

Establishment of the JSCE Recommendations for Design and Construction of Post-installed Anchors in Concrete

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Abstract

The “Recommendations for Design and Construction of Post-installed Anchors in Concrete (Draft)” was established by the Japan Society of Civil Engineers in March 2014. The Japan Society of Civil Engineers is the first to adopt recommendations for post-installed anchors. In this paper the basic concepts of the recommendations are described, and the design, construction, and maintenance contents are described in outline.

Keywords: Post-installed anchors, metal anchors, adhesive anchors, safety, third party impact, ancillary equipment, professional engineers, maintenance

1. Introduction

Post-installed anchors are widely used in the civil engineering concrete field for integrating new members to a structure such as seismic retrofit of bridge piers, installing bridge fall prevention devices, re-levelling breakwaters and levees, for installation of ancillary structures such as safety barriers, soundproof barriers, inspection passages, signs, etc., or for suspending blocks during construction, etc. However, post-installed anchors were considered to be a part of the ancillary equipment, so in the civil engineering field there has not been a unified guide for them until now.

Therefore in April 2012 the JSCE Concrete Committee commissioned Japan Construction Anchor Association to establish the “Sub-committee on Post-installed Anchors” (chairperson: Professor Hidetaka Umehara), to prepare the Recommendations for Design and Construction of Post-installed Anchors in Concrete, and to conduct survey research. This was initially scheduled for publication in March 2013, but additional investigations were carried out to incorporate the contents of the report of the committee investigating the accident in the Sasago Tunnel on the Chuo Expressway in which ceiling panels and partition wall panels installed for ventilation collapsed, so the Recommendations were published in March 2014.

This paper describes the basic concepts of the Recommendations, and a summary of the contents for the design, construction, and maintenance of post-installed anchors in civil engineering structures.

2. Outline of the Recommendations

The structure and scope of application of the Recommendations is shown in Fig. 1. Applications of post-installed anchors are broadly classified into application as a part of a structure, such as fixing bridge fall prevention devices, seismic retrofit of columns and walls, etc., and cases where the structure is not directly affected, namely cases where only the parent material, concrete, is affected, such as for installation of ancillary equipment such as ducts or signs (defined as post-installed anchor parts). These Recommendations mainly apply to methods of verification of the performance of the latter. In the case of the former where post-installed anchors are used to integrate the object installed with the structure, performance

verification is carried out in accordance with the Design section of the Standard Specifications for Concrete Structures.

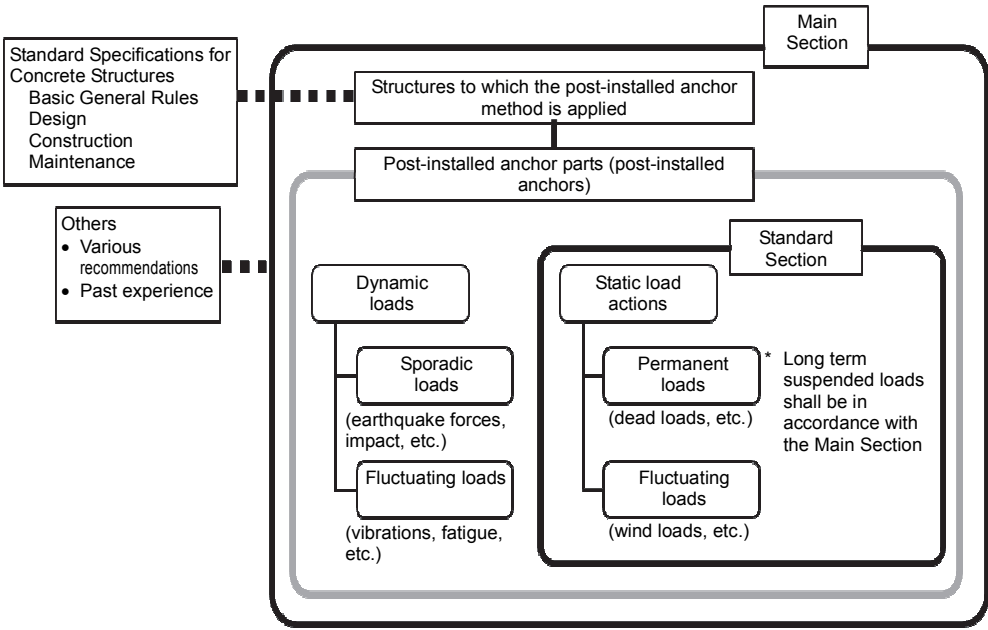


Fig. 1 Structure and scope of application of the (draft) Recommendations

Chapter 1	General	3.3	Quality of post-installed anchors
1.1	General	3.4	Parent material
1.2	Scope	Chapter 4	Construction
1.3	Definition of terminology	4.1	General
Chapter 2	Performance Verification of Structures to which the Post-installed Anchor Method is Applied	4.2	Site survey
2.1	General	4.3	Construction planning
2.2	Required performance	4.4	Hole drilling and anchoring
2.3	Basic rules of performance verification	4.5	Construction control
2.4	Loads	4.6	Inspection
2.5	Calculation of response values	4.7	Installation of ancillary equipment
2.6	Safety verification of post-installed anchor parts	4.8	Records
Chapter 3	Materials and Parent Material	Chapter 5	Maintenance
3.1	General	5.1	General
3.2	Types of post-installed anchors	5.2	Diagnosis
		5.3	Maintenance records

Fig. 2 Contents of the Main Section

The Recommendations consist of a “Main Section” and a “Standard Section”. The Main Section describes concepts and basic rules for design, construction, and maintenance based on the concept of performance-based design, content that can be widely applied in the civil engineering field using appropriate methods. On the other hand, the Standard section describes the quality of post installation anchors used and specific standard methods of design, construction, and maintenance, under the limited conditions of environment of use and type of load actions as shown in Fig. 1, taking into consideration the efficiency of design and construction, and convenience. In particular, from the point of view of types of load

actions, the Standard Section is only applicable to dead loads and actions whose time effect is small, which even though a variable load can be converted into a static load. Also, the text of the Standard Section states “(the Recommendations) shall not be used for suspended ancillary equipment”, and in the Main Section it is stated that at the present time it is necessary to avoid application as much as possible based on similar statements in the Commentary rather than the main text, taking into consideration future development of post-installed anchors. This is because at the present time data on the long term behavior, durability, seismic resistance, fatigue loading, etc., of post-installed anchors and post-installed anchor parts subject to continuous loading has not been accumulated sufficiently. Fig. 2 and Fig. 3 show the contents of the Main Section and the Standard Section respectively.

Chapter 1 General	Chapter 3 Materials and Parent Material
1.1 General	3.1 General
1.2 Scope	3.2 Post-installed anchors
1.3 Definition of terminology	3.3 Parent material
Chapter 2 Design of Post-installed Anchor Parts	Chapter 4 Construction
2.1 General	4.1 General
2.2 Basic rules of design	4.2 Site survey
2.3 Safety factors	4.3 Construction planning
2.4 Material design values	4.4 Drilling holes
2.5 Calculation of dimensions used in design	4.5 Anchoring
2.6 Load	4.6 Construction control
2.7 Calculation of response values	4.7 Inspection
2.8 Analysis for ultimate limit state	4.8 Installation of ancillary equipment
2.9 Calculation of the load resistance of post-installed anchor parts	4.9 Records
2.10 Details	Chapter 5 Maintenance
	5.1 General
	5.2 Diagnosis
	5.3 Records

Fig. 3 Contents of the Standard section

The content that was affected by the Sasago Tunnel ceiling panel and partition wall collapse accident survey report corresponds to the following items.

- a) Discussion on the issues regarding application to suspension
- b) Provision of a section on maintenance, to indicate the importance of maintenance
- c) Discussion on the necessity of back-up taking into consideration the degree to which third parties are impacted
- d) Setting the design life for post-installed anchor parts
- e) Discussion on the importance of records at the stages of design, construction, and maintenance
- f) Introduction of a method of taking into consideration non-uniformity of load distribution where load is resisted by several anchors
- g) Discussion of the importance of methods of making a load act during inspection

- h) Discussion on the limitations of hammering test for evaluating the performance of post-installed anchor parts
- i) Discussion of close inspection in maintenance, and if close inspection is difficult monitoring is to be applied

3. Types of Post-installed Anchors and Anchorage Principles

Post-installed anchors are classified into metal anchors, adhesive anchors, and other anchors such as plastic or for application to ALC panels, etc. Metal anchors are classified into metal expanding anchors and metal expanding end anchors. The anchorage principle is shown in Fig. 4. Metal expanding anchors are anchored by the “wedge action” obtained by opening out the expanding portion at the end, by impacting or rotating a part of the post-installed anchor. Therefore, the extent of the anchorage force is determined by bearing pressure and friction force between the hole wall of the parent material concrete and the expanding portion of the anchor, which is mainly determined by the strength of the parent material concrete. Metal expanding end anchors are also anchored by the “wedge action” of the expanding part of the end, but by providing a larger end expanding portion by enlarging the diameter of the bottom of the hole, the anchorage force is mainly provided by the support pressure of the parent material concrete.

As shown in Fig. 5, adhesive anchors are anchored by filling the gap between the hole wall in the parent material concrete and the bar of the anchor with adhesive, through the adhesive (bond) force between the concrete hole wall and the bar of the anchor, and meshing between aggregate such as No. 2-6 silica sand mixed in the adhesive and the hole wall concrete surface. The adhesive can be organic or inorganic, and if heat resistance or fire resistance is necessary, inorganic adhesive is widely used. The extent of the anchorage force is determined by the strength of the parent material concrete, as well as by the degree of irregularity of the hole concrete surface and the anchor bar and the shearing resistance of the adhesive.

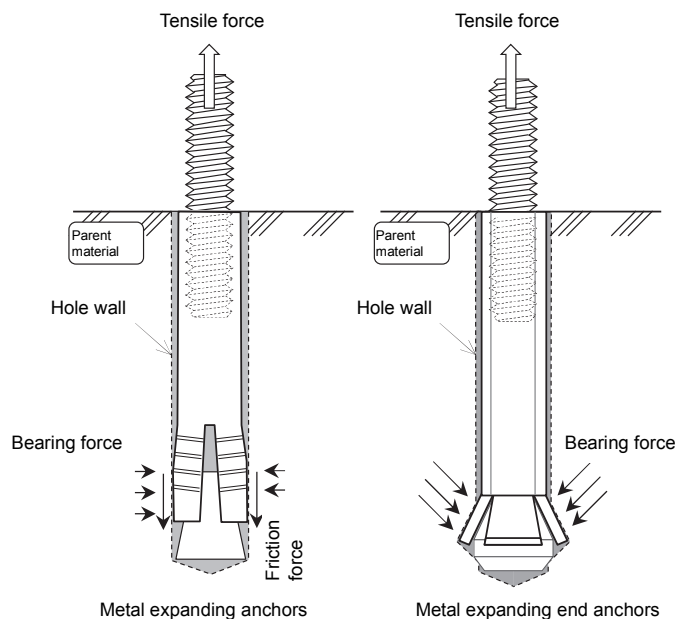


Fig. 4 Anchorage principle of metal anchors

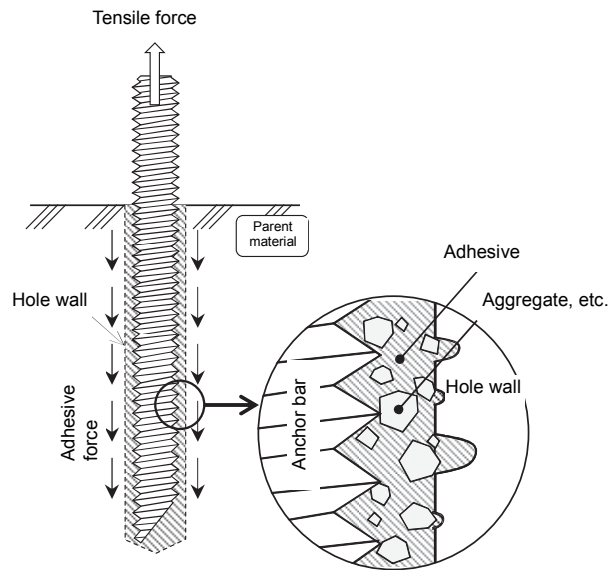


Fig. 5 Anchorage principle of adhesive anchors

4. Outline of the Main Section

The content of the Main section is the basic concepts and rules for the design, construction, and maintenance of structures to which post-installed anchors are applied and post-installed anchor parts, based on the system of performance verification.

As shown previously in Fig. 2, the Main Section consists of 5 sections: General, Performance Verification, Materials, Construction, and Maintenance, in accordance with the series of work flows (see Fig. 6) ranging from design and construction through to maintenance.

In Section 1 “General”, the applications of post-installed anchors and the important points at each work stage are described, and the division of the Main Section and the Standard Section and the relationship of the Recommendations to other recommendations in particular the Standard Specifications for Concrete Structures are explained in outline.

Terminology used throughout the whole Recommendations whose differentiation in usage should be particularly noted includes post-installed anchor method, post-installed anchor part, and post-installed anchor. The definitions of each of these is as follows, and when indicating all structures to which this method is applied, it is referred to as “structures to which the post-installed anchor method is applied” (refer to Fig. 7).

- Post-installed anchor method: A generic term for the design and construction of the method of drilling a hole in the parent material, and inserting a post-installed anchor inside the hole, and anchoring it.
- Post-installed anchor part: A part that includes the parent material to which the post-installed anchor is anchored and the main body and connecting bar of a metal anchor or the adhesive and anchor bar of an adhesive anchor.

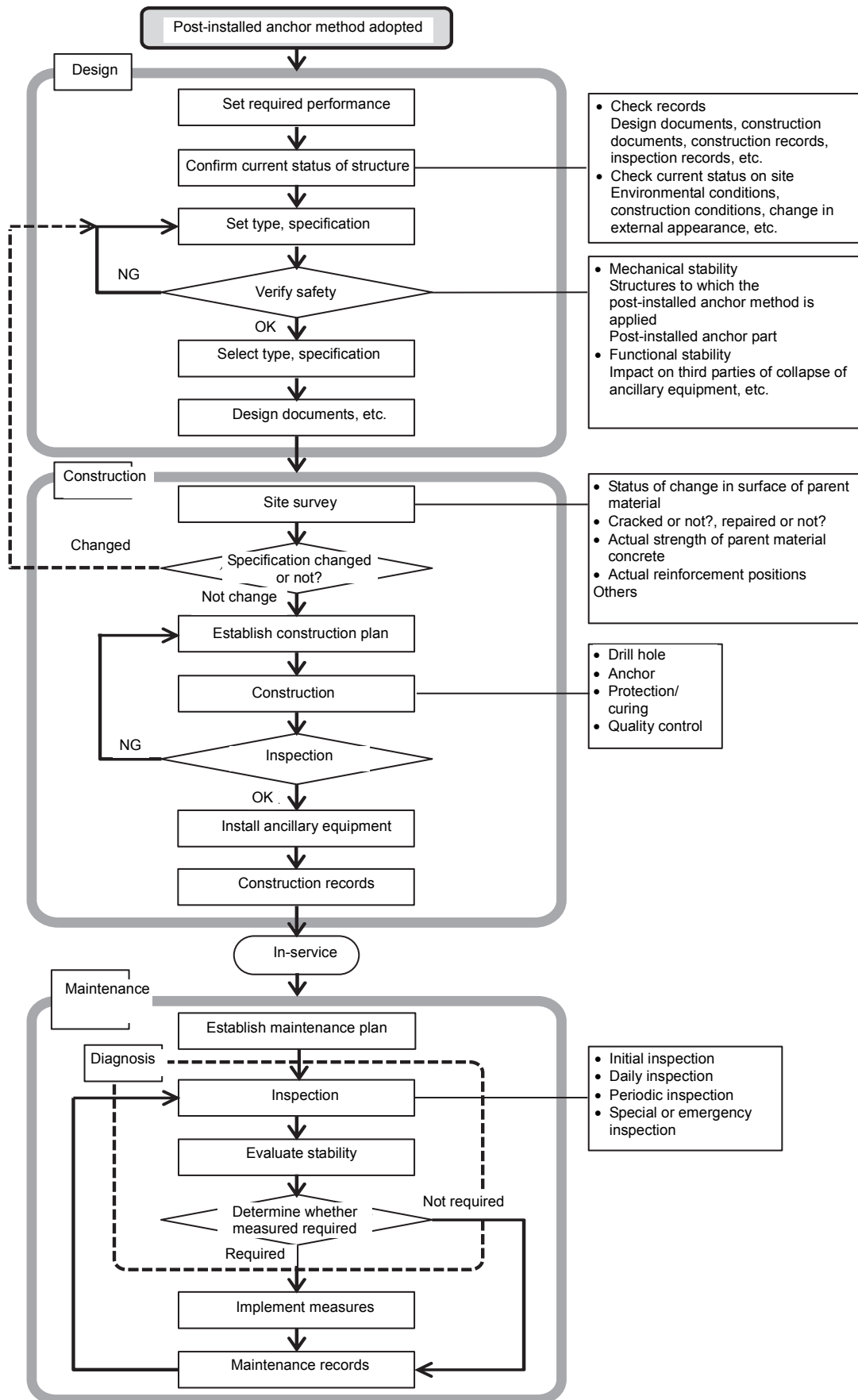


Fig. 6 Flow of design, construction, and maintenance for the post-installed anchor method (Main Section Commentary Fig. 1.1.2)

- Post-installed anchor: That which is embedded in a drilled hole in the parent material in order to fix ancillary equipment to the parent material (hereafter, abbreviated).

Section 2 “Performance Verification of Structures to which the Post-installed Anchor Method is Applied” adheres to the flow of verification of the Design Section of the Standard Specifications for Concrete Structures. While aiming for consistency with the Design Section of the Standard Specifications for Concrete Structures, the fundamental concepts particular to the post-installed anchor method and the conditions assumed for verification are described. Generally the Standard Specifications for Concrete Structures is applied when the object is a structures to which the post-installed anchor method is applied, and the Main Section and Standard Section of these Recommendations are followed for verification of the post-installed anchor part and the post-installed anchor itself.

In Section 3 “Materials and Parent Material” the types of post-installed anchor and the required quality is explained in outline, and the quality required from the parent material concrete is indicated. In particular, as a rule it is required that the parent material concrete be in an intact state without cracking and fragile parts in order for the post-installed anchor method to be applied, and there is a commentary on ensuring integrity.

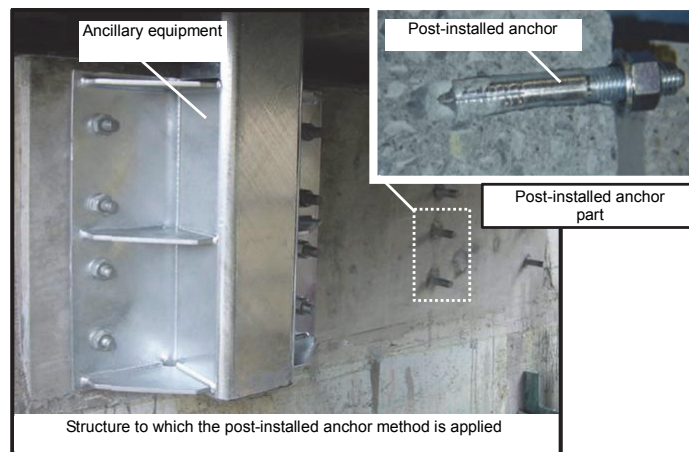


Fig. 7 Differences in the sites of application of the post-installed anchor method and distinctions in use of terminology

Section 4 “Construction” describes the basic rules and important points in the various activities related to the construction method, construction control, inspection, and installation of ancillary equipment for the post-installed anchor method. In the post-installed anchor method, one of the important work processes at the construction stage is to determine the actual situation by a site survey (Fig. 6), as difficulties frequently occur in construction with a specification that was set at the design stage, due to the actual reinforcement arrangement, structure conditions, or construction conditions.

In Section 5 “Maintenance”, the basic rules for maintenance of structures using the post-installed anchor method and post-installed anchor parts are described.

In addition to complying with the "Maintenance" section of the Standard Specifications for Concrete Structures", the importance of the maintenance aspects peculiar to the post-installed anchor method is indicated, in particular consideration of the effect on third parties of collapse of ancillary equipment, etc.

5. Outline of the Standard Section

The Standard Section deals with the case where failure of the post-installed anchor parts does not affect the members or deformation of the structures to which the post-installed anchor method is applied. It describes the standard methods and concepts in design, construction, and maintenance, and as shown in Fig. 3, it includes 5 chapters: General, Design of Post-installed Anchor Parts, Materials and Parent Material, Construction, and Maintenance. The Standard Section deals with metal expanding anchors and adhesive anchors.

Chapter 1 prescribes the conditions of use and the scope of application (see Fig. 8). If these requirements are not satisfied, the Main Section and the Standard Specifications for Concrete Structures must be followed. The Standard Section envisages use under a normal environment, but for use in special environments such as salt damage or freezing damage, etc., the Standard Section can be applied if measures are taken regarding the materials, wet areas, etc.

- (1) As a rule, the Standard Section shall not be used for suspended ancillary equipment.
- (2) The Standard Section shall not be used for anchors subject to large repeating loads, fatigue, or shock loading.
- (3) Use in normal environments is assumed as standard.
- (4) The Standard Section shall be applied to cases in which static tensile forces and shear forces act independently or simultaneously on post-installed anchors.
- (5) The parent material concrete shall be normal concrete in an intact condition with no cracking or honeycombing, having a design standard strength of 18 N/mm^2 or more.
- (6) The types of post-installed anchors are assumed to be metal expanding anchors and adhesive anchors, whose quality is ensured by an appropriate method.
- (7) The external diameter of anchor bolts shall be 8 mm or more and 25 mm or less.
- (8) The embedded length of post-installed anchors shall be 30 mm or more for metal expanding anchors, and 7 times the nominal diameter of the anchor bar or more for adhesive anchors.

Fig. 8 Conditions of use and scope of application of the Standard Section

Fig. 9 shows the categories and scope of application in accordance with the load actions, method of use, and type of structure. In the Standard Section, the load actions are static actions for cases where the structure is not directly affected, for installation of ancillary equipment such as temporary objects or equipment, etc. In the Standard Section, use in locations where ancillary equipment is suspended for a long period of time is prohibited, but use is permitted in locations where suspension is for a short period of time, such as temporary suspension of a concrete block. Use for a short period of time is use for several months, and use for a long period of time is use for a period of time longer than this. The main reason for the limitation in the scope of application is because experimental results are insufficient.

In Chapter 2 “Design of Post-installed Anchor Parts”, methods of verification of the safety of post-installed anchor parts are indicated. Safety of post-installed anchor parts is verified by analysis at the ultimate limit state. The ultimate limit state is represented by failure by yielding of the main body of the anchor, the connecting bar, or the anchor bar; failure of the parent material concrete supporting the post-installed anchor (cone failure or bearing failure); or failure at the boundary between the post-installed anchor and the parent material concrete (bond failure). The Standard Section prescribes equations for calculating the load resistance with respect to the postulated form of failure, and methods of verification based on reaching the ultimate limit state by failure at the lowest load resistance are described.

Action	Dynamic load actions				Static load actions			
	Sporadic load (earthquake, impact, etc.) Fluctuating loads (vibrations, fatigue, etc.)				Permanent loads (dead loads, etc.) Fluctuating loads (wind loads, etc.)			
Method of use	Long term use		Short term use		Long term use		Short term use	
	Suspended	Other	Suspended	Other	Suspended	Other	Suspended	Other
Structure type								
When the structure is directly affected	<p>*Anchoring the base of the main reinforcement in the seismic retrofit of bridge piers (RC retrofit)</p> <p>*Installing bridge fall prevention devices (tensile resistance type)</p> <p>*Installing bridge fall prevention devices (shear resistance type)</p> <p>*Re-levelling breakwaters and levees, etc.</p> <p style="text-align: right;">Design Section of the Standard Specifications</p>							
When the structure is not directly affected	<p>*When repeated loading or constant downward loading is applied when installing ancillary equipment (jetfan, suspended signs, etc.)</p> <p>*When it is necessary to consider impact loads or fatigue (installation of vehicle protective parapets)</p> <p>*Raising bridge railings, installation of noise barriers (elevated bridges)</p> <p style="text-align: center;">Main Section</p>				<p>Protective parapets for side walks Inspection passages Noise barriers</p> <p style="text-align: center;">Standard Section</p> <p>Installation of formwork and falsework Heavy objects Suspended transport Connecting scaffolding to a wall installing temporary works</p>			

Fig. 9 Categories and scope of application of the Standard Section

Fig. 10 shows the flow of verification in the Standard Section and safety factors. In formulating these Recommendations, in addition to the material factor, the member factor, the load action factor, and the structural analysis factor, a factor of the degree of effect and a factor of non-uniformity are provided.

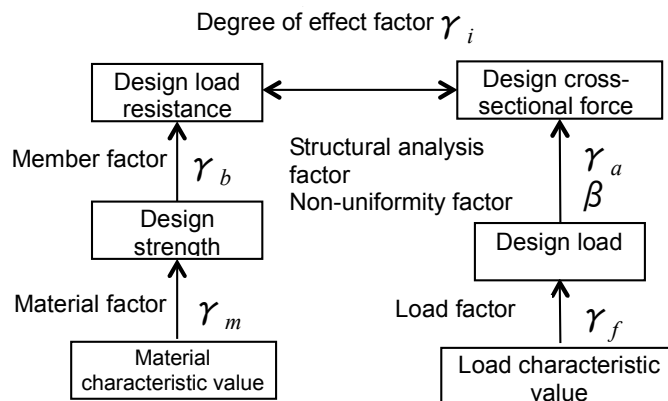


Fig. 10 Flow of verification and safety factors

The factor of the degree of effect is a factor defined to take into consideration the importance of the ancillary equipment fixed with the post-installed anchors and the impact on third parties if the ultimate limit state is reached. This factor can be 1.0 in cases where the effect of failure of the post-installed anchor parts on the surrounding environment can be reduced, such as by providing a backup function, etc.

If a load is resisted by several post-installed anchors, it is necessary to obtain the cross-sectional force per post-installed anchor taking into consideration the distribution of load and the non-uniformity of load. Therefore, a factor of non-uniformity is provided to take

into consideration the non-uniformity of the cross-sectional force. If it is not possible to set a rational value using tests, etc., the factor of non-uniformity can be taken to be 1.8, based on “Technical Standards for Port Facilities and Commentary (Second Volume)”.

Load resistance prediction equations are provided for each failure mode in the Standard section. According to research conducted in the past, in the case of cone failure of the parent material concrete, bearing failure, and bond failure, in the load-displacement relationship, non-linearity appears from about 40% of the load resistance, and when the level exceeds about 60% the displacement rapidly increases. Therefore, in order to reduce the effect of non-uniformity of deformation on the load resistance, the design load resistance is limited to 60% of the 95% confidence value by dividing by a member factor of 1.6. In addition, in the case of long term use, it is necessary to take into consideration the effect of time-dependent deformation. Therefore, it is considered that failure will not occur due to time-dependent effects if the loads are within the elastic range, in other words up to 40% of the 95% confidence value, so the load resistance is multiplied by a factor related to time of 0.5. For failure by yielding, the design resistance is considered to be 90% of the 95% confidence value, the elastic range is considered to be 50%, and the member factor is set to 1.1 and the time factor to 0.5.

Also, methods of taking into consideration the effects of edge distance normal and parallel to the force, and group effects are defined.

Chapter 3 “Materials and Parent Material” prescribes the selection of post-installed anchors and the condition of the parent material concrete. The applicable post-installed anchors are broadly divided into metal expanding anchors and adhesive anchors, which are classified into 8 types depending on the different mechanisms and materials. Also, it is a condition that the target parent material concrete has the required strength and is intact with no cracking or honeycombing.

Chapter 4 “Construction” prescribes the flow of site surveying, construction planning, hole drilling, anchoring, inspection, installation of equipment thereafter, and records. It is required that each of the processes described is carried out by professional engineers and skilled persons with sufficient knowledge and experience. In the site survey, the integrity of the parent material concrete and the condition of the reinforcement is surveyed based on the specification for the post-installed anchor parts provided in the design documents. In the construction planning, each of the processes for implementation of the post-installed anchor method, their time scale, the construction control system, the inspection items and their criteria are clearly indicated, together with the normal items for construction as a whole. Also, if it is deemed that it is difficult to carry out the construction in accordance with the construction plan, it is prescribed that an appropriate amendment shall be made to the construction plan in order that the required performance of the post-installed anchor parts can be satisfied.

In hole drilling, the positions are determined based on the position of the reinforcement from the survey, the equipment used and the work procedures shall be clearly indicated and appropriately carried out in accordance with the type of post-installed anchor, and after drilling the hole depth and diameter of the post-installed anchor parts indicated on the design drawings shall be confirmed to be within their specified ranges. In addition, after the holes are drilled the insides of the holes shall be cleaned corresponding to metal expanding anchors or

adhesive anchors, and protection shall be provided so that rainwater or foreign matter does not enter the holes.

In anchoring, the construction shall be carried out in accordance with the defined equipment and procedures for each post-installed anchor method, in order to ensure the effective embedment length. Also, after anchoring, protection shall be applied to ensure that the performance of the post-installed anchor parts are not affected. In the Guidelines, lists of points to note are provided for construction of both metal expanding anchors and adhesive anchors.

Table 1 Construction control items for anchoring

Type	Work content	Construction control items	Materials and equipment check items
Metal expanding anchors	Before anchoring	<ul style="list-style-type: none"> • Check conditions within hole • Check percussive force or tightening force 	<ul style="list-style-type: none"> • Check materials (type, condition, etc.) • Check equipment (specification, operation, etc.)
	After anchoring	<ul style="list-style-type: none"> • Check anchorage condition (visual, percussion) • Check condition of parent material concrete 	
	Protection	<ul style="list-style-type: none"> • State of protection against corrosion, shock, vibration 	<ul style="list-style-type: none"> • Check protection materials
Adhesive anchors	Before anchoring	<ul style="list-style-type: none"> • Check condition within hole • Check anchoring method (rotation, rotational percussion, placement) • Check environmental conditions (temperature, wetness conditions, etc.) 	<ul style="list-style-type: none"> • Check materials (type, condition, etc.) • Shape of the anchor bar tip • Check equipment (specification, operation, etc.)
	After anchoring	<ul style="list-style-type: none"> • Check embedment length and adhesive filling condition • Check hardening of adhesive • Check condition of parent material concrete 	
	Curing	<ul style="list-style-type: none"> • Check status of curing period and curing method 	<ul style="list-style-type: none"> • Check curing materials

In construction control, the control items that affect the performance of each process in construction are selected, and their timing and frequency must be clearly stated, but the control items for hole drilling and anchoring are summarized on tables. Table 1 shows the construction control items for anchoring.

Table 2 Inspection items and examples of their methods

Category	Inspection item	Information obtained	Example of inspection methods
Structures and ancillary equipment	Summary of structure and ancillary equipment	<ul style="list-style-type: none"> • Design criteria / design documents • Construction records • Maintenance records 	<ul style="list-style-type: none"> • Document inspection • Interviews • Close visual inspection • Distant visual inspection • Monitoring
	Summary of post-installed anchors	<ul style="list-style-type: none"> • Table of test results • Various quality inspection results 	
	Measures taken in the past	<ul style="list-style-type: none"> • Status of repairs / strengthening • Status of performance upgrading • Status of limitations on service 	
	Service state of the structure	<ul style="list-style-type: none"> • Loaded / unloaded • Summary of surrounding environment • Presence of abnormal sound or vibration 	
	Environmental conditions	<ul style="list-style-type: none"> • Weather conditions • Supply of water / chlorides • CO₂ concentration / acidity conditions pH • History of earthquakes / fires, etc. 	
Parent material concrete	Visual change in form or deformation	<ul style="list-style-type: none"> • State of cracking • Spalling, peeling • Exposure of steel, corrosion • Deformation • Physical properties • Presence of degrading factors? 	<ul style="list-style-type: none"> • Close inspection / distant inspection • Percussion test • Non-destructive test • Amount of rebound • Elastic wave / electromagnetic wave • Local failure survey • Extracting cores, chipping, drilling holes
	Concrete condition		
Post-installed anchor part	Condition of anchor bolts	<ul style="list-style-type: none"> • Corrosion of anchor bolts • Loss of cross-section • Anchorage condition • Pull out of anchor bolt • Looseness of tightening fitting 	<ul style="list-style-type: none"> • Close visual / distant visual • Percussion test / touch test • Non-destructive test / degree of rebound • Elastic wave / electromagnetic wave • Local failure survey • Extracting cores, chipping, drilling holes • Tensile (pull out) test

For inspection, inspection items that should be carried out in each construction process are appropriately selected, the inspection methods and judgment criteria are defined, and if the inspection result is “Fail”, appropriate measures must be taken. Also, ancillary equipment shall be installed and fixed with the design tightening force. This is because the performance of post-installed anchors is greatly affected by excessive tightening.

Records for construction of the post-installed anchor method and construction control and the inspection results shall be appropriately recorded, and appropriately retained by the manager of the structure throughout the service life.

In Chapter 5 “Maintenance”, it is required that a suitable maintenance plan for the post-installed anchor parts be prepared based on the maintenance category of the structure in accordance with the concepts of the Main Section, and that this plan be implemented. In the Standard Section, specific inspection items for inspection of the post-installed anchor method and examples of inspection methods are given as shown in Table 2.

6. Conclusions

Sufficient data has not been accumulated on the durability of the post-installed anchor method, so the scope of application of the Standard Section has been limited considerably. However, it is desirable that active investigation be carried out in the future so that the Standard Section can be applied to structures that fall under the scope of the Main Section as adopted this time. The post-installed anchor method is currently used in many civil engineering structures, but it is considered that the opportunities for application will increase with the life extension of structures. We hope that the Recommendations will be used by many, so that the reliability of the post-installed anchor method can be increased and it can be more effectively used.

Finally, we express our deep gratitude to each of the committee members and those that participated in the working groups who contributed greatly in preparation of these Recommendations, and to Japan Construction Anchor Association, who were commissioned to draft the Recommendations.

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