Some movements toward establishing comprehensive structural design codes based on performance-based specification concept in Japan

Y. Honjo
Gifu University, Gifu, Japan

ABSTRACT: There have been movements in Japan to develop a serious of comprehensive structural design codes which can harmonize all the major Japanese structural design codes. This movement is much motivated by the rapid development and popularisation of international and regional structural design codes such as ISO2394 and Structural Eurocodes, as well as of the performance based design concept especially after the conclusion of WTO/TBT agreement in 1995. In proposing such efforts, it is much contemplated to propose a concept that can harmonize all the major Japanese structural design codes that have been developed rather separated way due to many historical reasons. The performance based design (PBD) (or the performance based specification (PBS)) and the limit state design (LSD) are the two concepts we introduced to achieve this aim. One of the final aims of this activity is to propose a new framework of structural design codes for harmonizing structural codes in regional and international levels. Two of such efforts, namely development of 'Principles for Foundation Designs Grounded on a Performance-based Design Concept' (nick name ‘Geo-code 21’) by JGS (Japanese Geotechnical Society) and 'code PLATFORM ver.1' by JSCE (Japan Society of Civil Engineers) are presented in this paper.

1 INTRODUCTION
1.1 Background
Movements to establish a series of comprehensive design codes that are able to harmonize major civil engineering codes are emerging in Japan recently. These activities are much motivated by the conclusion of WTO/TBT agreement in 1995 and the rapid development and popularisation of international and regional structural design codes including ISO2394 and Structural Eurocodes.

In WTO/TBT agreement, it is stated that

'where technical regulations are required and relevant international standards exist or their completion is imminent, Members shall use them, or the relevant parts of them, as a basis for their technical regulations' (Article 2.4).

It also addresses that

'wherever appropriate, Members shall specify technical regulations based on product requirements in terms of performance rather than design or descriptive characteristics' (Article 2.8).
Based on these requirements, there are considerable work going on for the major Japanese structural design codes to revise them from the traditional descriptive specifications to performance based specifications, and from working (or allowable) stress design codes to the limit state design codes.

The impact of close completion of Structural Eurocodes (most probably before 2010) is also very pronounced in Japan. As it is clearly stated in Eurocode 0 that main purposes of establishing Eurocodes are (1) promote construction industries within EU region by unifying the market, and (2) strengthen the competitiveness of EU construction industry against non-EU. The works to draft Eurocodes stated sometime in 1970's, and they have taken almost 40 years to complete this series of documents which provides a set of rules for design of civil and building structures thereby eventually replace present design rules that are different from one country to another in EU and EFTA countries.

It is the essence of LSD (Limit State Design) to clearly identify a state that separates a structure from undesirable to desirable situation in design verification. Because of this characteristic, LSD is, at least, one of the most suitable design methods to carry out PBD/PBS. The relationships among WTO/TBT, PBD/PBS and LSD in the current design framework are illustrated in Figure 1. It is our belief that the specifications of performance of the structures would be described based on the concept of PBD/PBS, whereas the verification of design would be based on LSD/RBD for all the major design codes in the world.

1.2 Contents of the paper
In order to cope with the situations explained in the previous section, movements to establish a series of comprehensive design codes have been started in Japan. One of the initial works of this kind of movements started in 1997 at JGS (Japanese Geotechnical Society) as drafting of ‘Geocode 21’, a prototype comprehensive foundation design code that can harmonize all the major foundation design codes in Japan. The comprehensive design codes stand at the top hierarchy level in all the structural design codes in Japan to give concepts, framework and terminologies for structural design codes as indicated in Figure 2. It is not intended to be legally enforced but as agreements among the

* ‘Geocode 21’ is a nick name of this design code. This name has been used from the beginning of the project. The final official name of the code is Principles for Foundation Designs Grounded on a Performance-based Design Concept and the official number of the code is JGS-4001-2004.
professions (more specifically, the code writers) to draft structural codes based on the rules, terminologies and concepts established by the comprehensive codes. Therefore, it is thought that it is most appropriate for professional societies such as JSCE (Japan Society of Civil Engineers) and JGS (Japanese Geotechnical Society) to publish such codes.

In proposing the code, it was much contemplated to propose a concept that can harmonize all the major Japanese foundation design codes that have been developed rather separated way due to many historical reasons. The performance based specifications for describing requirements on and the limit state design for design verification are the essential two concepts that have provided bases for this comprehensive design code. By doing so, we intend to dispatch the Japanese foundation design technology to the world by a single voice. In the past six years of the research period, we have drafted the main text that consists of 8 chapters and appendixes of this code, which was published as a design standard of JGS (JGS-4001-2004) in 2004. The official name of the code is *Principles for Foundation Designs Grounded on a Performance-based Design Concept.*

Chapter 0 'Bases of structural design' in Geo-code 21 is drafted to propose a comprehensive design code for all civil and building structures. This idea has attracted interests of some officers at the Ministry of Land and Transportation (MLT) of the central government, and JSCE has contracted a research project form the MLT to draft such comprehensive code between 2001 and 2003. The outcome of this research activity is 'code PLATFORM ver.1', *Principles, guidelines And Terminology for structural codes drafting founded on the perFORMance based design concept.*

In this paper, both 'Geo-code 21' and 'code PLATFORM ver.1' are briefly presented. In order to make the description easier and more understandable, the latter is introduced first followed by the former. Also as an example, chapter 0 of Geocode 21 is presented in the appendix of this paper.

2. CODE PLATFORM VER. 1

2.1 Table of contents

Presented in Table 1 is the table of contents of 'code PLATFORM ver.1'. Quite number of terminologies are defined in the first chapter. It was a policy of the drafters of this code to minimize the number of newly defined terminologies as much as possible, and tried to use those defined in the

![Figure 2 Concept of the comprehensive design code](image-url)
authorized documents such as ISO 2394 (ISO,1998). Newly defined words did not exceed more than ten. Chapter 1 serves as a glossary of terminologies in drafting a new structural design code.

Chapter 2 specifies the scope and the framework of a structural design code. It gives the outline of performance requirements description structure and verification procedures that are described in more detail in the following chapters.

The main body of the document is Chapters 3 and 4 that respectively describe objective, performance requirements and performance criteria of a structure, as well as verification procedures that should be conformed by any structural design codes. These parts are explained in detail in the following section.

The last chapter, Chapter 5, specifies the contents of a structural design report that need to be reported from a designer to an owner. This is to clarify the information flow concerning design works and responsibility of each party involved in this activity.

2.2 Main features
In 'code PLATFORM ver.1', an ideal design code to harmonize all major design codes in Japan is pursued. Since the code is free from any legal constraints, it was considered appropriate to look for new generation of code that can be used in the next decade. None of the Japanese major structural design codes could be drafted with such freedom due to the various constraints, and this is a great advantage of this code. The scope of the code includes all categories of structures.

2.2.1 Performance requirements description structure
The performance requirements for structures are hierarchized in order to increase transparency and accountability of the code so as to improve dialogs between citizens and code writers for various aspects of structural performances of infrastructures. The hierarchy structure is presented in Figure. 2,

Table 1 Table of contents of code PLATFORM ver.1

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</table>
which consists of the three classes, namely Objectives, performance requirements and Performance criteria defined respectively as follows:

**Objectives:** Objectives are final social requirements to a structure for one of its specific performance (e.g. structural performance) described in general terminologies.

**Performance requirements:** Performance requirements describe functions of a structure that should be provided to achieve the stated objectives by general terminologies.

**Performance criteria:** Performance criteria specify details that are necessary to fulfill the performance requirements. In principle, they should be quantitatively verifiable in structural design, and should be defined based on four factors: limit states (e.g. damage levels of the structure), magnitude and frequency of an action or their combinations, time and the importance of the structure.

The three level representation of performance requirements on a structure is widely accepted including well know Nordic five levels (NKB, 1978).

(2) Design verification procedures and LSD

Two verification procedures are introduced in 'code PLATFORM ver.1', namely Verification approach A and B, as shown in Figure. 2. Verification approach A is the fully performance based design approach where designers are only given the performance requirements of the structures; and requested to verify their design, where the results would be checked, for example, by an accredited organization or committee.

On the other hand, Verification approach B is a verification procedure based on design codes: these codes may be established for each category of structures (e.g. highway bridges, buildings etc.) by the authorities who are either owner or one responsible for the administration and safety of the category of structures. In Verification approach B, 'code PLATFORM ver.1' is to be used as a code for code writers.

In both Approaches A and B, LSD is recommended to be used for verification, which ISO2394, General principles on reliability for structures, is founded on (ISO, 1998). It is presumed that LSD is one of the most suitable methods to realize PBD/PBS.

3. PRINCIPLES, GUIDELINES AND TERMINOLOGY FOR STRUCTURAL CODES DRAFTING FOUNDED ON PERFORMANCE BASED CONCEPT (GEO-CODE 21)

3.1 Contents of Geo-code 21

Presented in Table 2 is the table of contents of Geo-code 21. Chapter 0 is drafted to propose a comprehensive design code for all civil and building structures. We needed to draft such chapter because there was no such code in Japan at that time.

The ver.2 of Geo-code 21 has been translated into English, and is available in the Proceeding of IWS Kamakura pp. 401-457 (JGS, 2002). This draft can be seen in the home page given in the reference. Also 'Principles, guidelines And Terminology for structural codes drafting founded on the performance based design concept' has also been translated into English and going to be uploaded to JGS website very soon. The English translation of Chapter 0 is presented in the appendix of this paper.
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<th>Section</th>
<th>Title</th>
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<td>1.</td>
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<td>4.</td>
<td>DESIGN OF PILE FOUNDATION</td>
<td>(Sections are omitted here)</td>
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<td>5.</td>
<td>DESIGN OF COLUMN TYPE FOUNDATION</td>
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<td>DESIGN OF TEMPORARY STRUCTURE</td>
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<tr>
<td>Annex:</td>
<td></td>
<td>A An example of comprehensive design code: B Comments on seismic design of foundations C Comments on geotechnical information for foundation design D Determination of characteristic values from a small number of samples E Comments on shallow foundation design F Comments on pile foundation design G Comments on column type foundation design H Comments on earth retaining structures design I Comments on temporary structures</td>
</tr>
</tbody>
</table>
3.2 Harmonization of Japanese foundation design codes

Geo-code 21 is drafted pursuing for an ideal foundation design code at present time in Japan. That is to say, the code is aiming at systematizing and harmonizing the major foundation design codes in Japan that have been developed rather independently due to some historical and legal reasons.

In proposing such code, it is neither meaningful nor successful to try to develop a code at the same level to the existing major design codes: An advanced concept is definitely required in proposing such a code. The PBD/PBS concept is employed as the backbone of this code, and is used to harmonize the major design codes on a ground that is different from that of the present major design codes are based. The comprehensive design code is fully performance based design code; but at the same time, it can be looked at as 'a code for code writers'.

The aims of this code are as follows:

- To define means to specify the structure performances.
- Unification of terminologies.
- Methods and formats to introduce the safety margin to various limit states in design.
- Standardize characteristic value determination in geotechnical design.
- Standardize information flow (i.e. documents preparation) among owner, designer, constructor, geotechnical investigator and others.
- The limit state design (LSD) concept is introduced for design verification.

For all the major design codes in Japan, it is principal that the design changes from the next day a revised code is enforced for the category of structures under the control of that code because of the legal background. It is too strong constraint for a code to introduce new concepts. For this reason, it is our experience that all the new concepts introduced to the codes are creepingly deformed, stripped of its essential contents in the process of drafting, and finally enforced with no substances.

It is not expected that Geo-code 21 is to be used in the actual design from the day it is issued; it is rather pursuing an ideal code which all the code should finally merge into it in the near future. It is expected that various foundation design codes in Japan to accept the concepts and the formats etc. proposed in this code, and finally mildly harmonized to this code in a certain time interval.

3.3 Major characteristics of Geo-code 21

(1) Performance based design / performance based specifications (PBD/PBS)

One of the distinguished features of Geo-code 21 that is very different from Eurocodes and other ISO codes is introduction of PBD/PBS concept.

The performance requirements of foundations are hierarchized in order to increase transparency and accountability of the code. The hierarchy structure of Geo-code 21 has already been presented in Figure. 3. It consists of the three layers, namely Objective, performance requirements and Performance criteria. The definitions of these three levels are given as follows:

**Objectives**: Objectives are final social requirements to a structure for one of its specific performance (e.g. structural performance) described in general terminologies. For examples, 'buildings shall provide sufficient safety to the residence at the time of earthquake events so that they are preserved from serious injuries and loss of lives' or 'Marginal operation of functions expected to a structure is preserved'.

**Performance requirements**: Performance requirements describe functions of a structure that should be provided to achieve the stated objective by general terminologies. For examples,
'A structure shall not collapse during earthquake' or 'Damages to a structure shall be controlled to an extent where marginal operation is preserved'.

**Performance criteria:** Performance criteria specify details that are necessary to fulfil the performance requirements. In principle, they should be quantitatively verifiable in structural design.

Levels of performance criteria of a structure should be determined based on the magnitude and the frequency of load the structure is exposed to during its service life, and the importance of the structure. In Geo-code 21, three performance criteria levels are proposed (Honjo and Kusakabe, 2002).

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**Figure 3** Hierarchy of performance requirements, verification and codes

*(2) Diversification and standardization of design verification methods*

There seems to be two large trends in structural design codes development in the world: One is the diversification or the increase of freedom in the design which has gained momentum from the conclusion of WTO/TBT where use of the performance based specifications on all industrial products has been agreed.

The other trend is the standardization or the unification such as ISO and Eurocodes that attempt to standardize and unify all design verification methods in a region or the world. It is required to account for these two trends (i.e. the diversification and the standardization) simultaneously in developing a new code, although these two trends sometimes look contradictory to each other.

In order to account for these two trends at the same time, two different approaches in the verification of structural performance, namely Verification approach A and B, are proposed in Geo-code 21 (Figure 3). Verification approach A is the fully performance based design approach where designers are only given the performance requirements of the structures; the designers are requested to verify their design, and the results would be checked by authorized organizations et al.
On the other hand, Verification approach B is verification procedure based on design codes: these codes may be established for each category of structures (e.g. highway bridges, buildings etc.) by the authorities who are either owner or one responsible for the administration and safety of the category of structures. In Verification approach B, Geo-code 21 is to be used as a code for code writers.

We believe that even for the fully performance based design, i.e. Verification approach A, there do exist a number of principle points designer should check for each discipline of structure (e.g. foundations, concrete and steel structures etc.). In the comprehensive design code, these points are listed, and it is expected the code is used as a checklist in the examination of the design at the authorized organizations.

In Verification approach B, Geo-code 21 would be used as a code for code writers. There are a couple of layers of hierarchy of codes under this code (Fig. 3). The Specific Base Design Code is the major design code of each category of structures; for example, Specifications of Highway Bridges could be one of this category of code.

(3) Limit state design based code
Geo-code 21 is based on ISO2394, General principles on reliability for structures, which is founded on LSD and the reliability design concepts. The notations and the terminologies are defied in accordance with ISO2394 as much as possible. It is presumed in Geo-code 21 that LSD is one of the most suitable methods to realize PBD/PBS.

(4) Characteristic values of soil parameters
The most important role of design codes is to determine the safety margin (or elements) in design by balancing uncertainties involved in actions, resistances and calculation models in order to sufficiently satisfy the various performance requirements of a structure during its service life (Ovesen, 1989).

In geotechnical design, the geotechnical parameter values are different from a site to another, and they are estimated based on site investigations, laboratory tests or past experiences. It is very different from design of concrete or steel structures that the material parameter values are specified based on industrial standards and controlled in the manufacturing processes. Therefore, in order to introduce equal margin of safety to all the designed structures in geotechnical design, it is necessary and inevitable for all designers to understand in what sense a soil parameter value (i.e. a characteristic value) are a representative value of the ground. If there is no common understanding among the designers, the safety margin introduced in the design may differ from one structure to another.

We found that most of the design codes exist in Japan and abroad are quite insufficient in this aspect probably due to the fact that most of the design codes are written under the hegemony of structural engineers and not under that of geotechnical engineers.

In Geo-code 21, the definition of the characteristic value of a soil parameter is given as follows:
The most significant point here is that the characteristic value is defined as a mean value of a geotechnical parameter. By doing so, it is preventing for designer to arbitrarily include safety margins in the determination of a characteristic value by taking a conservative value. On the other hand, it is encouraged to introduce the engineering judgments that are most important element in geotechnical engineering by certifying the goal (i.e. to estimate the mean value of a geotechnical parameter).

The other important reason we employed the mean values to design is that it facilitate designers to get a "feel" of actual behaviour of their design up to the last stage of their design work. This aspect is more important in geotechnical design where interactions of a structure and ground are very complex and the reduction (or increase) in soil parameter values may not always introduce more safety to the design. For example, in design of a laterally loaded pile, reduction of horizontal subgrade reaction coefficient may lead to increase in deformation, whereas, a larger value may result increase the stress in the pile.

(5) A Checklist for design
Geo-code 21 is a comprehensive foundation design code that is fully founded on PBD/PBS concept. Within this framework, we made the following points our policies while drafting chapters of a particular type foundation:

- It was the aim of such chapters to create a checklist designing foundations based on the state of the art knowledge. The information contained in such a checklist should be neither too much nor too little. This checklist is useful in both designing foundations based on PBD and drafting a foundation design code for a particular category of structures, i.e. a specific base design codes.
- In this checklist, we tried to avoid quantitative descriptions and to use only the qualitative descriptions as much as possible. This is to secure sufficient room for the designers and the code writers to introduce their own engineering judgments in their activities.
- This code can be used as a textbook in advanced undergraduate and graduate classes, which is one of the aims we intended from the beginning of drafting the code.
- We are including some typical concrete foundation design methods in the appendixes of the code. These methods are simplified versions of the actual design methods used in Japanese major foundation design codes. The aim here is to show some of the possible design methods to the readers, and we think it especially helpful for the outsiders who are not familiar with the Japanese foundation design practice.
4. CONCLUSION

Some of the activities on harmonizing Japanese major civil engineering structural design codes are introduced in this paper. The authors are hoping this kind of activities are extended to Asian region so that we can cooperate together to develop our own regional codes system to promote construction industries within this region by unifying the market, and strengthen the competitiveness of our construction industry to the outside.

ACKNOWLEDGMENT

The authors are grateful to the members who have contributed to draft both 'Geocode 21' and 'code PLATFORM ver.1', that are too many to be listed due to the space limitation.

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JGS (2004), Principles for Foundation Designs Grounded on a Performance-based Design Concept (nickname ‘Geocode 21’)
APPENDIX

Chapter 0 of *Principles for Foundation Designs Grounded on a Performance-based Design Concept* (JGS-4001-2004) (nick name ‘Geocode 21)

**Chapter 0  BASIS OF STRUCTURAL DESIGN**

### 0.1 SCOPE

**a)** This code specifies the principles of structural design and of the drafting of structural design codes in Japan for buildings and civil structures in order to establish and maintain the appropriate structural performance requirements.

**Remark** Structural design codes which follow the requirements of this code will also fulfill the requirements of international standards such as ISO2394.

**b)** The status of this comprehensive design code is presented in Figure 0-1.

**Remark** Figure 0-1 shows the positions of the 'basic specific design codes' and the 'specific design codes.’ The design principles are composed of a hierarchy of performance requirements (objective - performance requirements - performance criteria) and verification methods (Approaches A and B).

![Figure 0-1: Hierarchy of the requirements and the verification methods](image)

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<th>Objective</th>
<th>Performance Requirements</th>
<th>Performance Criteria</th>
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<td>Approach B</td>
<td>Approach A</td>
</tr>
<tr>
<td><strong>Specific Base Design Code</strong></td>
<td>Specific Design Code</td>
<td>Specific Design Code</td>
</tr>
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</table>

**Figure 0-1** Hierarchy of the requirements and the verification methods
c) The objectives of a structure and the related performance requirements shall be determined primarily by the client or the owner. Furthermore, the regulating agencies such as central government agencies/local government authorities, who are responsible for the structural performance from the standpoint of public interest, shall specify the minimum performance requirements whenever necessary.

d) The specified objectives and related performance requirements should be interpreted as performance criteria that can be applied directly to the design verification.

e) The two verification methods allowed by this code are Approach A and Approach B; they are defined as follows:

- **Approach A** No restrictions are applied to the methods used to verify the structural performance. However, the chief designer must prove that the structure satisfies the specified performance criteria with a sufficient level of reliability.

- **Approach B** The chief designer must follow the proper procedures such as the design calculations specified in the basic specific design codes and the specific design codes of central government agencies/local government authorities/the owner.

**Remark 1.** This design code complies with both performance verification methods, namely, Approaches A and B. In Approach B, for which the basic specific design codes and the specific design codes of the various agencies/authorities are employed to verify the structural performance criteria of each structure, the terminologies used, the various values of the basic variables, the verification formats, and the methods applied to determine partial factors shall follow the items specified in this code.

2. Refer to the “JSCE recommendations for loads on civil structures” for the design loads of civil structures and to the “AIJ recommendations for loads on buildings” for the design loads of buildings.

3. Refer to the load specifications for each category of structures from such regulating agencies as central government agencies/local government authorities/the owner if such specifications exist.

### 0.2 OBJECTIVES

a) The objectives are descriptions of the reasons for building a structure. In this code, only the objectives related to the structural performances are of concern. They shall be expressed in nontechnical terms.

**Reference** It is recommended that the subject of the statements used to describe the objectives be “client” or “owner.”

b) The structural performance is characterized by the structural strength, the stability, the deformability, and the durability.

**Remarks** The objectives shall include, but not be limited to, considerations related to the safety, the serviceability, and the reparability of the structure. The preservation of other aspects of the performance, such as fire safety, acoustic responses, the landscape, and environmental concerns, are outside the scope of this design code.
0.3 PERFORMANCE REQUIREMENTS
a) The performance requirements are statements on the functions that need to be provided by a structure in order to achieve the objectives. In other words, the performance requirements describe the required functions of the structure for each item given in the objectives. The performance requirements shall be expressed in nontechnical terms.

Reference 1. Each item included in the performance requirements should be described separately.

2. It is recommended that the subject of the statements used to describe the performance requirements be “the structure.”

b) With respect to the various magnitudes and frequencies of loads experienced during the design working life, the structure shall satisfy all performance requirements, such as safety, reparability, and serviceability, with appropriate levels of reliability.

c) The structure shall be designed to be sufficiently safe so as to prevent serious injury to both occupants and surrounding personnel during all possible design situations throughout the design working life (safety).

Remark 1. The structure shall be designed, by the judgment of the client or the owner and based on the importance of the structure, such that normal functions are preserved (serviceability) to an appropriate degree of reliability and damage is limited to a certain tolerable level (reparability) against specified loading situations during the design working life.

2. It is not prohibited for the client or the owner of the structure to specify additional performance requirements, to those stated above, based on his/her own judgment.

0.4 PERFORMANCE CRITERIA
0.4.1 General
a) Performance criteria are items chosen from the performance requirements that shall be described in concrete (and possibly quantitative) ways so that they can be verified by some appropriate means.

b) Each performance criterion shall be stated using a combination of a limit state and a design situation while taking into account the design working life of the structure.

Remark 1. The importance of the structure should be considered when determining the performance criteria.

2. When specifying the performance criteria, it is recommended that the purposes of the performance criteria, i.e., the performance requirements, be as transparent as possible to the designers so that the requirements can be reflected in the design.

0.4.2 Design working life The client or the owner of the structure shall determine the design working life of the structure.

Remark The design working life of a structure may be determined by considering various factors including the life cycle costs, the durability, the deterioration, and the functional life of the structure. Care should be taken to ensure that the safety margin (i.e., the reliability) introduced for each limit state is closely related to the design working life of the structure.

Reference The design working life of structures is generally 100 years for civil structures and 50 years for buildings.
0.4.3 Limit states
a) The structural performance criteria of the structure shall be specified by means of several limit states according to the load levels which have been classified based on the frequency of their occurrence.

b) In principle, the following three limit states shall be specified for structures, although other limit states are not necessarily excluded:

**Serviceability limit state** The serviceability limit state is the limit state in which damage to the structure has occurred, but it is limited to a level that does not influence the structural durability and in which all common functions of the structure have been preserved. Regular use of the structure is possible, without repairs, and no excessive displacement or deformation of the foundation has occurred.

**Reparability limit state** The reparability limit state is the limit state in which damage to the structure has occurred and may have affected the durability of the structure. However, regular use of the structure is possible to a limited extent and there are reasonable prospects for full functionality of the structure if economically-feasible repairs are performed. This limit state can be interpreted as the state in which the majority of the value of the structure has been preserved. In addition, the reparability limit state sometimes implies a state in which marginal use of the structure is possible for rescue operations immediately following an extraordinary event such as a large earthquake.

**Ultimate limit state** The ultimate limit state is the limit state in which the structure may have sustained considerable damage, but not to the extent that the structure has reached failure, become unstable, collapsed, or to the extent that would result in serious injury or the loss of life. In terms of the ground, this is also the state in which the entire structure is still stable despite the loss of bearing capacity and no experience of an overturn or sliding has occurred to the foundation. In terms of the extent of damage to foundation members, the ultimate limit state is the state in which even the foundation members’ inability to support vertical loads has not caused brittle failure.

0.4.4 Actions and design situations
a) Actions are classified as being permanent, variable, accidental, or temporal.

b) A permanent action is an action working permanently throughout the design working life of the structure with a negligible amount of fluctuation in comparison to the average value.

**Reference** Permanent actions include, but are not limited to, self-weight, fixed loads (dead loads), static earth pressure, hydraulic pressure, and forced deformation.

c) A variable action is an action whose temporal fluctuation is neither negligible nor monotonic in comparison to the average value.

**Reference** Variable actions include, but are not limited to, live loads, temperature fluctuations, earthquakes, waves, wind, snow, ice, and the deterioration of members and/or the structure itself.

d) An accidental action is an action that exerts a considerable impact on the structure, but whose chance of occurrence during the design working life is relatively small.

**Reference** Accidental actions include, but are not limited to, collisions, explosions, fires, and earthquakes.
e) A temporal action is an action that occurs during the construction, the renovation, and/or the demolition of the structure. The structural system during construction may differ from that after the completion of the construction, and the effect of such actions must be taken into account.

Reference The magnitude and the frequency of actions can be obtained from “JSCE recommendations for loads on civil structures” for civil structures, and “AIJ recommendations for loads on buildings” for buildings.

f) The four design situations that require specified load combinations include, but are not limited to, the persistent, the extreme, the accidental, and the transient.

A persistent situation exists within the normal conditions of the use of the structure, and it is generally related to the design working life of the structure. Persistent situations include persistent actions as well as high-frequency variable actions such as high-frequency earthquake actions, wind, and floods.

An extreme situation is the rare occurrence of a variable action such as a very low-frequency earthquake, a wind load, or a flood.

An accidental situation is an exceptional condition of the use or the exposure of the structure to a flood, a landslide, a fire, an explosion, an impact, or local failure which in most cases lasts for a period of one week or less.

A transient situation is a provisional condition of the use or the exposure of the structure, during construction, repair, and/or demolition, which represents a time period significantly shorter than the design working life of the structure.

g) Load combinations are applied, in principle, to each design situation as specified below.

Load combinations are not, however, limited to the following cases:

Persistent situation Combination of permanent and high-frequency variable actions

Extreme situation Combination of permanent and low-frequency variable actions

Accidental situation Combination of permanent and accidental actions

Transient situation Combination based on temporal actions

0.4.5 Importance of the structures and their performance criteria

a) In designing the structure, the points that need to be considered by the client or the owner in order to determine the level of importance of the structure include human injury and the loss of life due to damage to the structure, the role of the structure during emergency rescue operations as well as reconstruction activities and the preservation of the asset value of the structure.

b) The client or the owner can, if deemed necessary, define the performance criteria by choosing appropriate load combinations and limit states according to the importance of the structure.

c) The structure shall be designed so as to preserve the serviceability limit state for persistent situations with an appropriate level of reliability.

d) The structure shall be designed so as to maintain the serviceability, the reparability, and/or the ultimate limit state for extreme situations with appropriate levels of reliability.

e) The structure may be designed so as to preserve the serviceability, the reparability, and/or the ultimate limit state for emergency situations with appropriate levels of reliability depending on the importance of the structure.

Remark A performance matrix is an effective method for describing the performance criteria.
of a structure. In a performance matrix, the design situations and the limit states are taken as axes of the coordinate system, and the performance criteria are coordinated according to the importance of the structure. A conceptual example of such a performance matrix is presented in Figure 0-2.

**Figure 0-2** Concept of the performance matrix

<table>
<thead>
<tr>
<th>Damage to a Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serviceability Limit State</td>
</tr>
<tr>
<td>High freq, Low impact</td>
</tr>
<tr>
<td>Medium freq, Med. impact</td>
</tr>
<tr>
<td>Low freq, High impact</td>
</tr>
</tbody>
</table>

Note: Ø Important Structure, Ø Ordinary Structure, Δ Easily Reparable Structure

**0.5 ACCEPTABLE VERIFICATION METHODS**

The performance criteria defined in the previous section shall be verified either by Approach A or Approach B described in the following sections.

**0.6 VERIFICATION BY APPROACH A**

**0.6.1 Approval organizations and reviewers**

a) Approach A does not require any specific methods in order to verify the performance of the structure. However, it does require the chief designer to show that the structure fulfills the specified performance criteria with an appropriate level of reliability. The document produced by the chief designer to prove this fact is called a “design report.”

Reference A social procedure that fully covers Approach A has not yet been established in Japan. The following procedure is one possible type of social system:

1) The chief designer shall request the performance verification of the structure by Approach A and shall submit the necessary design report and documentation for the investigation to the administrative organization/local government responsible for controlling the safety of the structure.
2) The approval organization which will actually conduct the performance verification using Approach A shall be appointed by the administrative organization/local government.
3) The chief designer shall prove that the requirements described in this code have been satisfied during the process of the investigation.
4) The approval organization shall organize a performance verification committee to examine each case. The majority of the committee members shall be qualified engineers accredited by publicly authorized organizations.
5) These accredited engineers may include professional engineers and first-class architectural engineers.
6) The approval organization shall archive all documents concerning the approval for
as long as the structure is in service. In addition, all information shall be publicly accessible, except for items concerning the privacy of the client or the owner.

0.6.2 Qualifications of the designers

a) The designers shall have sufficient experience and a thorough knowledge of the field in question.
b) The designers shall be qualified personnel whose professional technical level has been accredited by an appropriate organization.

0.7 VERIFICATION BY APPROACH B

0.7.1 General

a) When performing the verification of a structure by Approach B, the verification shall be conducted based on basic specific design codes and specific design codes that are chosen by central government agencies/local government authorities/the owner.

  Remark The basic specific design codes and the specific design codes can be drafted using the format specified in this design code when it is made as a design basis and is based on the performance design concept.

b) When applying Approach B, regulations concerning the strength, the rigidity, the displacement, etc. that can be applied directly to the performance verification shall be given for each structure and for each structural element.

  Remark It is permitted for manifold design methods, including design by calculation, loading tests, model tests, the observation method, the observational construction control system, and the prescriptive method, to be considered in the drafting of the basic specific design codes and the specific design codes.

0.7.2 The partial factor format

a) The items stated in ISO2394 for the “partial factor format” shall be followed when drafting basic specific design codes or specific design codes by the partial factor format.
b) All the necessary information related to the use of the partial factor format, such as the basic variables, the models, and the principles of probability-based designs, is contained in sections of ISO2394.

  Reference Information concerning the employment of the partial factor format, such as designs based on experimental models, the principles of reliability-based designs, combinations of actions, and estimations of action values may be found in certain sections of ISO2394.

0.7.3 Qualifications of the designers The engineer responsible for designing the structure shall be, in principle, a qualified person whose professional technical level has been accredited by an appropriate organization.

  Reference It is preferable that the chief designer be a qualified person who has been officially recognized as having attained a professional skill level.
0.8 DOCUMENTS CONCERNING DESIGN, CONSTRUCTION, AND MAINTENANCE

0.8.1 Information flow and concerning documents

a) With respect to the progress of a construction project, the concerned parties such as the client or the owner, the group of designers, the investigators, the contractors, and the construction product manufacturers shall exchange necessary and pertinent information via the proper forms of various documents.

b) During the preparatory stages of a construction project, the results of the various investigations shall be reported to the client or the owner by the investigators and/or by the designers in “reparatory investigation reports”/“feasibility study reports” when such studies are deemed necessary.

Reference In the case of foundation designs, a “geotechnical investigation report,” prepared by the investigators for the geotechnical design, is necessary. The contents of the report shall be as described in detail in Chapter 2 of this code entitled “Geotechnical Information.”

c) As mentioned in Section 0.6.1, the design results shall be reported to the client or the owner by the designers in the form of a design report during the design stage of the project.

Reference The contents of the report are described in detail in Chapter 1 of this code entitled “Basis of the Design of Foundation Structures.”

d) During the construction stage of a project, plans on construction management shall be reported to the client or the owner and to the designers by the builders in the form of a “construction management plan.” Furthermore, the contractors shall report on the results of the construction to the client or the owner and to the designers in a “construction management report.”

Reference Upon completion of a construction project, it is recommended that the designers submit a “maintenance management report” to the client or the owner. This report consists of a summary of items related to the maintenance of the structure in the design report and to changes in the design due to unforeseen conditions encountered during construction.

e) The design report shall be archived by the client or the owner for as long as the structure is in operation.

0.9 REVISION OF THE PRESENT CODE

This code, in principle, will be reviewed and revised at appropriate time intervals under the responsibility of the Japanese Geotechnical Society.

0.10 DEFINITIONS OF TERMINOLOGIES AND NOTATIONS

For the terminologies and notations used in this code, refer to Section 1.2 of ISO2374. Those terminologies and notations not defined in ISO2374, which are newly introduced in this code, are summarized in this section.
0.10.1 Definition of Terminologies

a) **Performance-based Design Code**  A performance-based design code is a code whose specifications on structures have not been given by prescriptive means, but by outcome performances based on the requirements of society and/or the client or the owner.

b) **Objectives**  The final social requirement of a structure with respect to one specific performance (e.g., the structural performance) is described in the general terminologies.

Reference  Examples include “Buildings shall provide sufficient safety to residents at the time of earthquake events so that they are protected from serious injury and loss of life” and “The marginal operations of the functions of a structure are preserved.”

c) **Performance requirements**  Performance requirements are functional statements, given in nontechnical terms, that describe the functions of a structure which are provided in order to achieve the stated objectives.

Reference  Examples include “A structure shall not collapse during an earthquake” and “Damage to a structure shall be controlled to the extent whereby the marginal operations are maintained.”

d) **Performance Criteria**  Performance criteria are details that are needed in order to fulfill the performance requirements. In principle, they should be quantitatively verifiable in the structural design.

e) **Approach A**  Approach A is an approach for which no restrictions are applied to the methods used to verify the structural performance. However, the chief designer must prove that the structure fulfills the specified performance criteria with a sufficient level of reliability.

f) **Approach B**  Approach B is an approach for which the chief designer must follow the procedures, for example, the design calculations specified by the basic specific design codes or the specific design codes proposed by central government agencies/local government authorities/the owner.

g) **Comprehensive Design Code**  Comprehensive design codes are codes that describe the basis of the design of civil structures and buildings within a country or region. It is not a code for designing individual structures, rather, it provides common items such as a means to specify the performance of the structures, the unification of terminologies, the introduction of safety margins for the design specifications, the format for verification, the standardization of the information transfer among concerned bodies, fundamental check lists for the design, etc. It is a code on the highest level of the design code system hierarchy that covers both Approach A and Approach B. It can be thought of as “a code for code writers,” but contains more basic and useful information than just that required by code writers.

h) **Basic Specific Design Codes**  Basic specific design codes are codes that specify the structural performance criteria of structures by regulating agencies such as central government agencies/local government authorities/the owner. It is likely that some recommendations for verification methods and acceptable methods for use with Approach B may also be provided.

i) **Specific Design Codes**  Specific design codes are codes that detail the performance criteria of specified structures which may be limited to a specific use or to a certain region, etc. The specifications shall be based on the basic specific design code that is ranked above this code. Certain acceptable verification procedures can be attached to this code.
j) **Geotechnical Category** A geological category is a design classification that classifies geotechnical designs into three categories depending on the importance of the structure and the level of geotechnical complexity.

**Remark** Although the classification is not strictly definite, it is more convenient to argue matters concerning geotechnical designs with this classification and these categories than without them. Note that the classification of a design may change during the progress of the construction.

k) **Geotechnical Category 1 (GC1)** The importance of the structure is relatively low and the geotechnical complexity is low.

l) **Geotechnical Category 2 (GC2)** The importance of the structure and the geotechnical complexity are both ordinary. This category also includes cases in which either of the two is significant.

m) **Geotechnical Category 3 (GC3)** Both the importance of the structure and the geotechnical complexity are significant. This category also includes cases in which the structure has outstanding importance independent of the level of geotechnical complexity.

n) **Design Situations (ISO)** The design situations are sets of physical conditions representing certain time intervals for which a design shall demonstrate that the relevant limit states have not been exceeded.

**Remark** The design situations generally consist of persistent, extreme, accidental, and transient situations. Additional situations may be set if deemed necessary.

o) **Persistent Situation (ISO)** A persistent situation exists within the normal conditions of the use of the structure, and it is generally related to the design working life of the structure.

p) **Extreme Situation** An extreme situation is the rare occurrence of a variable action such as a very low-frequency earthquake, a wind load, or a flood.

q) **Accidental Situation (ISO)** An accidental situation is an exceptional condition of the use or the exposure of the structure to a flood, a landslide, a fire, an explosion, an impact, or local failure which in most cases lasts for a period of one week or less (apart from situations where a local failure may remain undetected for a longer period).

r) **Transient Situation (ISO)** A transient situation is a provisional condition of the use or the exposure of the structure, during construction, repair, and/or demolishment, which represents a time period significantly shorter than the design working life of the structure.

s) **Design by Calculation** Design by calculation is a verification method for structures in which the behavior of the structure is modeled based mainly on mechanical knowledge; whether or not a limit state has been exceeded can be predicted through calculations.

t) **Verification by Loading Tests** Verification by loading tests is a verification method in which the structure is fully or partially exposed to loading in order to examine the structural performance. The tests are sometimes classified as being either confirmation tests or destructive tests, depending on whether or not the structure has been loaded to the ultimate limit state.

u) **Verification by Model Tests** Verification by model tests is a verification method in which a scaled model of the structure is exposed to loading in order to examine the structural performance.
v) **Observational Method** The observational method is a design procedure in which the initial design of a structure is modified during the construction based on observations made during the construction in order to optimize the design.

**Remark** The observational method is an original design procedure employed in geotechnical designs.

w) **Observational Construction Control System** The observational construction control system is a control system in which the information gained by observations during the construction is rapidly and systematically analyzed and synthesized for use in the next stage of the design and construction. It can be defined as a construction method that was developed from the observational method to which recent information technologies are introduced so as to improve on efforts to reduce labor and speed up the process.

**Remark** This control system is an original design procedure employed in geotechnical designs.

x) **Prescriptive Measure Method** In comparison to designs which employ the calculation method, simulating the limit states of a structure as accurately as possible, the prescriptive measure method (or the deemed to satisfy solution) verifies the performance of a structure by calculations or other means (for example, definite specifications) that are not directly related to the realization of the limit states.

**Remark** This prescriptive measure method includes the use of specified members for which no calculations are involved. It is thought that the effectiveness of these verification methods is justified by experience.

y) **Partial Factor Design Format** The partial factor design format is a format in which several partial factors are applied to various sources of uncertainties in the verification formula in order to ensure a sufficient safety margin; it is usually classified into the following two approaches:

z) **Material Factor Approach** (MFA) MFA is a type of partial factor format in which partial factors are applied directly to the characteristic values of basic variables.

aa) **Resistance Factor Approach** (RFA) RFA is a type of partial factor format in which partial factors are applied to resistances.

bb) **Geotechnical Investigation Report** The geotechnical investigation report is a document that describes the results of a soil investigation for the design of geotechnical structures.

c) **Geotechnical Parameters** The geotechnical parameters are the geometrical size of a structural element (e.g., the thickness of a layer, the inclination, etc.) and the parameters used to describe the mechanical and the physical characteristics of the geomaterials (e.g., stiffness and strength parameters, permeability, unit weight, etc.).

dd) **Measured Values** The measured values are the values obtained directly from the various kinds of field tests (e.g., groundwater table elevations, SPT N values, etc.) and laboratory tests (e.g., the results of triaxial tests, etc.).

e) **Derived Values** The derived values are the values which describe the characteristics of the geomaterials that are estimated from the measured values based on either theory or empirical/statistical correlations.

**Reference** Examples include friction angles and cohesion obtained from Mohr's circles in triaxial test results and the relative density of sand estimated from SPT N-values.
ff) **Characteristic Value**  The characteristic value is the representative value estimated as the most suitable value for predicting the occurrence of the limit state in question based on a structure-foundation-ground system employed in the design.

**Remark**  The characteristic value, in principle, is a cautious estimate of the mean of the derived values. The mean value here does not directly imply an arithmetical averaging, but statistical estimation errors should be considered when obtaining the mean. In addition, this cautious estimate of the mean value takes into account geological and geotechnical knowledge, experience from similar projects, and cross verification and coherence of values based on several different sets of results if such results are available.

gg) **Design Value**  The design value is the value obtained by multiplying a partial factor by a characteristic value in the case of an MFA partial factor format.

hh) **Primary Treatment**  Primary treatment is the treatment applied to the measured values to eliminate outliers and to remove systematic biases when obtaining derived values.

### 0.10.2 Definition of Symbols

a) Symbols conform to Chapter 3 of ISO2394. The terms not defined in ISO2394 are explained as follows:

- $C_c, C, C_q$: correction coefficients for the bearing capacity model
- $C_{sd}$: threshold of the amount of design subsidence, the amount of design dissimilarity subsidence, the design inclination angle, and the amount of design rotation on the bottom of a shallow foundation in each limit state
- $C_{pd}$: threshold of the amount of design direction displacement in the pile head of the pile foundation in each limit state
- $C_{pgd}$: threshold of the amount of design displacement or the amount of design deformation of each part of a grouped-pile foundation in each limit state
- $C_{hd}$: threshold of the amount of design displacement or the amount of design deformation of each part of a column-type foundation in each limit state
- $C_{rd}$: threshold of the amount of design displacement or the amount of design deformation of each part of a retaining structure in each limit state
- $C_{td}$: threshold of the amount of design displacement or the amount of design deformation of each part of a temporary structure in each limit state
- $E_{sd}$: amount of subsidence, amount of dissimilarity subsidence, inclination angle, and the amount of rotation on the bottom of a shallow foundation by the design load
- $E_{pd}$: amount of design direction displacement in the pile head of a pile foundation by the design load
- $E_{pgd}$: amount of design displacement or the amount of design deformation of each part of a grouped-pile foundation by the design load
- $E_{hd}$: amount of design displacement or the amount of design deformation of each part of a column-type foundation by the design load
- $E_{rd}$: amount of design displacement or the amount of design deformation of each part of a retaining structure by the design load
- $E_{td}$: amount of design displacement or the amount of design deformation of each part of a temporary structure by the design load
$F_{sd}$ vertical and horizontal subgrade reaction forces or stress levels on the bottom of a shallow foundation by the design load
section force or stress in part of a shallow foundation by the design load

$F_{pd}$ vertical force or the stress in the pile head of a pile foundation by the design load
section force or the stress in the pile head of a pile foundation by the design load

$F_{pgd}$ section force or the stress of each part of a grouped-pile foundation by the design load

$F_{hd}$ vertical subgrade reaction force or stress on the bottom of a column-type foundation by the design load shear subgrade reaction force on the bottom of a column-type foundation by the design load horizontal subgrade reaction force in front of a column-type foundation by the design load section force or the stress of each part of a column-type foundation by the design load

$F_{rd}$ action force on the bottom and a part of the soil of a retaining structure by the design load section force or the stress of each part of a retaining structure by the design load

$F_{td}$ vertical subgrade reaction force or the stress of a temporary structure by the design load section force or the stress of each part of a temporary structure by the design load

$m_R$ sample mean of the geotechnical parameters

$n$ number of samples

$N_s, N_q$ coefficient of the bearing capacity

$R_k$ characteristic value of the geotechnical parameters

$R_{sd}$ design vertical bearing capacity or the threshold of the design stress on the bottom of a shallow foundation in each limit state design sliding resistance on the bottom of a shallow foundation in each limit state design section force or the threshold of the design stress of each part of a shallow foundation in each limit state

$R_{sk}$ characteristic value of the vertical bearing capacity on the bottom of a shallow foundation

$R_{pd}$ design vertical bearing capacity or the threshold of the design stress in the pile head of a pile foundation in each limit state design section force or the threshold of the design stress of each part of a pile foundation in each limit state

$R_{pgd}$ design section force or the threshold of stress of each part of a grouped-pile foundation in each limit state

$R_{hd}$ design vertical bearing capacity or the threshold of the design stress on the bottom of a column-type foundation in each limit state design shear subgrade reaction force on the bottom of a column-type foundation in each limit state design horizontal subgrade reaction force on the bottom of a column-type foundation in each limit state design section force or the threshold of stress of each part of a column-type foundation in each limit state

$R_{rd}$ design resistance force and moment on the bottom and a part of the soil of a retaining structure in each limit state design section force or the threshold of stress of each part of a retaining structure in each limit state

$R_{td}$ design vertical bearing capacity or the threshold of the design vertical subgrade reaction stress of a temporary structure in each limit state design section force or the threshold of stress of each part of a temporary structure in each limit state
\( R_{pk} \) characteristic value of the vertical bearing capacity in the pile head of a pile foundation

\( R_{ptk} \) characteristic value of the vertical bearing capacity in the pile tip of a pile foundation

\( R_{psk} \) characteristic value of the vertical bearing capacity in the pile skin of a pile foundation

\( S_R \) sample standard deviation

\( t_{\alpha,\nu} \) central t-distribution with confidential Level \( \bar{\alpha} \) and degree of freedom \( \nu = n - 1 \)

\( \gamma_d \) partial factor concerning the vertical bearing capacity on the bottom of a shallow foundation in each limit state

\( \gamma_c \) partial factor concerning the component of the vertical bearing capacity on the bottom of a shallow foundation in each limit state

\( \gamma_r \) partial factor concerning the component of weight on the bottom of a shallow foundation in each limit state

\( \gamma_q \) partial factor concerning the component of the vertical bearing capacity on the bottom and a part of the soil of a shallow foundation in each limit state

\( \gamma_{ps} \) partial factor related to the friction of the pile skin in each limit state

\( \gamma_{pt} \) partial factor related to the bearing capacity of the pile tip in each limit state.

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**Standard related to this standard**