Committee Report: JCI-TC142A

Technical Committee on Establishment of Evaluation Method for Durability and Advanced Design of Post-installed Anchor in Concrete

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Abstract:

Adhesive and mechanical post-installed anchors are used for fastening incidental equipment in civil engineering/construction projects and for seismic rehabilitation of concrete structures in large numbers. There is an urgent need to evaluate the durability of these post-installed anchors, regardless of the type. While European and American standards already cover the evaluation of the durability including the effects of cracking of substrate concrete, creep and fatigue, and of the chemical resistance of adhesive, in Japan, almost no studies have been done on these matters. The purpose of this technical committee is to establish methods for evaluating the durability of post-installed anchors, and to reflect them in the design.

Keywords: Post-installed anchor, durability, design, mechanical anchor, and adhesive anchor

1. Introduction

Adhesive and mechanical post-installed anchors are used for fastening incidental equipment in civil engineering/construction projects and for seismic rehabilitation of concrete structures in large numbers. Construction projects for adding new functions required for increased longevity of concrete structures and for joining parts required for repair and reinforcement will continue to increase. In line with this, the use of post-installed anchors is anticipated to increase. The Japan Concrete Institute set up the Technical Committee on Fastening Technology for Concrete (1992 to 1993), and carried out a research study on the situation of post-installed anchor technology at that time.

Regarding the ceiling collapse that occurred in the Sasago Tunnel in December 2012, the accident is believed to have been caused by combined effects of multiple lacks of consideration with regard to adhesive post-installed anchors in each stage of design, execution of work, and maintenance[1)]. After this accident, efforts have been moving ahead to revise standards for designing post-installed anchors by various types of institutes. For example, Japan Society of Civil Engineers published "Recommendation of Design and Construction for Post-Installed

Anchor (Draft)"[2]. As there is an urgent need to evaluate, in particular, the durability of post-installed anchors, regardless of the anchor type, Japan is actively engaged in the collection of data and the development and verification of the evaluation methods on the durability including the effects of cracking of substrate concrete, creep and fatigue; and on the chemical resistance, with reference to the cases in Europe and America, which have already acquired various kinds of findings in this field, ahead of Japan.

Table-1: Committee Structure

Chairman	Minoru KUNIEDA	Gifu University
Vice-Chairman	Katsuhiko NAKANO	Chiba Institute of Technology
Secretary	Hitoshi HAMASAKI	Shibaura Institute of Technology
Secretary	Hitoshi WATANABE	Public Works Research Institute （～2015.3）
Secretary	Hirohisa KOGA	Public Works Research Institute （2015.4～）
Secretary	Munemori TAKAHASHI	HILTI Japan
Secretary	Naoshi UEDA	Kansai University
Committee Members	Katsuyoshi ARIKI	Urban Renaissance Agency
	Shigehiro ANDO	Sumitomo Osaka Cement
	Shigenobu IGUCHI	JR East
	Yoshinori ITO	Japan Testing Center for Construction Materials
	Shinya UCHIDA	Ritsumeikan University
	Masayuki OGAKI	Japan Construction Anchor Association
	Ema KATO	Port and Airport Research Institute
	Kazunori SAKAOKA	JR West
	Yasuhiko SATO	Hokkaido University
	Hiroshi NISHIDA	Nippon Expressway Research Institute
	Toshiya TADOKORO	Railway Technical Research Institute
	Tomoaki SUGIYAMA	Taisei Corporation
	Kohei NAGAI	The University of Tokyo
	Itaru NISHIZAKI	Public Works Research Institute
	Tomohisa MUKAI	Building Research Institute
	Daisuke Yamazaki	Sho-bond Corporation
	Yuichhiro Ryu	Railway Technical Research Institute(2014.7～)

Based on this situation, the Japan Concrete Institute set up the Technical Committee on Establishment of Evaluation Method for Durability and Advanced Design of Post-installed Anchor in Concrete (2014 to 2015), systematized the results of durability research studies being conducted actively, primarily in Japan, and investigated design methods and technologies developed in other countries with regard to the durability, to hold discussions which contribute to the enhancement of the durability design. Table-1 shows the committee structure, and the committee formed three working groups: Literature Investigation WG (head: Dr. Sugiyama), Technology Investigation WG (head: Mr. Takahashi), and Design WG (head: Dr. Nakano), and was engaged in the research study for two years.

2. Literature Investigation on Academic Papers (Literature Investigation WG)

2.1 Overview of Investigations

The purpose of this Working Group is to present the current situation of academic researches on post-installed anchors, and to be a document for future accumulation of technological findings. The report includes: situation of the publication of the research findings on post-installed anchors in Japan; review of the areas of researches on the design enhancement and the durability concerning multiple keywords; and a list of the investigated research papers as an appendix of the committee report.

Table-2: List of Investigated Literature

Society/Institute Name	Paper Title	Number of Papers
The Japan Concrete Institute	Journal of Advanced Concrete Technology	84
Architectural Institute of Japan	AIJ Journals	16
	AIJ Summaries of Academic Lectures	443
	AIJ Local Branch Report (9 branches)	52
	Journal of Structural Engineering	2
Japan Society of Civil Engineers	JSCE Journal	2
	Journal of Structural Engineering	3
	Proc. of the JSCE Annual Meetings	85
	Proc. of the JSCE Annual Meetings, Kanto Branch	6
	Proc. of the JSCE Annual Meetings, Kansai Branch	4
The Japan Society of Materials Science	Proceedings of the Concrete Structure Scenarios, JSMS	10
The Japanese Society for Non-Destructive Inspection	Journal of Symposium on Non-Destructive Inspections of Concrete Structures	5
American Concrete Institute	ACI Structural Journal	19
	ACI Materials Journal	1
American Society of Civil Engineers	Journal of Structural Engineering	6
International Federation for Structural Concrete	Structural Concrete	2
Total		740

Table-3: Keywords for Literature Investigation

Anchor Type (choose up to two items)	Brief Description	Keyword 1-2
Adhesive	: e.g. Organic or non-organic type; Fixing primarily with adhesion	496
Mechanical	: e.g. Expansion, undercutting; Fixing primarily by friction/bearing	185
Combined	: e.g. Hybrid anchor; Construction methods with multiple resistance	116
Other	: Other than those described above; including pre-installed anchors for reference	75
Method (choose up to three items)	Brief Description	Keyword 3-5
Experiment	: Researches by means of experiment	690
Analysis	: Research by means of analysis (e.g. FEM)	35
Design/evaluation method	: Researches involving studies/suggestions on design/evaluation methods	91
Investigation	: Researches involving on-the-spot investigations, etc.	7
Study Item 1 (choose up to three items)	Brief Description	Keyword 6-8
Short-term load (ultimate strength)	: Strength/proof stress of anchors including earthquake resistance; Primarily static load	595
Long-term load	: Properties in the conditions with continuous load, including the description about the durability	36
Chemical resistance	: Effects of chemicals like alkali; including researches solely on resin	8
Fatigue	: Effects of high-cycle repeated loads	27
Dynamic	: Behaviors and properties under dynamic loads	24
Resistance to fire/high temperature	: Properties under conditions of fire and/or high temperature (not as high as fire)	19
Radiation	: Effects of radiation, etc.	2
Testing technique	: Methods for testing performance, etc. in relation to maintenance	33
Effect of execution of work	: Variation in the performance, etc. in relation to quality assurance	54
Construction method development	: Development of new construction methods	176
Study Item 2 (choose up to three items)	Brief Description	Keyword 9-11
Anchorage length	: In relation to the effects of the embedment length	216
Edge (end)	: In relation to the effects of concrete edges; including covers	81
Group (spacing)	: In relation to the effects of anchor spacing and multiple anchors; including pitches/gauges	105
Concrete	: In relation to the effects of the strength, lightweight concrete, and substrates	171
Cracking	: In relation to the effects of cracking of substrates	16
Diameter	: In relation to the effects of the diameters of anchor bolts	107
Repetition	: Experimental load applied repeatedly in one way or plus-minus alternately	63
Loading condition (choose up to two items)	Brief Description	Keyword 12-13
Tension/tensile	: In relation to the resistance to tension	462
Shear/shearing	: In relation to the resistance to shear	203
Combined	: In relation to the resistance to tensile and sharing forces applied at the same time	72

The investigated literature is as listed in Table-2. The investigation was done on papers and synopses published primarily by the Japan Concrete Institute, the Architectural Institute of Japan, Japan Society of Civil Engineers, the Japan Society of Materials Science, and the Japanese Society for Non-Destructive Inspection. As for publications in countries outside Japan, those published by the American Concrete Institute (ACI) were selected as main targets. To be more specific, 740 publications were investigated. While most of the research papers describe architectural issues, the number of those dealing with civil engineering matters has been increasing in recent years.

The papers investigated are those describing the properties of joining areas that use single or multiple post-installed anchors. Those describing general performance of members including post-installed anchors in researches for using post-installed anchors in reinforcement of structural members were basically excluded from the investigation. While the investigation was done on the researches related to post-installed anchors, it also included major researches on pre-installed anchors (anchors located prior to the casting of concrete), if they were referred to by the descriptions of performance evaluation methods or experimental results, etc.The literature collected/investigated was classified using the keywords listed in Table-3. The keywords were selected to investigate/classify the literature according to post-installed anchor type (e.g. adhesive, mechanical), method of research (e.g. experiment, analysis, investigation), study item 1, primarily considered as an target of a research (e.g. ultimate strength, chemical resistance, long-term performance), study item 2, primarily considered as a key factor of an experiment (e.g. anchorage length, concrete), and target load (e.g. tensile load, shearing load, combined load), as shown in the table. The figures in the rightmost column of the table show the numbers of applicable papers investigated.

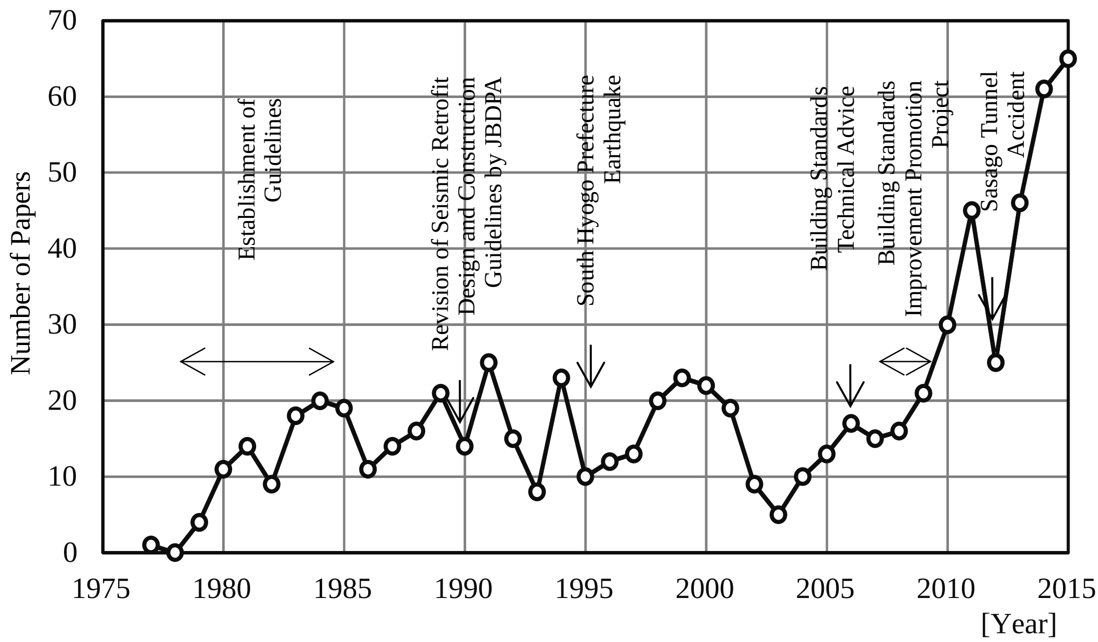

Fig.-1: Transition of the Number of Papers Published

Fig.-1 below shows the transition of the number of paper publications in Japan. The report also specifies the numbers of the published papers that are applicable to the above-mentioned keywords for each period (until 1985, 1986 to 1995, 1996 to 2005, and from 2006). There are transitions of the number of the published papers and the research fields, caused by factors including the social situation changes. The building standards improvement promotion project and the Sasago Tunnel accident have increased the number of papers published in recent years.

2.2 Research Introduction (Paper Review)

The basic resistance mechanism and design formulas of post-installed anchors are detailed in "Chapter 4: Load Capacity Mechanism" of "Fastening technology research committee report for concrete, Present state of the construction for the post anchor technology, April, 1994" published by JCI. This committee report reviews the research by describing the current situation of the area of researches on the design enhancement and the durability, focusing on the academic researches carried out thereafter. To be more specific, this committee report explains major researches carried out in the areas (1) through (9) listed below in Japan, focusing on matters related to the structural performance evaluation for which the above mentioned report contains less review, as well as matters related to the durability and long-term performance.

(1) Ultimate strength: The effects of the embedment length, edge distance, and group on the tensile and shearing strengths, etc.

(2) Substrate concrete: The effects of the cracking of low-strength concrete (15N/mm^2 or less) and high-strength concrete (36N/mm^2 or more) as the substrate, etc.

(3) Chemical resistance: The chemical resistance of the adhesive material (resin) in adhesive anchors[3)] and the alkali resistance added to the adhesive performance when embedded in concrete[4)] (refer to Fig.-2), etc.

(4) Long-term performance (durability): The durability for the long-term continuous load. Load levels and loading days until destruction[5)], bond creep properties[6)] (refer to Fig.-3), etc.

(5) Fatigue: Studies on repeated loads, etc.

(6) Dynamic behavior: Studies on drawing destruction caused by the effects of high-speed loads, etc.

(7) Fire/high temperature resistance: The effects of fire when embedded in concrete, and the effects of high-temperature of concrete as the substrate, etc.

(8) Inspection method: Researches on nondestructive evaluation of the filling condition of adhesive agents of adhesive post-installed anchors, etc.

(9) Effect of execution of work and quality control: The effects of the construction methods such as hole cleaning conditions and hole drilling methods on the proof stress (refer to Fig.-4), the effects of machinery construction, etc.

Refer to the report for the details of the above-mentioned research review.

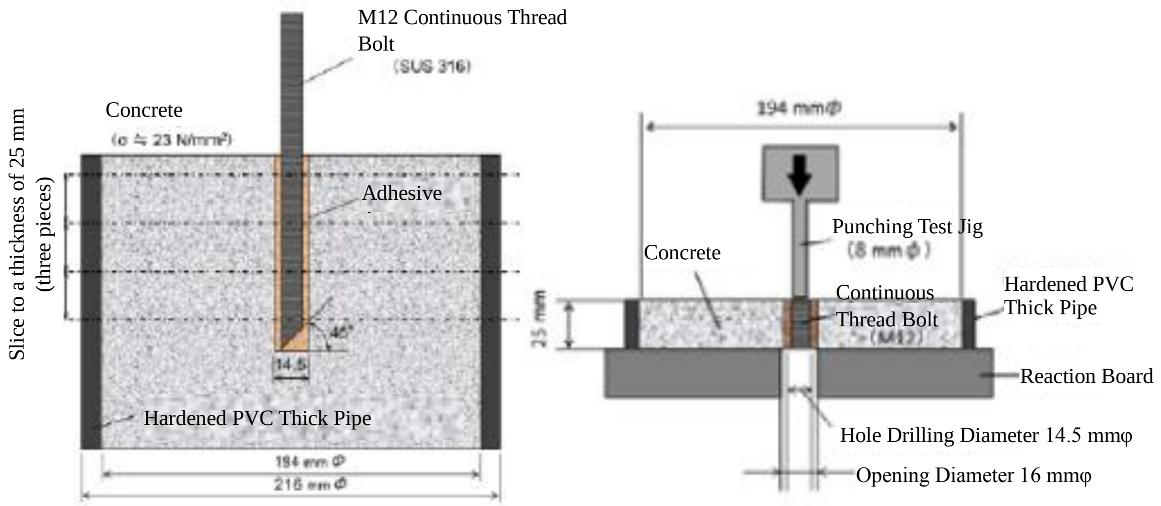

Fig.-2: Overview of Punching Test[4)]

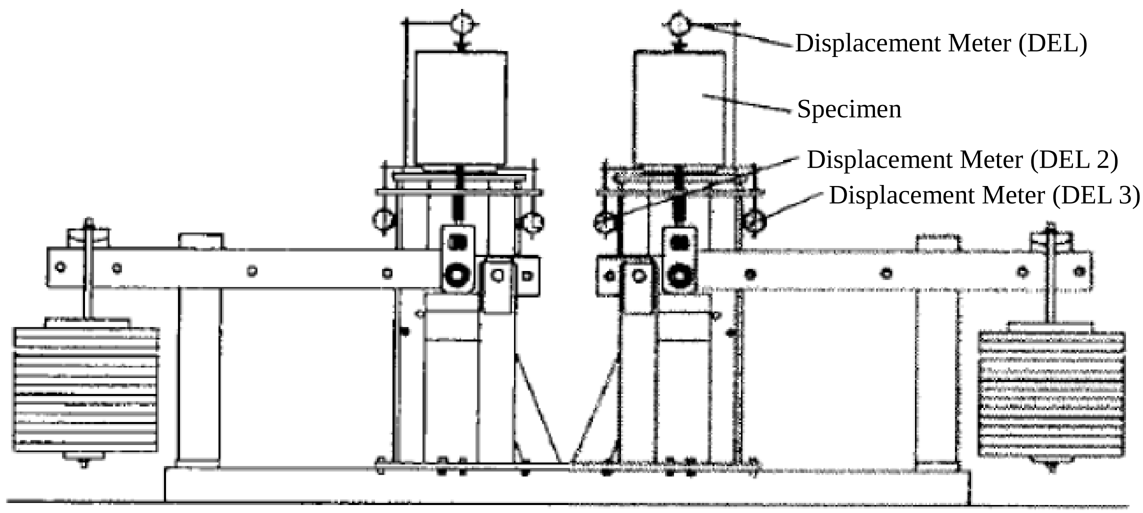

Fig.-3: Counterweight Loading Device[6)]

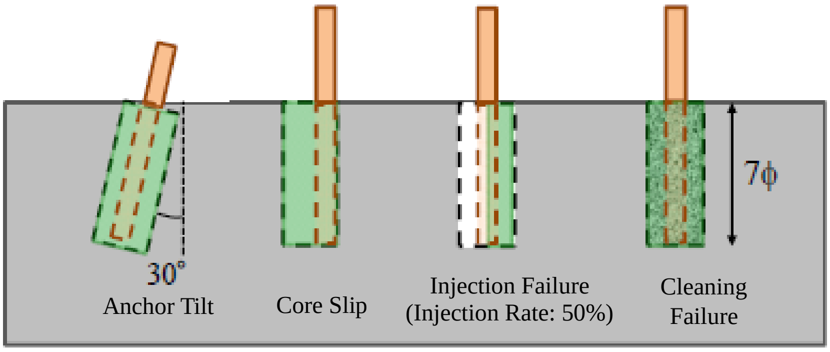

Fig.-4: Examples of Wrong Installation[7)]

3. Current Situation of Post-Installed Anchor Technology (Technology Investigation WG)

This WG reports the results of investigations on the current situations of the application of post-installed anchors in the fields of civil engineering and architecture, and of the performance evaluation methods. Post-installed anchors are largely classified into adhesive anchors, mechanical anchors, and other anchors. As the current situation of the application of post-installed anchors, Table-4 outlines the investigation results of the use, range of application and construction quality verification testing for each of civil engineering and architecture. The report also explains the current situation of evaluation methods of the performance of post-installed anchors and an example of methods used in Europe/America for evaluating the durability, as basic data for studying on the standardization of ideas on design. The latest information about the current situation of the qualifications of constructors is also summarized.

3.1. Current Situation of the Application of Post-Installed Anchors

In the field of architecture (structural usage), seismic rehabilitation and improvement work use post-installed anchors for adding reinforced concrete wall and steel frame braces. The most frequently used post-installed anchors for such construction work are the revolution and blowing types of adhesive capsule type anchors, for which the applicable guidelines specify the range of the application in detail. For the construction quality verification testing, on-site nondestructive testing is often covered by applicable guidelines, and the verification tests are performed at the specified frequency.

The field of architecture (usage for equipment/facility) is characterized by the fact that most of the equipment materials are fastened by post-installed anchors. In this range of application, mechanical anchors are used most frequently, as their fastening function works immediately after the installation. Although not all of the guidelines describe the construction quality verification testing in detail, visual inspections are required by some guidelines.

In the field of civil engineering, as the investigations were performed under the categories of Railway, Expressways, and General Civil Engineering, the report does not gather the results under the fields of "structural usage" and "usage for equipment/facility". Table-4 outlines these investigation results. Note that the information listed under the field of Railway was provided by East Japan Railway Company (hereafter referred to as JR EAST) and West Japan Railway Company (hereafter referred to as JR WEST), and the information listed under the field of Expressway was provided by Nippon Expressway Research Institute Company Limited (hereafter referred as NEXCO).

Table-4: Current Situation of the Application of Post-Installed Anchors (Outline)

Field		Use	Range of Application	Construction Quality Verification Testing
Construction	Structure	Seismic rehabilitation ・Addition of reinforced concrete walls ・Addition of steel frame braces	・Improved body driving type ・Adhesive capsule type anchors (revolution/blowing types) Anchor bolt diameters, embedment lengths, and anchor bolt lengths of each of the types are defined.	Performance verification testing ・Performed at laboratories of manufacturers, etc. On-site nondestructive testing ・Tension test: Three anchors per lot for each diameter per day ・Hammering test: All
	Equipment	Fastening of equipment materials Sashes, gangways, rainwater gutters, signboards, shelves for outdoor units, lightweight ceilings, stands, vending machines, scaffold ties, scaffold brackets, elevator guide rails, electrical equipment, etc.	・Mechanical anchors Shaft driving type, internal cone driving type, body driving type, sleeve driving type, etc. ・Adhesive anchors Capsule type anchors (revolution/blowing types)	Some supervision guidelines prescribe: Performance verification: Examination results of manufacturers, etc. Construction verification: Visual inspections (1) Types, diameters, positions, quantities, angles, etc. (2) Hardening of adhesive anchors
Civil Engineering	Structure (Railway) (Expressway)	Bearing widening work Prevention work for bridge fall Precast railings Utility pole supporting beam extension	・Adhesive anchors Capsule type, injection type ・Mechanical anchor (JR WEST: Usable for simple structures)	JR EAST: Pulling tests (the frequency differs depending on the application), measurements of anchor lengths (adhesive anchors with diameters of 20 mm or more) NEXCO: Benchmark tests, regular control tests, daily control tests (with the specification of frequency and quantity to be tested)
	Equipment	Electrical equipment & fastening of incidental structures Handrails, drop arms, signal foundations, footholds for inspections, drainage gutters, signs, peeling prevention nets or fiber sheets, temporary equipment	・Adhesive anchors Capsule type, injection type ・Mechanical anchors Undercut type, expansion type (driving type, fastening type)	JR EAST: Pulling tests (the frequency differs depending on the application) NEXCO: Benchmark tests, regular control tests, daily control tests (with the specification of frequency and quantity to be tested)

In the field of civil engineering (structural usage), seismic rehabilitation of bridges including the bearing widening work and prevention work for bridge fall, or joining of precast railings, utility pole supporting beam extension, and other construction work use post-installed anchors. These construction projects primarily use adhesive anchors, and their range of application is prescribed in the specifications for each business operator. This applies also to the construction quality verification testing.

In the field of civil engineering (usage for equipment/facility), post-installed anchors are used in a lot of fastening work for handrails, drop arms, signal foundations, footholds for inspections, drainage gutters, signs, peeling prevention nets, fiber sheets, and others. Their range of application specifies adhesive or mechanical anchors.

In this way, seismic rehabilitation of structures uses adhesive anchors in the field of structure for civil engineering and construction, and guidelines and/or specifications prescribe the range of application and the construction quality verification testing. This applies also to the field of equipment. However, the investigation this time has revealed large differences in the range of application and the construction quality verification testing among guidelines/specifications, especially in the equipment field.

3.2 Current Situation of the Methods for Evaluating Post-Installed Anchors

Table-5 compares Japan and Europe/America with regard to the systems to evaluate the quality and performance of post-installed anchors. The systems can be broadly divided into the specification specifying type and the performance specifying type according to the differences in design methods. In Japan, Japan Construction Anchor Association (hereafter referred to JCAA) operates a product certification project, to verify that anchors satisfy the performance required by the association. With an increase in the variety of the types of post-installed anchors and the diversified construction methods in recent years, JCAA began a new system, "Construction Method/Product Certification", to judge whether the product satisfies the conditions, judgment formulas, and set values specified by the applicant. The system is also characterized by the fact that it is operated in combination with a qualification system for constructors for the purpose of reducing the effects of construction work, as described in the next section. In Europe and America, European Organization for Technical Approvals (EOTA) and the American Concrete Institute (hereafter referred to as ACI) prescribe the certification standards. In their systems, reliability tests for verifying the stability of the construction quality and use conditions tests for verifying the conditions where products are used and the durability, etc. are performed against the benchmark test results, and the performance evaluation is performed for giving material characteristic values with the benchmark test results reduced according to the test results. Each factor has its minimum requirements set.

Table-5: Comparison Table for Product Certification Systems between Japan and Europe/America

Issuing Organization	JCAA		EOTA	ACI
Classification	Specification Specifying Type	Performance Specifying Type	Performance Specifying Type	
Evaluation Method	Pass/Fail Judgment	Pass/Fail Judgment	Performance Evaluation	
Explanation	Verify whether the test results satisfy the values of the judgment formulas.	Verify whether the test results satisfy the conditions, judgment formulas, and set values specified by the applicant.	Reduce the benchmark test results by the various types of effect test result factors. However, each factor has its minimum requirements set.	

3.3 Post-Installed Anchor Construction Qualification System

In Japan, JCAA and Post-Installed Anchor Construction Cooperative (hereafter referred to as AAC) operate a system for qualifying constructors. JCAA and AAC administer examinations in accordance with qualification types, and specify the ranges of application for the construction qualifications. In America, ACI operates a construction qualification system that passes/fails applicants through written and practical examinations. One of the characteristics of the system is that its practical examination requires the upward construction method of adhesive anchors.

3.4 Methods for Testing Post-Installed Anchors

The tensile and shear test methods for conducting the performance evaluation of post-installed anchors in places like laboratories were investigated. The test methods presented by EOTA and ACT were the same. Although JCAA specifies the standard test method and the set-test method for certifying products, they are not available to public. Standard Specifications for Civil Engineering Works published by JR EAST (revised in August, 2015) include a tensile test method.

3.5 Properties of Resin for Adhesive Anchors

There are various methods for evaluating resin forming adhesive anchors in Japan and Europe/America. In Japan, normally, the cured resin testing is performed, and the values are specified as performance requirements by owners, various types of guidelines and supervision guidelines, and the product certification system of JCAA. The systems in Europe and America specify the properties and performance through testing in accordance with resin types.

3.6 Performance and Evaluation of Durability

For evaluation on the durability, JCAA performs alkaline resistance tests using cured resin. EOTA and ACT also perform alkaline resistance tests, although the method is different from that used at JCAA, sulfur dioxide resistance tests, and tensile creep tests and freezing and thawing tests with consideration of environmental temperatures. In recent years, JR EAST also specified the methods for alkaline resistance tests and tensile creep tests. Anyway, the task that needs to be achieved is to clarify the acceleration factor of the facilitating conditions and the consistency with the durability in the actual environment, in the durability evaluation performed by each organization.

3.7 Summary

The investigation by the WG has revealed that post-installed anchors are used in a broad variety of applications. However, the current situation is that there are no unified rules among the fields and groups for the range of application, construction quality verification, and product performance evaluation. To seek a design with common philosophy and its enhancement, standardized product performance evaluation of post-installed anchors and established methods for evaluating the durability must be achieved in the future.

4. Clarification of Issues in Designing Post-Installed Anchors and Design Enhancement (Design WG)

4.1 Introduction

This WG organizes the current philosophies for designing "post-installed anchors" in the fields of architecture and civil engineering, and attempts to make suggestions for the purpose of clarifying the issues in enhancing their design.

4.2 Designing Post-Installed Anchors in the Field of Architecture

In this section, major construction applications of post-installed anchors are divided into the following two cases: for securing structural members including reinforcing members to the existing buildings (building construction), and for securing non-structural members including equipment and facility to floors, walls, and ceilings of buildings (securing of accessories), to show the relations with the related standards/guidelines. Each of the sub-sections describes an overview (history of changes and abstract). Fig.-5 shows the standards/guidelines with regard to post-installed anchors in the field of architecture.

The standards/guidelines for building construction projects include "Design/Construction

Guidelines for Post-Installed Anchors and Continuous Fibers, Notification No. 1024 of the Ministry of Land Infrastructure, Transport and Tourism[8)]", one of the legal regulations under the Building Standards Law; and "Design Guidelines for Seismic Rehabilitation of Existing Reinforced Concrete Buildings and Commentary, 2001 Revision, The Japan Building Disaster Prevention Association[9)]", applicable to unfit buildings under the Act on Promotion of Seismic Retrofitting of Buildings (Seismic Retrofitting Promotion Act). For securing accessories, there is a legal regulation under the Building Standards Law, "Notification on Hot-Water Supply Equipment Toppling Prevention Measures, Notification No. 1338 of the Ministry of Land Infrastructure, Transport and Tourism; and guidelines, "Guidelines for Seismic Design and Construction of Building Equipment, The Building Center of Japan[10)]" and " Guidelines for Seismic Design of Non-utility Generation Equipment, Nippon Engine Generator Association[11)]". Also, "Design Recommendations for Composite Construction, Part 4: Design Guideline for Post-installed Anchor and Commentary, 2010 Revision, The Architectural Institute of Japan[12)]" is a guideline that covers both structural and non-structural members.

4.3 Designing Post-Installed Anchors in the Field of Civil Engineering

This section describes "JSCE Recommendations for Design and Construction of Post-installed Anchors in Concrete, Japan Society of Civil Engineers[2)]" as guidelines for designing post-installed anchors for the use in civil engineering; design/construction guidelines on railway structures; and design/guidelines on road structures.

Fig.-6 illustrates the standard document structure employed by Japan Society of Civil Engineers. The post-installed anchor construction method is used primarily for two purposes: using anchors as part of structures, for example, for fixing bridge fall prevention devices or seismic rehabilitation of pillars/walls; and using anchors in a way that they affect only the concrete as the substrate (post-installed anchor part) without having direct impact on structures, for example, for installation of incidental equipment such as ducts or signs. The guidelines of Japan Society of Civil Engineers describe the methods for verifying the performance of post-installed anchors in the later use, while the anchors for the former use are designed according to the Standard Specifications for Concrete Structures, Design". This committee report describes the overview of the Standard Specifications.

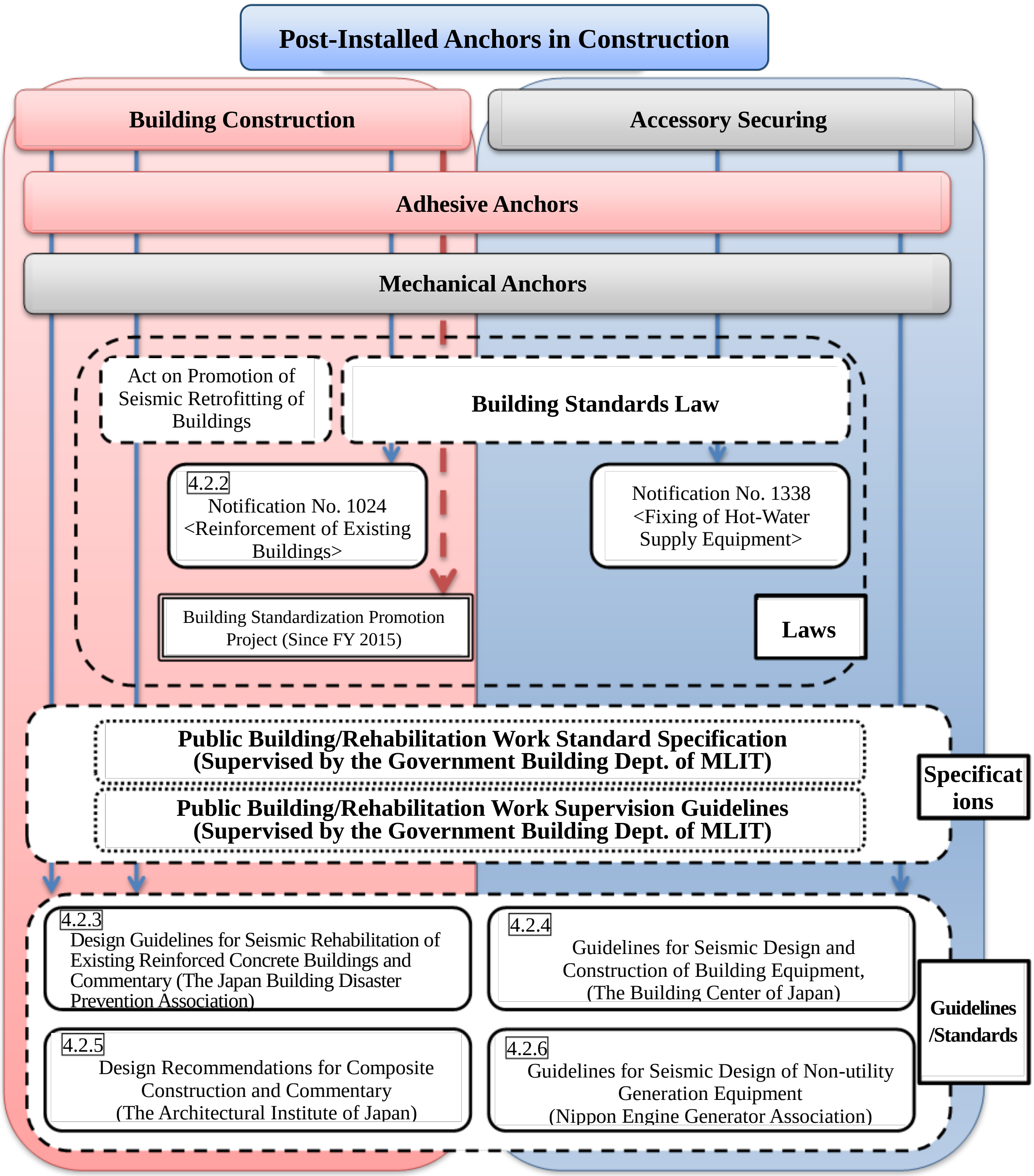

Fig.-5 Standards/Guidelines for Construction

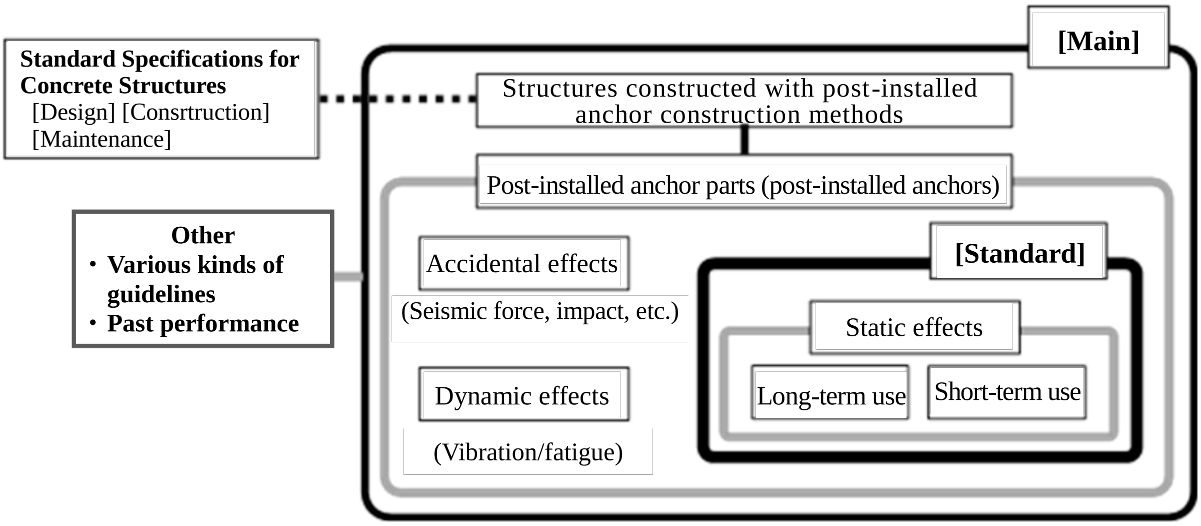

Fig.-6 Standard Structure Employed by Japan Society of Civil Engineers [2)]

One of the documents that include technical standards with regard to post-installed anchors used in railway structures is "Guide to Design and Construction for Post-Installed Anchor" (hereafter referred to as the Guide) published by the Japanese National Railways in 1985, and by the Railway Technical Research Institute in 1987. The Guide consists of: scope, application categories, types & construction methods, materials, design, execution of work, and tests.

For the selection of post-installed anchors, for example, JR EAST makes a selection considering the durability of the materials, workability, and directions allowing the construction work to be executed, with reference to Table-6. Some railway companies have their internal rules and/or manuals concerning the design and construction with reference to the Guide, and perform construction using post-installed anchors in accordance with their actual situations.

Post-installed anchors are used for the construction work on expressways as follows: adhesive anchors are used for repair/reinforcement of concrete structures, for example, seismic rehabilitation of reinforced concrete bridge piers, widening of edges, and installation of bridge fall prevention structures; and mechanical anchors are used for the installation of attachments for bridges such as inspection passages and drain pipes, and of incidental equipment inside tunnels (jet fans and signals, etc). At East Nippon Expressway, Central Nippon Expressway, and West Nippon Expressway, "Post-Installed Anchor Management Guidelines (Draft)" was set up in 1996 for the construction management of the seismic rehabilitation using adhesive anchors as rules concerning post-installed anchors. Currently, "Design Guidelines Part 2, Bridge Maintenance" incorporates the guidelines with regard to the design, and "Structure Construction Management Guidelines" describe the execution of work and management.

Table-6: Types of/Where to Use Post-Installed Anchors (JR EAST)

Type		Construction Method	Durability of Materials: Filler	Durability of Materials: Anchor bolt	Workability	Direction Allowing Construction: Upward	Direction Allowing Construction: Downward	Direction Allowing Construction: Sideways	Component to be Installed Using Post-Installed Anchors: Type	Component to be Installed Using Post-Installed Anchors: Example
Adhesive	Inorganic	Capsule	○	○	△	○	○	○	Structural member *1	Bearing widening work, prevention work for bridge fall, and precast railings
		Injection	○	○	○	X	○	○	Non-structural member	
	Organic	Capsule	△	○	○	△	○	○	Structural member *1	
		Injection	△	○	△	△	○	○	Non-structural member *2	
Mechanical (Undercut)		--	△	○	○	○	○	○	Non-structural member	Drop arms, footholds for inspections
Mechanical (Expansion)		Driving type	–	△	△	○	○	○	Non-structural member *3	Drainage gutters, railway signs, temporary equipment
		Fastening type	–	△	○	○	○	○		

Legends ○: Very good △: Not very good X: Not acceptable

*1: Those subjected to fatigue due to the load of trains are excluded.

*2: The temperature should not be higher than 80 °C under the service conditions.

*3: Those subjected to a heavy tensile load or repeated load applied for a long period, and used for the construction of a portion that has a large impact on a train or passengers/the public are excluded.

4.4 Comparison with Design Methods in Countries outside Japan

This section describes the differences among EOTA, ACI, the construction in Japan, and the civil engineering in Japan in ways of thinking toward safety coefficients, setting characteristic values, and time (including the durability), by clarifying the differences in the preconditions such as the attitude toward the construction quality and maintenance in designing.

4.5 Recommendations on Design

This section provides recommendations by this committee on the future design and selection of post-installed anchors. Anchoring methods using post-installed anchors are classified into two methods, fastening and connecting. With fastening, anchors work as if they are anchoring equipment with short-length anchor bolts. This method is assumed to be used in situations where the stress redistribution is difficult like corn-type failures and bond splitting failures. With connecting, anchors work as if they are connecting between members with long anchor bolts. This method is assumed to be used in situations where the stress redistribution is possible like yielding of anchor bolts.

Fig.-7 shows a flow for selecting post-installed anchors. First, the importance of the anchor needs to be clarified based on the effects of the anchor failure on the structural safety and any third party, and on the required functions. Then, considering the matters including the width of the member of the concrete structure where the anchor will be installed, the method of considering uncertainty concerning the environment and uncertainty concerning the execution of work is examined based on the above-mentioned importance, as well as any difference between the actual environment where the anchor will be installed and the standard environment of the test by which the quality of the post-installed anchor to use was verified, to determine the method of anchoring the anchor. This means, the allowable value needs to be set in the allowable stress intensity design method, and the safety coefficient in the limit state design method. Finally, items that do not allow quantitative verification like the difficulty of the maintenance should be examined, to determine the anchor method and the anchor type to be used.

The quality and reliability of post-installed anchors are considered to be ensured by setting up the standard tests in accordance with the impact of the environmental effect and the impact of the dynamic effect. Fig.-8 illustrates the effect categories, and Table-7 and Table-8 list examples for each category. The effects will be classified into nine effect categories, and the anchors that have passed the standard tests performed according to the category will be used. Of course, there is a difference between the conditions under which the effects considered/set in the standard tests and the actual effects, so such effects need to be considered as the safety coefficient.

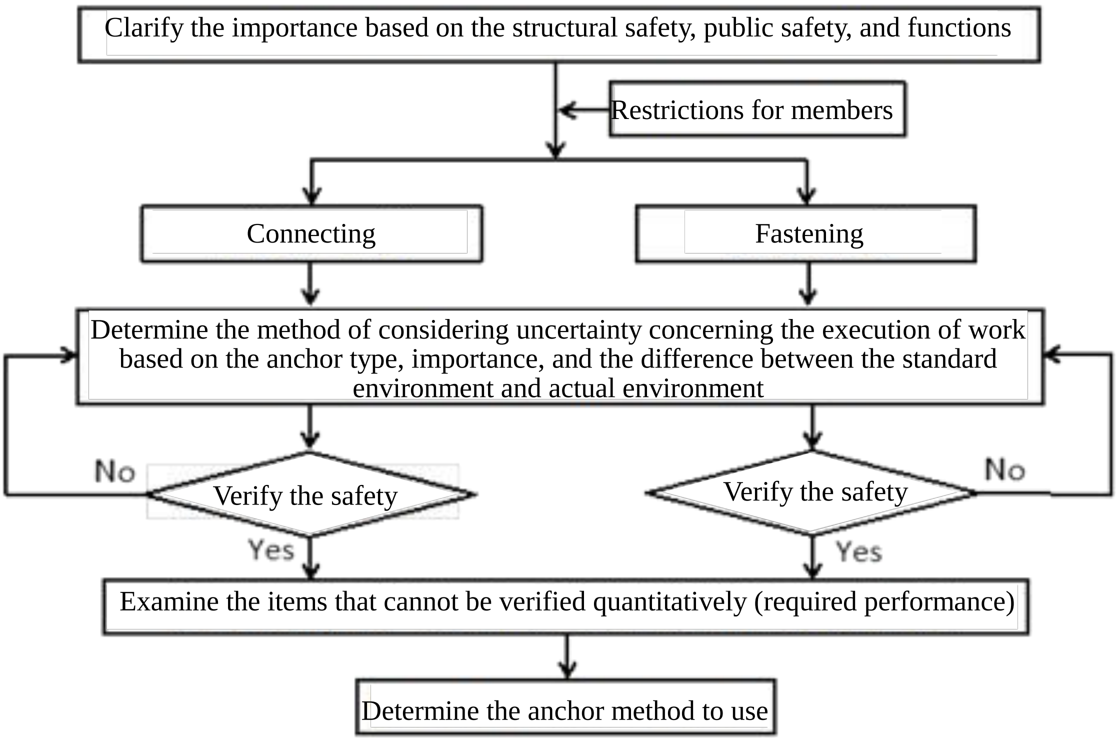

Fig.-7: Flow of Selection of Post-Installed Anchor (Draft)

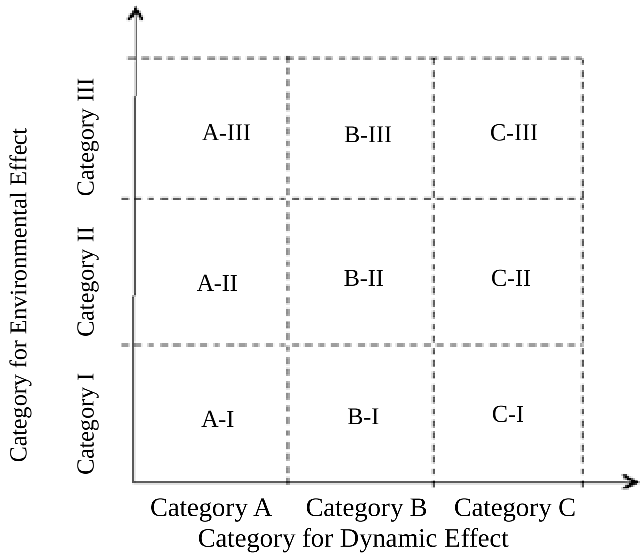

Fig.-8: Effect Categories in Standard Tests (Draft)

Table-7: Examples of Environmental Effect Categories

Environmental Effect Category I	In an environment with normal temperature, without dryness or moisture.
Environmental Effect Category II	In an environment where the temperature is always low and the temperature is always high.
Environmental Effect Category III	Subjected to freezing and thawing. Subjected to chemical erosion.

Table-8: Examples of Dynamic Effect Categories

Dynamic Effect Category A	Subjected to a short-term static load.
Dynamic Effect Category B	Subjected to a long-term static load. Subjected to repeated loads.
Dynamic Effect Category C	Subjected to fatigue and/or vibration.

5. Summary

With regard to post-installed anchors, this committee was able to describe the situation of the academic researches, the history of technical changes and the current situation of the standards, sorted design methods, views on how the design should be in the future and on the durability design. The original purpose of this committee was to propose durability design methods for post-installed anchors. However, findings in Japan on this area are much less than expected, and there are items on which no studies have been done as of now. More data needs to be accumulated with reference to the progress of the academic research reported in this committee report and other matters.

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