Committee Report : JCI-TC051A

# Technical Committee on Diagnosis and Retrofit of Historic Structures in Architectural and Civil Engineering Fields

Yasuo TANIGAWA, Masanori TUJI, Shigemitsu HATANAKA, Hitoshi HAMASAKI, Takayoshi AOKI, Takahiko SASAKI, Takehiro SAWAMOTO, Toshikazu HANAZATO

**Abstract**

Conservation/restoration projects for historic structures have conventionally been centered on wooden structures, but those for modern structures mostly built with bricks, stone, and reinforced concrete have also been attracting attention in recent years. For such conservation/restoration, no damage to the structures is accepted in most cases, while the reproduction of the original materials and techniques is also a key challenge. This Committee summarized the technologies for the research, diagnosis, repair, and retrofitting of historic structures, while preparing a guidebook for historic structures that focuses on those designated as Japan’s important cultural properties and registered tangible properties.

Keywords: authenticity, diagnosis, historic structures, restoration.

## 1. Introduction

Amid the growing technical demand in recent years for the conservation and retrofitting of modern structures mostly built with bricks, stone, and reinforced concrete, there have been few systematic studies on the research, diagnosis, repair, and retrofitting methods for brick and stone buildings. These have therefore been dealt with mostly on an ad hoc basis. Also, the diagnosis, repair, and retrofitting methods conventionally practiced for reinforced concrete structures are not applicable as they are to historic structures.

Meanwhile, the introduction of the registration system for tangible properties in 1996 has caused a rapid increase in the number of historic structures registered as tangible properties, with the number of concrete structures alone exceeding 600. Also, about 70 concrete structures, including those built after WWII, have been designated as important cultural properties.

When carrying out conservation and restoration of historic structures, ensuring authenticity is one of the key propositions. The term authenticity refers to trueness or venerability, which may be regarded as an element to be conserved as historic heritage. More specifically, the "Nara Document on Authenticity" adopted during the Nara Congress of the World's Cultural Heritage presented the following factors as perspectives for ensuring authenticity as follows:

(1) shapes and design; (2) materials and texture; (3) uses and functions; (4) tradition and skill; (5) location and ambient environment; (6) spirit and sensitivity; and (7) other internal and external factors.

The Technical Committee on Diagnosis and Retrofit of Historic Structures in Architectural and Civil Engineering Fields summarized the existing studies and technologies applicable to the research, diagnosis, repair, and retrofitting of historic structures in a committee report and formulated *The 200 Best Historic Structures – a Guidebook* of Japan's historic structures.

## 2. Overview of committee activities

The committee, whose members are as given in **Table 1**, was formed for two years from June 2005 to March 2007 and consisted of three working groups: the Deterioration/repair Working Group (Manager: Yasuo Tanigawa), the Seismic Diagnosis/retrofitting Working Group (Manager: Shigemitsu Hatanaka), and the Guidebook Preparation Working Group (Manager: Masanori Tsuji). It held a symposium in June 2006, in which an interim report of the committee activities and 15 technical papers were presented.

**Table 2** gives the contents of the committee report. This paper reports on the committee activities, summarizing the committee report and the guidebook.

**Table 1　Committee member**

| | |
|---|---|
| Chairman | Yasuo Tanigawa (Meijo Univ.) |
| Secretary | Masanori Tsuji (Tokyo Univ. of Science), Shigemitsu Hatanaka (Mie Univ.) |
| Member | Takayoshi Aoki (Nagoya City Univ.), Masanobu Ashida (Denki Kagaku Kogyo Co.,Ltd.), Kimitaka Uji (Tokyo Metropolitan Univ.), Sadamu Ono (C&R Consultant Corp.), Hideo Katsumata (Obayashi Corp.), Takahiko Sasaki (Railway Technical Research Institute), Takehiro Sawamoto (Institute of Technologists), Yoshio Shindo (Docon Corp.), Hitoshi Takayama (Institute for Applied Optics), Nobufumi Takeda (Obayashi Corp.), Yoshiaki Tominaga (The Japanese Association for Conservation of Architectural Monuments), Satoshi Nishioka (The Japanese Association for Conservation of Architectural Monuments), Hidekazu Nishizawa (Kyoto Univ.), Tetsuya Hasegawa (Japan Architectural Examination Design Office Co.,Ltd.), Naoji Hasegawa (Agency of Cultural Affairs), Toshikazu Hanazato (Mie Univ.), Syunsuke Hanehara (Iwate Univ.), Syunsuke Baba (Okayama Univ.), Hitoshi Hamasaki (Building Research Institute), Shoji Hayashi (Shimizu Corp.), Makoto Hisada (Tohoku Univ.), Masaki Muto (National Institute for Land and Infrastructure Management), Hiroaki Mori (Taiheiyo Cement Corp.), Kazumasa Morihama (Public Works Research Institute), Katsuhiko Yamawaki (Nikken Sekkei Ltd.) and Noboru Yuasa (Nihon Univ.) |

**Table 2 Contents of committee report**

| |
|---|
| 1. Current state and problems of conservation/restoration of historic structures - |
| 2. Current state of historic structures designated as cultural properties |
| 3. Basic survey of historic structures |
| 3.1 Research-diagnosis-repair-retrofitting flow |
| 3.2 Document search |
| 3.3 Preparation of drawings |
| 3.4 Visual survey of deterioration state |
| 3.5 Identification of materials |
| 4. Types of causes and research/diagnosis methods |
| 4.1 Material deterioration |
| 4.2 Structural deterioration |
| 5. Deterioration diagnosis/repair methods for historic structures |
| 5.1 Deterioration diagnosis |
| 5.2 Repair |
| 6. Bearing capacity diagnosis and restoration methods for historic structures |
| 6.1 Bearing capacity diagnosis |
| 6.2 Restoration/strengthening |
| 7. Examples of investigated structures |
| [Separate volume] 200 Best Historic Structures – a Guidebook |

## 3. Current status of historic structures

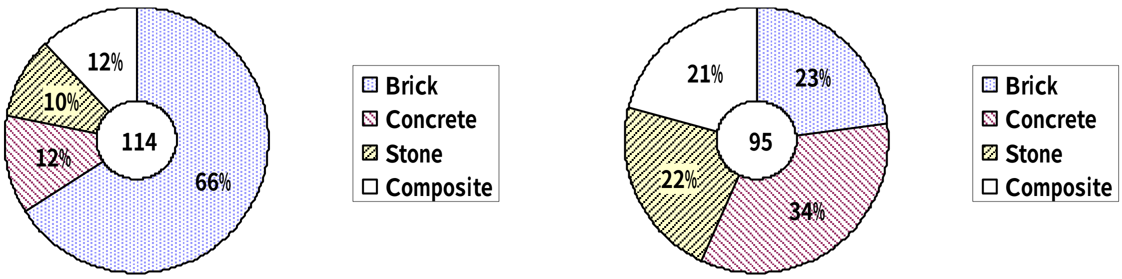
### 3.1 Classification of historic structures

Most of the approximately 2,300 historic structures that have been designated as important cultural properties are wooden structures. However, brick, concrete, and stone structures built primarily in the Meiji period (1868-1912), as well as the Taisho period (1912-1926), have also been designated as important cultural properties, accounting for about 10% of the total. Among the approximately 5,900 registered tangible assets, brick, concrete, and stone structures account for about 15%.

**Figures 1** and **2** show the compositions of brick, concrete, and stone structures designated as important cultural properties and registered tangible assets, respectively, by the structural type. Note that these structures include partially steel-framed structures and partially wooden structures. “Composite” in the figures refers to those made of composite structures of bricks, concrete, or stone.

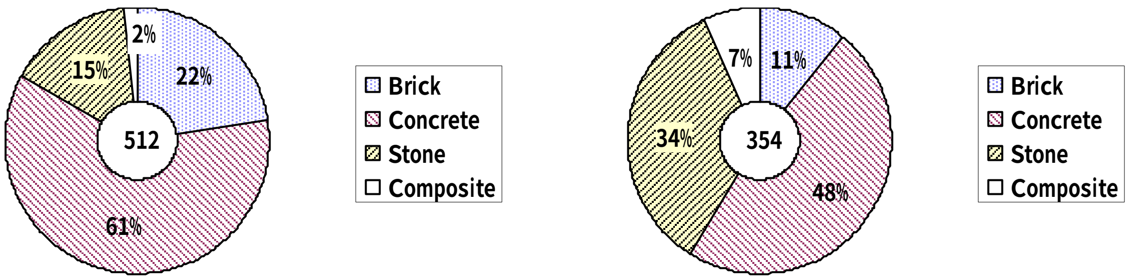
Architectural and civil structures built with bricks, concrete, and stone designated as important cultural properties totaled 114 and 95, respectively, by July 5, 2006. Brick and concrete structures account for the largest part of architectural and civil engineering fields, respectively. Such buildings registered as tangible assets by March 2, 2006, totaled 512 and 354 in the architectural and civil engineering fields, respectively, among which concrete structures account for the largest part in both fields.

When classifying important cultural properties in the architectural field by their uses, public facilities including museums and railroad facilities account for the largest part, followed by factories/warehouses, residential facilities, educational institutions, and public offices. Among those in the civil engineering field, tunnels for railways, roads, and waterways account for the largest part, followed by bridges and levees. Among the registered tangible assets classified by their uses, public facilities are the largest in number in the architectural sector, followed by residential facilities, educational institutions, factories/warehouses, and commercial facilities, whereas levees are the largest in number in the civil engineering sector, followed by buildings of power stations, lighthouses, docks, etc., and bridges.




(i) Building structures (ii) Civil structures

**Fig. 1 Structural types of important cultural properties (as of July 5, 2006)**




(i) Building structures (ii) Civil structures

**Fig. 2 Structural types of registered tangible properties (as of March 2, 2006)**

### 3.2 Selection of historic structures for the Guidebook

#### (1) Process of selecting architectural structures

When selecting architectural structures for the Guidebook, 383 brick structures and 586 concrete structures were selected from those selected in the *Report of the Investigation of Modernized Japanese Heritage (Buildings)* published based on research in each prefecture and other guidebooks, technical papers, and reports. *A Guidebook to Historic Structures (an interim report)* was formulated by arranging their photographs and technical summaries. In the final report, 50 each of brick and concrete structures were selected from those that appeared in the interim report.

**(2) Process of selecting civil structures**

Civil structures were selected by the following four principles: (1) those ranked as “A” in the *Civil Engineering Heritage in Japan – 2800 Important Structures as Monuments of Modernized Japan 1865-1945* (JSCE, 2005); (2) to take as many types as possible so as to make known the various aspects of the attractiveness of civil engineering heritage; (3) to avoid those inaccessible without permission and those scarcely accessible due to being left abandoned; and (4) the selection should be such that it allows the viewers to feel the technological development of each period through the structures. Note that among the 100 historic structures (50 concrete and 50 brick/stone) appearing in the Guidebook, 24 structures (12 concrete and 12 brick/stone) in the civil engineering field have undergone conservative restoration.

**(3) Preparation of the Guidebook**

The color-printed A5 size guidebook contains the selection of historic structures listed in **Table 3**, showing one structure on each page in the geographical order of prefectures together with a technical summary and map for access.

## 4. Research/diagnosis of historic structures

### 4.1 Research/diagnosis flow

The basics of research and diagnosis of a structure, not only historic but any, are to (1) grasp the specifications of the structure to estimate the initial state; (2) grasp the degree of changes due to deterioration and damage; and (3) estimate the causes of deterioration and damage to consider appropriate measures (repair/retrofitting plan). The concept of research/diagnosis for current general structures may not be applicable to historic structures, as many years have passed since their construction and the materials differ from those currently used. Also, the records of drawings and specifications to provide basic information may be lost, requiring the preparation and restoration of drawings as part of the research work in many cases. **Figure 3** shows a basic flow of research/diagnosis for historic structures in consideration of these points. The chapter and section numbers in the figure are related to the descriptions in the report.

## Table 3 List of historic structures selected for the Guidebook

| No. | Concrete buildings | Brick buildings | Concrete civil structures | Brick/stone civil structures |
|---|---|---|---|---|
| 1 | Otaru Peterburg art museum | Old Hokkaido Main Government Office Building | Wakkanai north breakwater dome | 3rd conservation garage for rolling stock (Old Temiya 3rd Locomotive Garage) |
| 2 | Kimura Sangyo laboratory | Old Nihon Yusen Corporation Otaru Branch | Otaru port north/ south breakwater slope type caisson dock | Demachinoma / Old Yoshizakino Fukuroma |
| 3 | Iwate-ken public hall | Hakodate Chinese Hall | Sasanagare dam | Ishii water gate |
| 4 | Sakata-shi Hikarioka Bunko | Iwate Bank (Old Morioka Bank) Old Main Office Building | Old Osarizawa mine selection warehouse Old Osarizawa mountain large thickener | Kabayama power plant |
| 5 | Koriyama-shi public hall | Old Anikouzan foreigner's lodging | Kotaki hot watercourse | Usui 3rd bridge (Usui river bridge) |
| 6 | Old Makabe post office | Yamagata-ken Old Municipal Government Office Building and Convention Center | Asakasosui Jurokukyou water gate | Megane-bashi dam |
| 7 | Tochigi-ken office building | Old Tomioka silk mill | Yokotone water gate | Tokiwa-bashi bridge / Nihon-bashi bridge |
| 8 | Gunma-ken main government office building | Usui pass railway facilities | Ishioka 1st power plant | Overhead bridge between Ochanomizu and Mansei-bashi / Shineikan overhead bridge |
| 9 | Kyorinji old Hondo | Royal Western-style cake shop (Old Honjo Commerce Bank's warehouse) | Kurobe dam (Shimotaki power plant → Kinugawa power plant) | Murayamashimo pond 1st water tower |
| 10 | Asahi Bank Kawagoe branch office | Seishido | Rokugou water gate | Dock Yard Garden (Old Yokohama 2nd ship dock) |
| 11 | Chiba-city Gallery/Inage | Nihon Seikoukai St. Paul church chapel | Komazawa waterworks water tower | Mikuni Port Essel embankment |
| 12 | Chiba-shi Chuo-ku city center | Ministry of Justice old main building | Kanrei tunnel | Komabashi power plant Ochiai waterway bridge |
| 13 | Kofu Kaikan | Old Konoeshidan Command Center | Shinkou pier 3rd wharf | Ushibuse River French type waterway |
| 14 | Meiji-Seimei main government office Building | Tokyo station Marunouchi mail building | Ookouzu dam / movable weir | Koudaimon-nishi bridge |
| 15 | Kabuki-za | Marine old astronomical observatory in Tokyo University of Mercantile Marine | Shiroiwa erosion control dam (main dam,1st - 7th sub dam) | Amagi tunnel (Mt. Amagi tunnel) / Isejin tunnel (Isegami tunnel) |
| 16 | Mitsui Honkan | Keiougijyuku library | Komaki Dam (Komaki Power Plant) | Spur dike of Kisogawa river |
| 17 | Old Tokyo museum main building | Yokohama-shi opening memorial hall | Yatsusawa power plant 1st watercourse bridge (Saruhashi watercourse bridge) | Oosunagawa tunnel |
| 18 | Yokohama Mitsui-Bussan building | Old Kanazawa Rikugun Heikishisho (Ishikawa-ken history museum) | Ashiyasu erosion control dam | (Old) Oosakayama tunnel |
| 19 | Kanagawa-ken main government office building | Kanazawa-shi Tamagawa library annex (old Senkohsha C-1 factory) | Choukai-bashi bridge / Dokusho power plant | Kusatsu river Holland erosion control weir / Tenjingawa river Yoroi erosion control weir |
| 20 | Nittsu Kinen Kan | Kohama St. Luke church | Ote-bashi bridge / Sakaebashi bridge | Old Sunayamaike pump |
| 21 | Nyuzen-machi Nizayama art space | Handa Red Brick Building (Old Kabuto Beer factory) | Ooi Dam (Ooi power plant) | Biwako lake 1st water tunnel / 2nd tunnel / Nanzenji watercourse / Old Keage power plant |
| 22 | Old Morita Bank head office | Nishio-shi Iwase Bunko library | Gorokuyousui Gyakusui water gate (Ushiki water gate) | Minatogawa river tunnel |
| 23 | Kofu Houjin Kaikan | Sangyo Gijyutu memorial hall (Old Toyota autmatic cloth factory) | Nishihamana-bashi bridge | Kobe-shi museum for water science (Okuhirano water purification plant) |
| 24 | Tanzan-Ou Kinen Houtoku library | Old Nagoya district court building | Shimizu lighthouse (Miho lighthouse) | Old Kobe-shi foreigner settlement sewer |
| 25 | Aichi-ken main government office building | Old Toyobouseki Corp. Tomita factory cotton warehouse | Urushide-bashi bridge / Tsuge-bashi bridge | Tatsunotoi |
| 26 | Nagoya-shi main government office building | Matsuzaka-shi Municipal Center (Old KANEBO Matsuzaka cotton warehouse) | Iwazu power plant sluice dam (Rokyo dam) | Old Tomogashima 3rd battery |
| 27 | Gamagori Prince Hotel (former Gamagori Hotel) | Doshisha (Old English school, Theology school and Harisu science school) | Old Matsushige water gate | Hinomisaki lighthouse |
| 28 | JR West Hokuriku - Line old Nagahama station railroad museum | Old Teikoku Kyoto museum | Nagoya-shi theater practice hall AKUTENON (Former Inaba water tower) | Mitsuishikongougawa river bridge (up line) / Nodoubashi bridge (down line) |
| 29 | Old Mizuguchi library | Old Nihon Bank Kyoto branch office | Old Yokkaichi port north jetty | Old harbor of Katsuyama |
| 30 | Old Kyoto Central Telephone Center Nishijin branch office | Otani University Jingen-Kan (Old government office) | Tanisaka tunnel | Old Kojima bay reclamation 1st area embankment |
| 31 | Old Kyoto Central Telephone Center branch office | Maizuru government memorial hall (Old Maizuru navy weapon warehouse) | Hinooka 11th bridge / Yamanotani Bridge | Memorial hall of Mino water purification plant |
| 32 | MINAMIZA | Osaka central public hall | Ooe Bridge/Yodoya Bridge | Old Kyoubashigawa river Gangi-gun |
| 33 | Osaka-jo castle tower | Nihon Seikoukai Christ church | Ajikawa under river tunnel (sidewalk) | Miyahara water purification plant water supply pond |
| 34 | Mengyo hall | Old Kobe settlement $15^{th}$ building | Nunobiki dam / bridge | Old Mitakayama north battery |
| 35 | Ijokaku | Hamada-shi 1st junior high school of indoor stadium | Kobe Port $1^{st}$-$3^{rd}$ Jetty ((Old)$4^{th}$ Jetty-$2^{nd}$ Jetty) | Tsunoshima lighthouse staff rest area |
| 36 | FREUNDLIEB main office (Old Union church) | Goshima Torajiro memorial hall | Uegahara filtration plant filtration pond | Old Tadotsu bay outport west waterbreak |
| 37 | Old Yamurake home | Old Chugoku Bank Ushimado branch | Onbara dam (Heisakubara power plant) / Okutsu power plant water control pond | Stone wall of Megijima |
| 38 | Old Yonago-shi government office building | Atatajima lighthouse museum | Sakatsu sluice water gate / Sakatsu south water gate | Stand of Yamane-ground / Old Higashi-taira mineral warehouse |
| 39 | Oohara art museum main building | Old Shimonoseki U.K. consulate office | Honjyou dam | Uchidagawa river bridge (Meganebashi) |
| 40 | Hiroshima peace memorial museum | Creative Space Red Brick (Old Ymaguchi-ken Yamaguchi Library) | Hounenike dam | Old Douyama manufacture wharf / Old Wakamatsu Minami wharf |
| 41 | Hiroshima world peace memorial cathedral | Ozu red brick hall (Old Ooshu Commercial Bank) | Old Takuma Navy flying corps slip | Miike port entrance water gate |
| 42 | Onoda cement Yamanote club | Old Nihon-Seimei Corp. Kyushu branch | Old Kojima central battery | Old Oogarami embankment |
| 43 | Yamaguchi-ken Rodo-Kinko Shimonoseki branch office | Kosuge ship dock winch cabin | Ittohyou submerged bridge | Nagasaki sewage 6th drain (Shisitokigawa branch) |
| 44 | Ube-shi Watanabe Oh memorial hall | Old Nagasaki U.K. consulate office | Old National Railway Shime shaft derrick | Stone pavement of slope of Westside of Maria-en (Dondon-zaka) |
| 45 | Matsuyama local meteorological observatory | Tabira church | Maehata 1st warehouse | Sashiki tunnel |
| 46 | Ehime-ken government office building | Kashiragashima church | Old Hario radio tower | Misumi Nishi port shore protection (old Misumi port) |
| 47 | Moji-ku government office building | Ushizu red brick (Old Tanakamaru-Shouten brick warehouse) | Old Katashima torpedo launch test field | Gunchiku Sanbancho reclamation water gate |
| 48 | Sasebo-city Municipal culture hall | Old 5th high school | Hakusui dam | Bakeibashi bridge |
| 49 | Himosashi cathedral | Kumamoto-shi waterworks memorial hall (Old Hakkeisuiya reservoir pump center) | Old Bungonomori locomotive garage | Shimazu-ke filtration pond |
| 50 | Yonahara St. Clara monastery | Aburazu red brick hall (Old Kouno Muneyasu-Ke warehouse) | 3rd Gokase river bridge / Tsunanose river bridge | Ganiku-Hi-Jya-Ga (public water glass) |

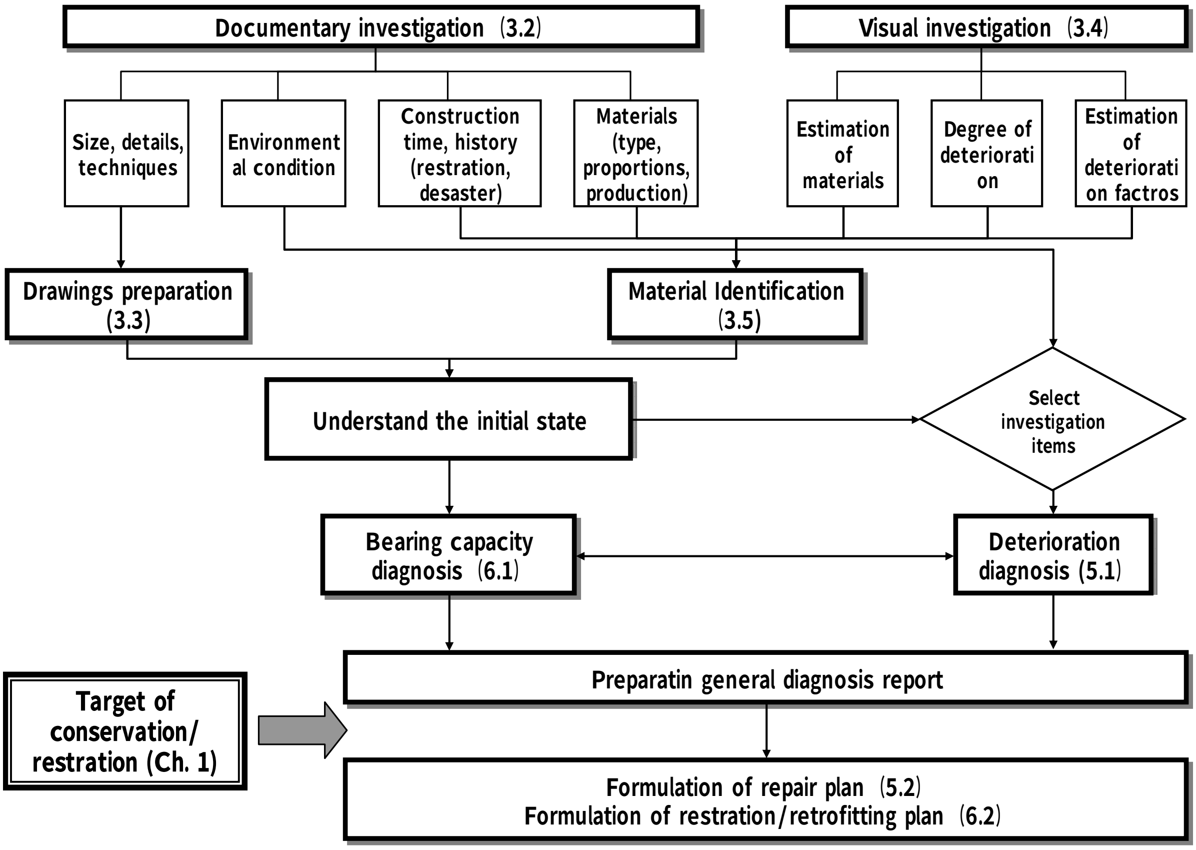



**Fig. 3 Basic flow of diagnosis of historic structure**

## 4.2 Material deterioration and methods of research/diagnosis

In age-old historic structures, changes in the materials composing concrete, such as reinforcement corrosion, may have progressed to a significant degree, causing reductions in the load-bearing capacity. Material deterioration can be divided into three groups by the cause of deterioration:

(1) deterioration due to reductions in the reinforcement content in the member cross-section,

(2) deterioration due to reductions in the strength and elastic modulus of concrete, and

(3) deterioration due to reduction in the member cross-sectional area.

(1) is attributed to carbonation and salt attack; (2) is attributed to deterioration induced by alkali-aggregate reaction and frost damage; and (3) is attributed to deterioration resulting from chemical erosion-induced concrete dissolution.

When carrying out repair or retrofitting of historic structures suffering these deteriorations, the following should be considered:

(1) Which material caused the deterioration by what mechanism?

(2) Which phase of deterioration the structure is in?

(3) How should the rate of deterioration progress be estimated?

**Table 4 Typical investigation methods for estimating deterioration causes of reinforced concrete structures**

| Investigation method | Principle, investigation item, etc. | Cause of deterioration | | | | |
|---|---|---|---|---|---|---|
| | | Carbo-nation | Chloride attack | ASR | Frost damage | Chemi-cal erosion |
| Documentary search | Design drawings/spec., as-built drawings/spec., inspection record | ◎ | ◎ | ◎ | ◎ | ◎ |
| Visual observation/photography | Binoculars, camera | ○ | ○ | ○ | ◎ | ○ |
| Sounding | Hammering sound, waveform analysis | ○ | ○ | | ○ | |
| Surface moisture measurement | Specific inductive capacity (high frequency capacitance) | ○ | ○ | ◎ | ◎ | ○ |
| Chipping | Carbonation depth | ◎ | ○ | | | |
| | Crack depth | ○ | ○ | ○ | ○ | |
| | Cover depth, location, size of rebars | ◎ | ◎ | | | ◎ |
| | Rebar corrosion | ◎ | ◎ | | ○ | ◎ |
| | Tensile strength of rebars | ○ | ○ | | | ○ |
| Core sampling | Carbonation depth | ◎ | ○ | | | |
| | Crack depth | ○ | ○ | ○ | ○ | |
| | Compressive/tensile strength, elastic modulus | ○ | | | ○ | |
| | Proportioning analysis | ○ | ○ | | ○ | ○ |
| | Chloride ion content | | ◎ | ◎ | ○ | |
| | Alkali content analysis | | | ◎ | | |
| | Reactivity of aggregate | | | ◎ | | |
| | Expansion measurement | | | ◎ | | |
| | Pore diameter analysis | | | | ◎ | |
| | Air void distribution | | | | ○ | |
| | Gas permeability | ○ | | | | ○ |
| Chemical composition analysis of concrete | Thermal analysis (TG, DTA) | ○ | | | | ○ |
| | X-ray diffraction | ○ | | ◎ | | ○ |
| | Fluorescent X-ray spectrometry | | ◎ | ◎ | | ○ |
| | Electron probe X-ray microanalysis (EPMA) | ○ | ◎ | ○ | | ◎ |
| | Scanning electron microscopy (SEM) | | ○ | ◎ | | ○ |
| Drilling | Carbonation depth | ◎ | ○ | | | |
| | Chloride ion content | | ◎ | ◎ | ○ | |
| Electromagnetic radar inspection | Cover depth, rebar location | ◎ | ◎ | | | ◎ |
| Electromagnetic induction | Cover depth, rebar location/diameter | ◎ | ◎ | | | ◎ |
| Infrared method | Cracking, honeycombs, voids | ○ | ○ | ○ | ○ | |
| Half-cell potential method | Probability of rebar corrosion | ○ | ○ | | | ○ |
| Polarization resistance method | Probability of rebar corrosion | ○ | ○ | | | ○ |
| | Corrosion rate of rebars | ○ | ○ | | | ○ |

◎ : Provides principal data for deterioration cause estimation and progress prediction

○ : Provides data for deterioration cause estimation and progress prediction

Blank: Serves as a reference in some cases.

The combinations of the deterioration items and research methods that are currently deemed optimum were summarized. **Table 4** gives an example of research methods for detecting and estimating the causes of deterioration in reinforced concrete structures.

As for brick structures, representative deterioration phenomena of bricks are brought about by freezing and thawing, salt weathering, and joint deterioration. These deterioration items and research methods that are currently deemed optimum were also summarized, including the methods of confirming the occurrence of deterioration.

The Committee Report summarizes the state-of-the-art technology regarding the following as non-destructive test methods: the rebound number method, sound method, ultrasonic method, impact echo method, simple water absorption test, diagnosis method for rebar corrosion, and thermography method. As for slightly destructive test methods, the Committee Report summarizes the core sampling method, scratch method, drilled powder method, Windsor pin method, and micropore method. Methods of applying chemical analysis tests to concrete and bricks were summarized as well.

## 4.3 Identification of materials

The use of the same materials as the original is often required for repair and restoration to ensure the authenticity of historic structures. The material originally used can be identified by literature and initial specifications, as well as by chemical analysis to a certain extent. **Figure 4** shows a typical flow for identifying the original materials.

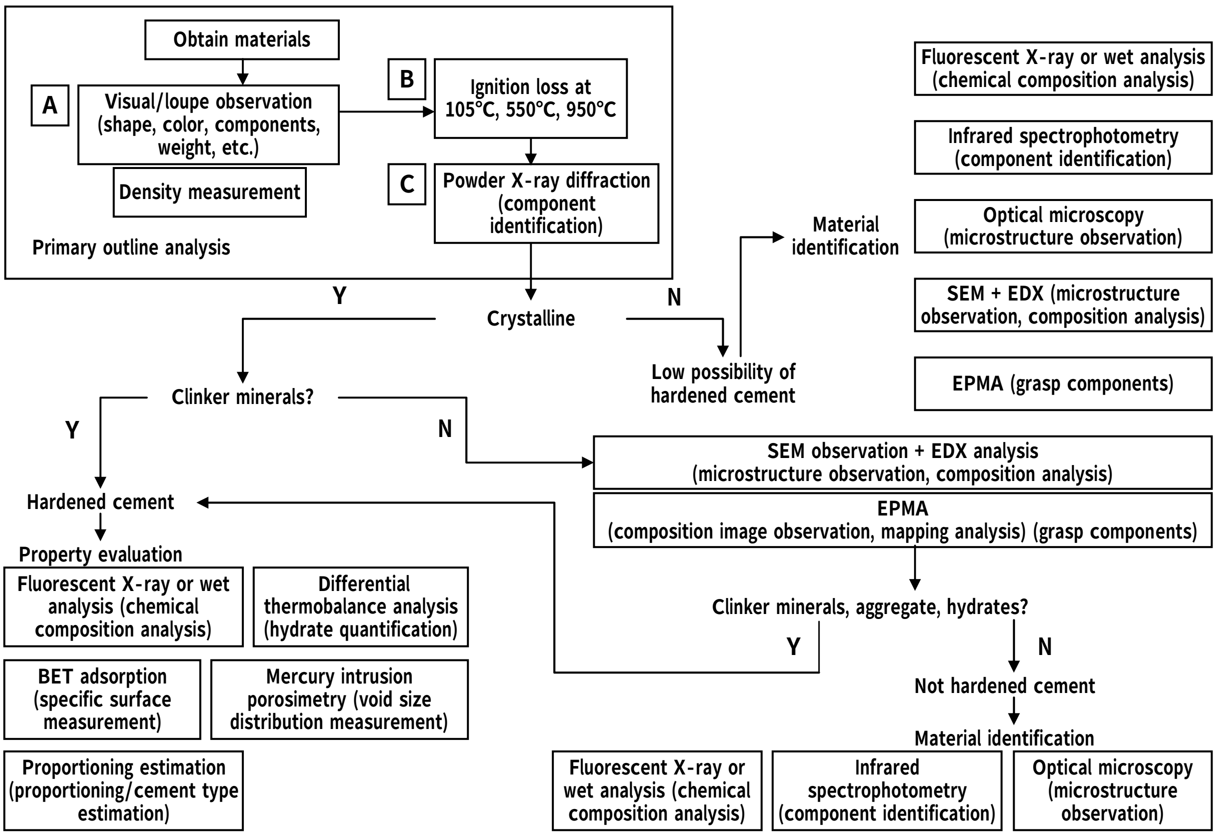



**Fig. 4 Typical analysis flow for identifying materials**

## 4.4 Diagnosis of bearing capacity

### (1) Overview

Many historic structures may be structurally hazardous, being built to conform to insufficient seismic design codes of the time. Also, various environmental external forces may have caused deterioration over time in their materials and members, reducing their structural stability. The strength and bearing capacity of materials and constructions themselves may be insufficient in some cases. It is therefore necessary when repairing historic structures to adequately evaluate their bearing capacity and seismic performance. The Committee systematically sorted out and classified the domestic and overseas examples of diagnosis for each structure type.

### (2) Reinforced concrete structures

Seismic diagnosis of reinforced concrete structures and steel-framed reinforced concrete structures is generally carried out based on the *Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings* published by the Japan Building Disaster Prevention Association[1), 2)]. Though it is reasonable to apply this standard to historic structures, these can be out of the scope of its application because of the old structural details, different shapes of reinforcement, etc. The Committee Report investigates an operation procedure of this standard assuming its application to historic structures.

In the case of low strength concrete, the absence of established evaluation methods for shear strength and ductility of low strength concrete members poses a problem, as these items strongly affect the safety factor of their seismic diagnosis criteria. The Committee Report made a proposal regarding the application principles of seismic diagnosis criteria to structures involving low strength concrete.

Since no criteria are available for seismic diagnosis of civil structures, these were judged by fulfillment of the seismic performance requirements specified by the current standards. The Committee Report summarized the seismic performance requirements of the *JSCE Guidelines for Concrete No. 5, Standard Specifications for Concrete Structures-2002, "Seismic Performance Verification"* JSCE, 2005; Railway Technical Research Institute, *Design Standards for Railway Structures and Commentary - Seismic Design-1999*, RTRI, 2007; and JRA, *Specifications for Highway Bridges Part V - Seismic Design*, Maruzen, 2003. The committee Report also introduces (1) seismic design based on static analysis and (2) seismic design based on dynamic analysis.

### (3) Brick structures

The structural bearing capacity of an architectural structure under permanent loading is generally examined by the following methods: (1) checking of the ground contact pressure of foundations under fixed and live loads, (2) checking if the unit stress of slabs and beams is not more than the allowable stress for sustained loading, and (3) checking if the compressive unit stress of brick walls is not more than the allowable stress for sustained loading of brick walls. Seismic diagnosis is made by calculating the basic seismic indexes, $E_0$, of walls in in-plane and out-of-plane directions from the shear capacity of joints and taking the smaller value as the $E_0$ of the subject direction, following the seismic diagnosis criteria for reinforced concrete structures.

Since few reports have been available for seismic diagnosis of civil structures, the Committee Report primarily introduces examination procedures.

The analysis and diagnosis procedures practiced in Italy are also introduced in the Committee Report.

**(4) Stone and other structures (brick and wooden structures and brick and steel structures, etc.)**

There have been very few studies on seismic diagnosis of stone structures among masonry structures in Japan and overseas. Some examples of such studies are introduced in the Committee Report.

No standard or guidelines are available in Japan for brick and wooden structures and brick and steel structures. It is therefore considered acceptable at present to carry out seismic diagnosis of these structures by appropriately combining the methods for brick, wooden, and steel structures. It is expected that research in this area be brought forward domestically and internationally.

## 5. Repair and retrofitting methods for historic structures

### 5.1 Repair methods for historic structures

Though the existing repair techniques are basically applicable to historic structures in most cases, restraints are imposed on the changes in the appearance, and materials are required to reproduce the original state to the extent that is possible. The level of repair also leaves much room for discussion, as to whether the original state should be restored or the repair should only stop (or retard) the progress of deterioration, as well as what material should then be selected.

The Committee Report introduces the following repair technologies for historic structures: electrochemical method, section restoration method, injection method, surface improving method, surface cover method, and pointing. All of these methods other than pointing are practiced as repair methods for general reinforced concrete structures.

Pointing is a method in which only the joints of brick and stone structures are replaced when only the joint materials have deteriorated but the base materials remain sound. **Photo 1** shows the state of pointing application. Though pointing takes time requiring inefficient work, it is a method whereby the function of the structure can be restored only with the repair of joints utilizing the original materials, unless the base materials are deteriorated. In the United Kingdom, a number of railway structures remain sufficiently sound 150 years after construction, thanks to joint repair.

**Photo 1　State of pointing**

### 5.2 Retrofitting and restoration methods for historic structures

#### (1) Overview

When restoring historic structures, the retrofitting method is required not to impair their historic values following the principle of restoring cultural properties. In other words, the method should (1) apply minimum retrofitting and (2) be reversible, paying regard to the authenticity of the structures. In order to minimize retrofitting, it is necessary to make the most of the bearing capacity and seismic performance that the structure inherently possesses. To this end, structural analysis technology including load evaluation becomes important along with the diagnostic technology.

The Committee Report introduces the methods of bearing capacity retrofitting and seismic retrofitting applied as required to concrete, brick, stone, and other structures based on the results of diagnosis.

#### (2) Reinforced concrete structures

The deformation performance of historic structure of all structural types is low, as their materials, members, and construction are low in strength and bearing capacity. For this reason, ductility upgrading can cause significant damage to the structure under an earthquake. It is therefore necessary to exercise care when restoring/retrofitting historic structures in regard to the following:

(1) Strength upgrading should be applied while exercising care to minimize deformation.

(2) Strengthening members should be dispersed to mitigate stress concentration.

(3) Extra capacity should be imparted to the structure.

Architectural structures are generally strengthened with addition of reinforced concrete walls in many cases, as well as with steel members. Strengthening of columns with carbon fibers and steel panels are also generally practiced.

Methods of retrofitting civil structures are systematically organized for bridges, tunnels, railways, dams/levees, canals, lighthouses, and water supply and sewage systems[3)]. The Committee Report describes specific examples of seismic retrofitting for (1) columns of a breakwater dome, (2) a bridge, (3), dam, (4) floodgate, and (5) intake tower. For the repair of Sasanagare Dam, Japan's first buttress dam completed in 1923, the thickness of each of the 23 buttresses was increased to more than three times, and the cross-section of the 6 horizontal beams was increased twice as large both lengthwise and crosswise (**Photo 2**)

Before restoration

After restoration

**Photo 2 Restration of Sasanagare Dam**

**(3) Brick structures**

In regard to brick buildings, the changes in the strengthening methods applied to these buildings over time are summarized for each segment based on the records of past projects. Seismic retrofitting is generally carried out by combining multiple methods even for a single building. Seismic improvement technologies applied to brick structures can be classified as follows:

(a) Reduction and control of seismic loads

(1) Seismic isolation

(b) Improvement in structural performances

(1) Addition of reinforced concrete walls (on the inside)

(2) Addition of reinforced columns and beams

(3) Addition of steel panels

(4) Strengthening with steel framing

(5) Insertion of steel reinforcement

(6) Prestressing using prestressing steel

(7) Epoxy injection

(8) Addition of steel or reinforced concrete buttresses

(c) Supplementary (partial) strengthening

(1) Strengthening of openings

(2) Addition of circumferential girders

(3) Strengthening of floor slabs to ensure in-plane rigidity

(4) Strengthening of foundations

The Committee Report introduces such domestic examples as the Courthouse of the Nagoya Court of Appeal, District Court, an important cultural property, to which seismic retrofitting was applied by placing reinforced concrete buttresses and steel circumferential girders and inserting steel reinforcement (**Fig. 5**)[4] and the former Yamagata Prefectural Assembly Hall, another important cultural property, which was strengthened by external steel buttresses, insertion of reinforcing steel, and steel circumferential girders at the tops of walls (**Fig. 6**)[5], as well as those in foreign countries.

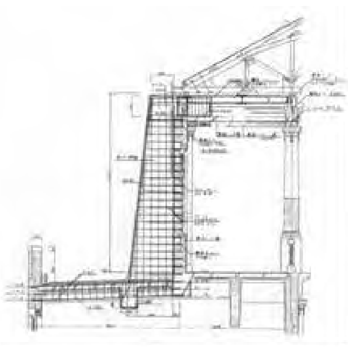


**Fig. 5 Strengthening with reinforced concrete buttresses[4]**

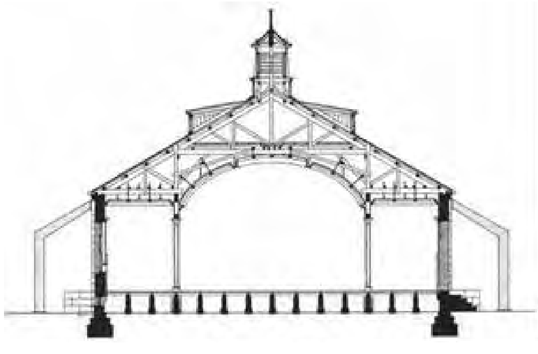


**Fig. 6 Strengthening with steel buttresses[5]**

Repair and retrofitting of brick civil structures have scarcely been carried out in consideration of the outward appearance of bricks or their conservation as cultural properties but mostly conducted to restore the function of, or as measures to prevent falling of masonry from, tunnels, arch bridges, and bridge piers. The repair/retrofitting methods practiced in the civil engineering field can be classified as follows:

(a) Repair

(1) Hoop steel wrapping

(2) Concrete replacement

(b) Retrofitting

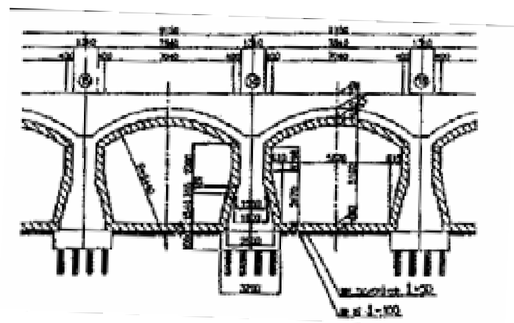
(1) Concrete lining

(2) Steel panel lining

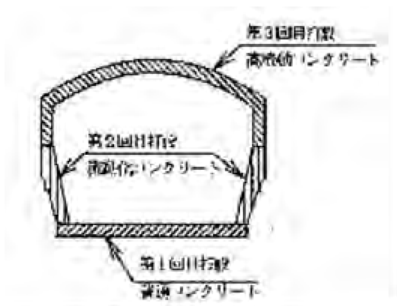
The Committee Report introduces several examples including seismic retrofitting of The Tokyo Brick Arch Viaduct between Tokyo and Hamamatsucho stations on the JR Yamanote Line (**Fig. 7**). This viaduct, completed in 1910, is the only continuous arch viaduct made of bricks still in service in Japan. In the seismic retrofitting work of this viaduct, the arches and sidewalls were strengthened with reinforced concrete inner lining to conserve the appearance of brickwork.

**(4) Stone structures**

Seismic retrofitting methods for brick structures can basically be applied to stone structures. In Japan, diagnosis and retrofitting of lighthouses built in the Meiji Period were carried out from 1990 to 2001. Examples of stone residences and lighthouses are introduced in the Committee Report.



(a) Strengthened areas



(b) Ordar of placing self-compacting concrete

**Fig. 7 Tokyo Brick Arch Viaduct**

## 6. A collection of retrofitting examples

Examples of seismic retrofitting applied mostly to designated cultural properties were surveyed, with the adopted methods being sorted out for each case. Isolation retrofitting projects have recently been increasing in number, becoming an effective means of seismic improvement for cultural property structures.

## 7. Afterword

The necessity of technologies for conservation/restoration of historic structures is expected to increase in the future. See the Committee Report for details of the state-of-the-art technologies. Technical manuals may become necessary regarding the diagnosis and repair/retrofitting technologies.


## Acknowledgment

The authors extend their sincere gratitude to the committee members for their committed efforts.


## References


1. The Japan Building Disaster Prevention Association: Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (in Japanese), 2001.
2. The Japan Building Disaster Prevention Association: Standard for Seismic Evaluation of Existing Steel-Encased and Reinforced Concrete Buildings (in Japanese), 1997.
3. GYOSEI Corp.: The examination methods for existing structures - Preservation and utilization of Modern Civil Engineering Heritage (in Japanese), 1998.
4. The Japanese Association for Conservation of Architectural Monuments: Report on the Restoration Work at the Former Courthouse of the Nagoya Court of Appeal, District Court and Ward Court, an Important Cultural Property designated by the Japanese Government (in Japanese), pp.293-294, 1989.11.
5. The Japanese Association for Conservation of Architectural Monuments: Report on the Restoration of Yamagata Prefectural Government Building and Assembly Hall, Volume 1 The Assembly Hall (in Japanese), p.264, 1991.3.
6. T. Saito: Overhead Railway of Tokyo Brick Arch - Design and Construction of Strengthening, The Journal of Japan Railway Civil Engineering Association (in Japanese), pp.300-302, 2003.4.