainstream Intake Weir	industrial facility, transportation, engineering work	1905	concrete gravity dam	2003.12.25	Maizuru City, Kyoto
	旧岸谷川上流支流取水堰堤 Former Kishitani River Upper Stream Subsidiary Stream Intake Weir	industrial facility, transportation, engineering work	1905	concrete gravity dam	2003.12.25	Maizuru City, Kyoto
旧京都中央電話局西陣分局舎 Former Kyoto Central Telephone Exchange Nishijin Branch		public facility	1923	reinforced concrete and wood frame	2006.7.5	Kyoto City, Kyoto
松殿山荘 Shoden Sanso Villa	宝庫 Treasure Storehouse	cultural facility	1934	reinforced concrete	2017.11.28	Uji City, Kyoto
綿業会館 Cotton Trade Hall		commercial and business facility	1931	steel frame reinforced concrete	2003.12.25	Osaka City, Osaka
淀川旧分流施設 Yodo-gawa River Former Distributary Channel Facilities	毛馬洗堰 Kema Overflow Weir	industrial facility, transportation, engineering work	1910	brick masonry, concrete and reinforced concrete overflow weir	2008.6.9	Osaka City, Osaka
	毛馬第一閘門 Kema First Lock Gate	industrial facility, transportation, engineering work	1907	brick masonry and concrete lock	2008.6.9	Osaka City, Osaka
大江橋及び淀屋橋 Oe-bashi Bridge and Yodoya-bashi Bridge	大江橋 Oe-bashi Bridge	industrial facility, transportation, engineering work	1935	reinforced concrete double arched bridge, reinforced concrete side spans on both sides with newel posts and bridge railing (including 16 lamp posts)	2008.12.2	Osaka City, Osaka
	淀屋橋 Yodoya-bashi Bridge	industrial facility, transportation, engineering work	1935	reinforced concrete double arched bridge, reinforced concrete side spans on both sides with newel posts and bridge railing (including 16 lamp posts)	2008.12.2	Osaka City, Osaka
旧山邑家住宅（淀川製鋼迎賓館） Former Yamamura Family Residence（Yodoko Guest House）		residence	1924	reinforced concrete	1974.5.21	Ashiya City, Hyogo
移情閣 Ijokaku (Sun Yat-sen Memorial Hall)		residence	1925	wood-frame concrete block masonry	2001.11.14	Kobe City, Hyogo
布引水源地水道施設 Nunobiki Reservoir Waterworks Facilities	分水堰堤 Diversion Dam	industrial facility, transportation, engineering work	1907	arched concrete dam	2006.7.5	Kobe City, Hyogo
	分水堰堤附属橋 Diversion Dam Bridge	industrial facility, transportation, engineering work	1907	reinforced concrete single-arched bridge	2006.7.5	Kobe City, Hyogo
	分水隧道 Diversion Dam Tunnel	industrial facility, transportation, engineering work	1907	stone masonry and concrete tunnel	2006.7.5	Kobe City, Hyogo
	締切堰堤 Closed Dam	industrial facility, transportation, engineering work	1908	arched concrete dam	2006.7.5	Kobe City, Hyogo

Name of Property	Name of Structure	Classification	Year of Construc-tion	Structure and Classification	Date of Designa-tion	Location
布引水源地水道施設 Nunobiki Reservoir Waterworks Facilities	放水路隧道 Floodway Tunnel	industrial facility, transportation, engi-neering work	1908	stone masonry and concrete tunnel	2006.7.5	Kobe City, Hyogo
	五本松堰堤 Gohonmatsu Dam	industrial facility, transportation, engi-neering work	1900	gravity concrete dam	2006.7.5	Kobe City, Hyogo
	谷川橋 Tanigawa-bashi Bridge	industrial facility, transportation, engi-neering work	early Taisho era	reinforced concrete single-arched bridge	2006.7.5	Kobe City, Hyogo
	雌滝取水堰堤 Clothing Store-house	industrial facility, transportation, engi-neering work	1900	arched concrete dam	2006.7.5	Kobe City, Hyogo
旧村山家住宅 Former Murayama Family Residence	衣装蔵 Clothing Store-house	residence	late Meiji era	reinforced concrete	2011.6.20	Kobe City, Hyogo
	美術蔵 Art Storehouse	residence	around Taisho era	reinforced concrete	2011.6.20	Kobe City, Hyogo
神戸女学院 Kobe College	総務館、講堂及び礼拝堂 Administration Building (including Auditorium and Searle Chapel)	educational facility	1933	reinforced concrete, wood frame（with connecting corridor between Literature Hall）, wood frame and steel frame（with connecting corridor between Science Hall, Gymnasium, and Social Center）	2014.9.18	Nishinomiya City, Hyogo
	図書館 Library	educational facility	1933	reinforced concrete, wood frame（with connecting corridors between Literature Hall as well as Science Hall）	2014.9.18	Nishinomiya City, Hyogo
	文学館 Literature Building	educational facility	1933	reinforced concrete	2014.9.18	Nishinomiya City, Hyogo
	理学館 Science Building	educational facility	1933	reinforced concrete	2014.9.18	Nishinomiya City, Hyogo
	音楽館 Music Building	educational facility	1933	reinforced concrete	2014.9.18	Nishinomiya City, Hyogo
神戸女学院	体育館 Gymnasium	educational facility	1933	reinforced concrete（with connecting cor-ridor between Gymna-sium and Science Build-ing, with chimney）	2014.9.18	Nishinomiya City, Hyogo
	葆光館 Hokokan (High School Building)	educational facility	1933	reinforced concrete, wood frame（with connecting corridor between auditorium）	2014.9.18	Nishinomiya City, Hyogo
	社交館 Social Center	educational facility	1935	reinforced concrete	2014.9.18	Nishinomiya City, Hyogo
	汽罐室 Boiler House	educational facility	1933	reinforced concrete（Boiler House with chimney）	2014.9.18	Nishinomiya City, Hyogo
	正門及び門衛舎 Main Gate and Guard House	educational facility	1933	reinforced concrete and wood frame	2014.9.18	Nishinomiya City, Hyogo
旧美歎水源地水道施設 Mitani Old Fountain-head Water Facilities	貯水池堰堤 Reservoir Dam	industrial facility, transportation, engi-neering work	1922	gravity concrete dam	2007.6.18	Tottori City, Tottori
	美歎川上流量水堰 Mitani-gawa River Upper Stream Measuring Weir	industrial facility, transportation, engi-neering work	1915	gravity concrete dam	2007.6.18	Tottori City, Tottori
	通り谷量水堰 Toridani Measur-ing Weir	industrial facility, transportation, engi-neering work	1915	gravity concrete dam	2007.6.18	Tottori City, Tottori
	一号濾過池 First Filtration Pond	industrial facility, transportation, engi-neering work	1915	brick masonry and con-crete	2007.6.18	Tottori City, Tottori

Name of Property	Name of Structure	Classification	Year of Construction	Structure and Classification	Date of Designation	Location
旧美歎水源地水道施設 Former Mitani Reservoir Waterworks Facilities	二号濾過池 Second Filtration Pond	industrial facility, transportation, engineering work	1915	brick masonry and concrete	2007.6.18	Tottori City, Tottori
	三号濾過池 Third Filtration Pond	industrial facility, transportation, engineering work	1915	brick masonry and concrete	2007.6.18	Tottori City, Tottori
	四号濾過池 Fourth Filtration Pond	industrial facility, transportation, engineering work	1915	brick masonry and concrete	2007.6.18	Tottori City, Tottori
	五号濾過池 Fifth Filtration Pond	industrial facility, transportation, engineering work	before 1928	brick masonry and concrete	2007.6.18	Tottori City, Tottori
	接合井 Junction Well	industrial facility, transportation, engineering work	1915	brick masonry and concrete	2007.6.18	Tottori City, Tottori
	量水器室 Water Meter Chamber	industrial facility, transportation, engineering work	early Showa era	reinforced concrete	2007.6.18	Tottori City, Tottori
高梁川東西用水取配水施設 Takahashi-gawa River East and West Water Intake and Service Facilities	酒津取水樋門 Sakazu Intake Sluice	industrial facility, transportation, engineering work	1920	reinforced concrete sluice	2016.7.25	Kurashiki City, Okayama
	南配水樋門 South Service Sluice	industrial facility, transportation, engineering work	1923	reinforced concrete sluice	2016.7.25	Kurashiki City, Okayama
	北配水樋門 North Service Sluice	industrial facility, transportation, engineering work	1922	reinforced concrete sluice	2016.7.25	Kurashiki City, Okayama
本庄水源地堰堤水道施設 Honjo Reservoir Dam Waterworks Facilities	堰堤 Dam	industrial facility, transportation, engineering work	1916	gravity concrete dam	2009.5.13	Kure City, Hiroshima
	第一量水井 First Measuring Pool	industrial facility, transportation, engineering work	1916	concrete	2009.5.13	Kure City, Hiroshima
広島平和記念資料館 Hiroshima Peace Memorial Museum		cultural facility	1955	reinforced concrete	2006.7.5	Hiroshima City, Hiroshima
世界平和記念聖堂 Hiroshima Memorial Cathedral for World Peace		religious facility	1954	reinforced concrete	2006.7.5	Huroshima City, Hiroshima
宇部市渡辺翁記念会館 Ube City Watanabe Memorial Hall		cultural facility	1937	reinforced concrete and steel frame reinforced concrete	2005.12.27	Ube City, Yamaguchi
旧毛利家本邸 Former Mouri Family Main Residence	台所付倉庫 Storehouse with Kitchen	residence	1916	reinforced concrete	2011.11.29	Hofu City, Yamaguchi
	用達所倉庫 Office Storehouse	residence	1916	reinforced concrete, building area128.07 ㎡, 2-stories with basement, gabled roof covered with roof tiles, with lean-to on south with metal sheeting roof	2011.11.29	Hofu City, Yamaguchi
	石橋 Stone Bridge	residence	1916	reinforced concrete single-arched bridge	2011.11.29	Hofu City, Yamaguchi
	本門 Main Gate	residence	1916	single-bay yakui-mon gate, reinforced concrete	2011.11.29	Hofu City, Yamaguchi
有近家住宅 Arichika Family Residence	正門 Main Gate	residence	ca. 1924	concrete	2012.12.28	Yamaguchi City, Yamaguchi
三河家住宅 Mikawa Family Residence		residence	ca. 1928	reinforced concrete	2007.12.4	Tokushima City, Tokushima
豊稔池堰堤 Honen-ike Dam		industrial facility, transportation, engineering work	1929	Multiple arch concrete dam	2006.12.19	Kanonji City, Kagawa
萬翠荘（旧久松家別邸） Bansuiso (Former Hisamatsu Family Villa)	本館 Main Building	residence	1922	reinforced concrete	2011.11.29	Matsuyama City, Ehime

Name of Property	Name of Structure	Classificaation	Year of Construc-tion	Structure and Classificaton	Date of Designa-tion	Location
長浜大橋 Nagahama Ohashi Bridge		industrial facility, transportation, engi-neering work	1935	steel drawbridge, reinforced concrete（6 bridge piers, 2 bridge abutments）	2014.12.10	Ozu City, Ehime
旧魚梁瀬森林鉄道施設 Former Yanase Shinrin Railways	二股橋 Futamata-bashi Bridge	industrial facility, transportation, engi-neering work	1940	concrete 2-arched bridge	2019.6.30	Kitagawa Village, Kochi
	掘ヶ生橋 Horigawo-bashi Bridge	industrial facility, transportation, engi-neering work	1941	reinforced concrete single-arched bridge	2019.6.30	Kitagawa Village, Kochi
旧筑後川橋梁（筑後川昇開橋） Former Chikugo-gawa River Bridge (Chiku-go-gawa River Drawbridge)		industrial facility, transportation, engi-neering work	1935	steel drawbridge, 2 concrete bridge abut-ment（including wing walls on left bank）, 14 reinforced concrete bridge piers	2003.5.30	Okawa City, Fukuoka and Saga City, Saga
三井石炭鉱業株式会社三池炭鉱宮原坑施設 Miyanohara Pit (Miike Coal Mine and Miike Port)	第二竪坑櫓 No.2 Shaft	industrial facility, transportation, engi-neering work	1901	steel frame shaft with concrete foundation	1998.5.1	Omuta City, Fukuoka
南河内橋 Minamikawachi-bashi Bridge		industrial facility, transportation, engi-neering work	1926	2-span steel truss bridge, including 1 con-crete bridge pier and 2 bridge abutments with wing walls	2006.12.19	Kitakyushu City, Fukuoka
旧志免鉱業所竪坑櫓 Former Shime Coal Mine Shaft Tower		industrial facility, transportation, engi-neering work	1942	reinforced concrete, building area 270.71 ㎡, eight-storied with tower and basement	2009.12.8	Shime Town, Fukuo-ka
佐世保無線電信所（針尾送信所）施設 Sasebo Radio Trans-mission (Hario Transmitting Station) Facilities	無線塔 Radio Towers	industrial facility, transportation, engi-neering work	1922	3 reinforced concrete towers	2013.3.6	Sasebo City, Nagasa-ki
	電信室 Telegraph Room	industrial facility, transportation, engi-neering work	1922	reinforced concrete	2013.3.6	Sasebo City, Nagasa-ki
	油庫 Oil Storage	industrial facility, transportation, engi-neering work	1922	reinforced concrete	2013.3.6	Sasebo City, Nagasa-ki
本河内水源地水道施設 Hongochi Reservoir Waterworks Facilities	低部堰堤 Lower Dam	industrial facility, transportation, engi-neering work	1903	gravity concrete dam	2017.7.31	Sasebo City, Nagasa-ki
三井石炭鉱業株式会社三池炭鉱旧万田坑施設 Manda Pit (Miike Coal Mine and Miike Port)	第二竪坑櫓 No.2 Shaft	industrial facility, transportation, engi-neering work	1909	steel shaft, concrete foundation with brick masonry entrance	1998.5.1	Arao City, Kumamo-to and Omuta City, Fukuoka
旧玉名干拓施設 Former Tamana Recla-mation Facilities	明丑開潮受堤防 Meichu-kai Sea Dike	industrial facility, transportation, engi-neering work	ca. 1917 / ca. 1929	stone masonry and concrete dike	2010.6.29	Tamana City, Kuma-moto
	明豊開潮受堤防 Meiho-kai Sea Dike	industrial facility, transportation, engi-neering work	ca. 1929	stone masonry and concrete dike	2010.6.29	Tamana City, Kuma-moto
	大豊開潮受堤防 Daiho-kai Sea Dike	industrial facility, transportation, engi-neering work	ca. 1929	stone masonry and concrete dike	2010.6.29	Tamana City, Kuma-moto
	末広開西三枚戸樋門 Suehiro-kai West Three-door Sluice Gate	industrial facility, transportation, engi-neering work	ca. 1929	stone masonry and concrete sluice	2010.6.29	Tamana City, Kuma-moto
白水溜池堰堤水利施設 Hakusui Reservoir Dam Farm Irrigation Facilities	主堰堤 Main Dam	industrial facility, transportation, engi-neering work	1938	gravity concrete dam	1999.5.13	Takeda City, Oita
	副堰堤 Subsidiary Dam	industrial facility, transportation, engi-neering work	1938	gravity concrete dam	1999.5.13	Takeda City, Oita
大宜味村役場旧庁舎 Former Ogimi Village Hall		public facility	1925	reinforced concrete	2017.2.23	Ogimi Village, Okina-wa

Appendix - 2. List of Restoration Reports of Concrete Structures

Buildings and Structures	Designation	Title of reports	Published by	Date of issue
旧池田氏庭園 旧池田家住宅洋館	名勝・重文	国指定名勝旧池田氏庭園保存整備管理計画 (大仙市文化財報告書 ; 第 11 集)	大仙市教育委員会文化財保護課 編	平成 22 年
		国指定名勝旧池田氏庭園洋館保存修復工事報告書	文化財建造物保存技術協会 編	平成 23 年
旧三河島汚水処分場喞筒場施設	重文	重要文化財 (建造物) 旧三河島汚水処分場喞筒場施設保存修理工事報告書	文化財建造物保存技術協会 編	平成 26 年
築地本願寺本堂	重文	築地本願寺本堂修復工事報告書	築地本願寺	平成 25 年
三越日本橋本店	重文	三越日本橋本店本館調査報告書 改訂第 2 版	三越日本橋本店本館調査検討会 編	平成 28 年
高島屋東京店	重文	高島屋東京店建造物歴史調査報告書	高島屋東京店建造物歴史調査検討会 編	平成 22 年
		重要文化財高島屋東京店保存修理工事報告書	文化財保存計画協会 編	平成 25 年
		重要文化財高島屋東京店保存修理工事報告書	文化財保存計画協会 編	令和元年
国立西洋美術館本館	重文	国立西洋美術館本館歴史調査報告書	日本建築学会国立西洋美術館歴史調査 WG 編著	平成 19 年
明治神宮宝物殿	重文	明治神宮宝物殿改修工事報告書	明治神宮宝物殿改修工事報告書作成委員会 編	昭和 61 年
旧前田家本邸	重文	重要文化財旧前田家本邸洋館ほか一棟保存修理工事報告書	文化財建造物保存技術協会 執筆・編集	令和元年
佐渡金銀山遺跡 旧佐渡鉱山採鉱施設	史跡	史跡佐渡金銀山遺跡保存管理計画書 第 1 期	佐渡市世界遺産推進課	平成 24 年
		史跡佐渡金銀山遺跡保存管理計画書 第 2 期	佐渡市産業観光部世界遺産推進課	平成 30 年
	重文	旧佐渡鉱山近代化遺産建造物群調査報告書	佐渡市教育委員会	平成 20 年
富岩運河水閘施設	重文	重要文化財富岩運河水閘施設 (中島閘門) 閘門操作室保存修理工事報告書	文化財建造物保存技術協会 編著	平成 22 年
桃介橋	重文	桃介橋修復・復元工事報告書	南木曽町 編著	平成 6 年
旧品川燈台	重文	明治村建造物移築工事報告書 第 2 集 (品川燈台 (重要文化財 旧品川燈台) 菅島燈台附属官舎 (重要文化財 旧菅島燈台付属官舎) 小那沙美島燈台)	博物館明治村 編	昭和 53 年
梅小路機関車庫	重文	重要文化財梅小路機関車庫耐震対策工事報告書	西日本旅客鉄道 (株) 大阪工事事務所 , ジェイアール西日本コンサルタンツ (株), 大鉄工業 (株) 編著	平成 28 年
旧京都中央電話局西陣分局舎	重文	新建築 2019 年 3 月号	NTT ファシリティーズ CUP	令和元年
移情閣	重文	兵庫県指定重要有形文化財移情閣移築修理工事報告書	建築研究協会 編・著	平成 13 年
神戸女学院	重文	重要文化財神戸女学院 : ヴォーリズ建築の魅力とメッセージ : 創立 140 周年記念版	神戸女学院	平成 27 年
旧山邑家住宅（淀川製鋼迎賓館）	重文	要文化財旧山邑家住宅 (淀川製鋼迎賓館) 保存修理工事報告書	建築研究協会 編	平成元年
		重要文化財旧山邑家住宅 (淀川製鋼迎賓館) 保存修理災害復旧工事報告書	建築研究協会 編	平成 10 年
旧美歎水源地水道施設	重文	重要文化財旧美歎水源地水道施設保存修理工事報告書	文化財建造物保存技術協会 編著	平成 30 年
宇部市渡辺翁記念会館	重文	新建築 1994 年 4 月号	村野・森建築事務所	平成 6 年
旧志免鉱業所竪坑櫓	重文	重要文化財旧志免鉱業所竪坑櫓保存活用計画	志免町教育委員会	平成 25 年
旧筑後川橋梁	重文	重要文化財旧筑後川橋梁 (筑後川昇開橋) 保存修理工事報告書	文化財建造物保存技術協会 編著	平成 23 年

Appendix - 3. List of Concrete Structures Visited for Research

Date	Name of buildings and structures【current name】	Designation
2018.10.17	広島平和記念資料館	国重要文化財
2018.10.18	世界平和記念聖堂	国重要文化財
2018.11.06	丸沼堰堤	国重要文化財
2018.11.08	旧佐渡鉱山採鉱施設大立竪坑捲揚機室ほか	国重要文化財
2018.11.13	梅小路機関車庫	国重要文化財
2019.01.10	神戸女学院総務館講堂及び礼拝堂ほか	国重要文化財
2019.01.11	旧山邑家住宅【ヨドコウ迎賓館】	国重要文化財
2019.01.30	東京大学大講堂（安田講堂）	登録有形文化財
2019.03.15	大阪城天守閣	登録有形文化財
2019.03.19	旧志免鉱業所竪坑櫓	国重要文化財

Editor's postscript

We are deeply grateful to all the people who provided support to the investigation and research activities of the Modern Cultural Heritage Section of the Center for Conservation Science at the Tokyo National Research Institute for Cultural Properties. We plan to continue publishing this series of reports focused on conservation of industrial heritage properties into the coming years. Your continued support will be highly appreciated.

Photographs of the cover

1	2	3
4	5	6
7	8	9

1. Magliana Pavilion, Rome, Italy （Kitagawa Daijiro）
2. Marunuma Dam （Ishida Shin-ya）
3. St. Clement's Catholic Church, Bettlach, Switzerland （Kitagawa Daijiro）
4. Former Yamamura Family Residence （Ishida Shin-ya）
5. Palazzetto dello Sport, Rome, Italy （Kitagawa Daijiro）
6. Hiroshima Peace Memorial Museum （Ishida Shin-ya）
7. Former Shime Coal Mine Shaft Tower （Ishida Shin-ya）
8. Former Shime Coal Mine Shaft Tower （Ishida Shin-ya）
9. Otani-ha Branch Hongan-ji Temple Hakodate Branch Temple （Ishida Shin-ya）

* (photo credit)

Conservation and Restoration of Concrete Structures

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Tokyo National Research Institute for Cultural Properties
13-43 Ueno Park, Taito-ku, Tokyo, 110-8713 Japan
TEL +81 (0)3-3823-2241(switchboard)
FAX +81 (0)3-3823-2434
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