Principles for Foundation Designs Grounded on a Performance-based Design Concept

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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).

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.

### 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 demolition, 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.

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

b) **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.).

d) **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.

f) **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.

g) **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.

h) **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:

- $C_r, C_p, C_q$: 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
- $C_{id}$: threshold of the amount of design displacement or the amount of design deformation of each part of a retaining structure in each limit state
- $E_{ad}$: 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
- $E_{id}$: amount of design displacement or the amount of design deformation of each part of a retaining structure by the design load
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

$F_{psd}$: 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

section force or the stress of each part of a grouped-pile foundation by the design load

$F_{shd}$: 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

$F_{td}$: design vertical bearing capacity or the threshold of the design vertical subgrade reaction stress of a temporary structure in each limit state

section force or the stress of each part of a temporary structure in each limit state

$m_R$: sample mean of the geotechnical parameters

$n$: number of samples

$N_c, N_p, N_q$: coefficient of the bearing capacity

$R_k$: characteristic value of the geotechnical parameters

$R_{ad}$: 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

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

$R_{psd}$: 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

$R_{shd}$: design shear subgrade reaction force on the bottom of a column-type foundation in each limit state

design horizontal subgrade reaction force in front of a column-type foundation by the design load

$R_{td}$: 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

$t_{cv}$: central t-distribution with confidential Level $1 - \alpha$ and degree of freedom $\nu = n - 1$

$\gamma$: 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

\( \gamma_f \) 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.

================================================================================================================================================================

**Standard related to this standard**

1. BASIS OF THE DESIGN OF FOUNDATION STRUCTURES

1.1 SCOPE
a) This code addresses the design of foundations for civil structures and buildings.
b) The list of foundation structures includes, but is not limited to, deep foundations such as pile foundations, shallow foundations such as spread footings, and earth pressure-resistant structures such as retaining walls.
c) In the design of foundations, the specifications presented in Chapter 0 “Basis of Structural Design” shall be followed.
d) The designs of foundations can be classified into three geotechnical categories according to the importance of the structure and the anticipated geotechnical complexity of the structure. They are presented in Table 1-1.

<table>
<thead>
<tr>
<th>Importance of the structure</th>
<th>Minor</th>
<th>Ordinary</th>
<th>Significant</th>
<th>Outstanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor/Ordinary</td>
<td>GC1</td>
<td>GC 1/2</td>
<td>GC 2</td>
<td>GC 3</td>
</tr>
<tr>
<td>Significant</td>
<td>GC1</td>
<td>GC 2</td>
<td>GC 2</td>
<td>GC 3</td>
</tr>
<tr>
<td>Major</td>
<td>GC2</td>
<td>GC2/3</td>
<td>GC 3</td>
<td>GC 3</td>
</tr>
</tbody>
</table>

Geotechnical Category 1 (GC1) is a design classification in which the importance of the structure is relatively low and the geotechnical complexity is low.
Geotechnical Category 2 (GC2) is a design classification in which the importance of the structure and the geotechnical complexity are both ordinary. It also includes cases in which either of the two measures is significant.
Geotechnical Category 3 (GC3) is a design classification in which both the importance of the structure and the geotechnical complexity are significant. It also includes cases in which the importance of the structure is outstanding.

Reference
When the design of basic structures is discussed, the above classifications are adopted for their convenience, even though sometimes a certain design does not fit strictly into one of the categories. It should be noted that it is necessary to refer to these classifications during both the investigation and the construction as the geotechnical category can change during these processes.

e) The present design code is mainly concerned with Geotechnical Categories 2 and 3, although it is possible to also apply it to Geotechnical Category 1.

1.2 OBJECTIVES
a) The objectives are the reasons for building a foundation structure. In this code, only the objectives of the structural performances of foundations are of concern. The objectives shall be expressed in nontechnical terms.

Remark
Since a foundation structure constitutes part of an entire structure, the objectives of the foundation structure are to coincide with those of the entire structure.

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

1.3 PERFORMANCE REQUIREMENTS
a) The performance requirements are statements on the functions that need to be provided by a foundation structure so as to achieve the objectives. In other words, performance requirements describe the required functions of the foundation structure for each item given in the objectives. The performance requirements shall be expressed in nontechnical terms.

Reference
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”.

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b) The performance requirements of foundation structures shall include, but not be limited to, safety, serviceability, reparability, workability, and cost.

1.4 PERFORMANCE CRITERIA

1.4.1 Design working life The design working life of foundation structures shall be determined based on the definition for the design working life of the superstructure presented in Section 0.4.2.

1.4.2 Limit states

a) The limit states, which must be considered in the design of foundation structures, should be determined by the performance requirements for foundation structures. The performance criteria are specified by several limit states according to the performance requirements.

b) In principle, the following three limit states shall be specified for foundation structures, although other alternatives 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 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 limit 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.

1.4.3 Actions and design situations

a) Actions that apply to foundation structures are classified as being permanent, variable, accidental, or temporal. The definitions of these actions are given in Section 0.4.4.

b) The four design situations that require specified load combinations are the persistent, the extreme, the accidental, and the transient. The definitions of these situations are given in Section 0.4.4. It is common to consider several load combinations for each design situation.

Reference Refer to Section 0.4.4 for the load combinations of each design situation.

c) During the foundation design, actions should be designated as being either direct or indirect. Direct actions are independently determined, whereas indirect actions are obtained as a result of interaction between the structure and the ground. It should be noted that indirect actions are often encountered in foundation designs where soil-structure interaction is common.

Remark 1. Since direct actions should be determined prior to design calculations, it is desirable to exclude loads that are obtained as a result of design calculations to action.

Reference For instance, it is preferable not to consider passive earth pressure as a direct action even though active earth pressure is a direct action in the design of retaining structures.
2. There are some indirect actions, such as negative skin friction and actions induced by ground displacement, which need to be quantified by considering the soil-structure interaction.

3. Repeated loading, such as earthquake loading, can be replaced by an equivalent static load. In determining the quantity, it is necessary to take into account the magnitude and the duration of the repeated loading as well as the limit state under consideration.

4. Dynamic loading effects may be incorporated directly into the design calculations if deemed necessary.

1.4.4 Importance of structures and performance criteria

a) Each performance criterion for a foundation structure shall be stated using a combination of a limit state and a design situation while taking into consideration the importance of the structure (refer to Section 0.4).

b) The client or the owner of the structure under construction shall decide the importance of the foundation structure after considering the following: the influence of the loss of the structure itself as a piece of property and the influence of the loss on society in relation to economic activity, the role that the concerned structure will play in rescue and restoration activities, and the asset value of the structure, etc. when damage to the foundation structure itself occurs or causes damage to surrounding structures.

c) The client or the owner of the structure under construction shall provide not only a combination of an appropriate design situation for the design of the foundation structure and an appropriate limit state, but also the performance criteria for the foundation structure according to the degree of importance of the structure.

Reference When a foundation structure is designed, the relation between the importance of the structure and the performance criteria is effective according to the performance matrix outline in Figure 0-2.

1.5 DESIGN OF FOUNDATION STRUCTURES

1.5.1 General

a) Various conditions are considered when a foundation structure is being designed and the best foundation type is being selected.

b) The present design code is mainly concerned with Geotechnical Categories 2 and 3, but it is also possible to apply Geotechnical Category 1 (refer to Section 1.1).

c) The two verification methods that are allowed in foundation designs are Approach A and Approach B, which are defined in Chapter 0.

Reference The definitions are repeated as follows:

Approach A In Approach A, 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.

Approach B In Approach B, the chief designer must follow the procedures of, for example, the design calculations specified by basic specific design codes or specific design codes, proposed by central government agencies/local government authorities/the owner.

d) The design verification methods that can be used in foundation designs are design by calculation, loading tests, model tests, the observational method, the observational construction control method, and the prescriptive method (deemed to satisfy solution), which are defined as follows:

Design by Calculation This is a design method used to verify the performance of a structure in which the behavior of the structure is modeled based on mechanical knowledge. Whether or not a limit state has been exceeded can also be predicted through calculations.

Verification by Loading Tests This is a performance verification method whereby a 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.

Verification by Model Tests This is a performance verification method whereby a model that has been scaled down from the structure is exposed to loading in order to examine the structural performance.

Observational Method The observational method is a design procedure whereby the initial design of the structure is
modified during the construction based on observations made during construction in order to optimize the design. It is an original design procedure employed in geotechnical designs.

**Observational Construction Control System** This is a construction control system whereby information gained during observations of the construction is rapidly and systematically analyzed and synthesized for use in the next stage of design and construction. It can be defined as a construction method developed from the observational method to which recent information technologies are introduced so as to improve on efforts to reduce labor and to speed up the process. It is an original design procedure employed in geotechnical designs.

**Prescriptive Measure** (or Deemed to Satisfy Solution) Compared to the design by calculation method, which simulates the limit states of a structure as accurately as possible, the prescriptive measure (or deemed to satisfy solution) verifies the performance of the structure by calculations or by other means (for example, described specifications) that are not directly related to the realization of limit states. This verification includes the use of specified members for which no calculations are involved. It is thought that the effectiveness of these verification methods can be justified by experience.

e) The procedure specified in Chapter 2 shall be followed when determining the characteristic value of geotechnical parameters. Definitions for the geotechnical parameters and the characteristic values are also given in the same chapter.

**Remark 1.** The characteristic values for the geotechnical parameters need to be determined from a site investigation and laboratory testing.

1. The characteristic value of a geotechnical parameter is often a representative value of model parameters and is based on the modeled ground. Therefore, it is affected by various factors such as the size of the structure under consideration, the stress level, drainage conditions, strain levels etc.

2. In order to introduce appropriate and homogeneous safety margins against the limit states in foundation designs, the determination procedures for the characteristic values of geotechnical parameters shall be standardized such that arbitrary judgments shall be excluded, but appropriate engineering judgments shall be considered.

3. The scale and the number of site investigations and laboratory tests should be considered when determining the characteristic values.

f) Environmental conditions that may affect the durability of foundation structures shall be taken into account during the design of the foundation, if necessary. The optimum foundation type shall be selected by considering various design conditions.

**Remark** Designs which consider the life cycle costs of a structure, taking into account not only the initial construction costs but also maintenance and renewal costs, may be conducted so as to identify the optimum alternative.

g) The chief designer shall report on the results of the design process to the client or the owner in the form of a “foundation structure design report.”

**Reference** More details on this report can be found in Section 1.9.

### 1.5.2 Design of foundation structures by design calculation

**a)** Design by calculation consists of the design calculation model, actions, geotechnical parameters, the geometry of the structure, and restricting values for the deformation, the displacement, the stress, the reactions, and/or the reaction stress of the specified limit state.

**Remark 1.** The design calculation model should be capable of accurately simulating the behavior of the structure within reasonable limits.

1. It is desirable that the design calculation model be capable of making accurate predictions. It is also necessary for the precision of the model to match that of the geotechnical information provided by the site investigation and laboratory testing, and to have sufficient stability and durability.

2. Different calculation models may be employed to check the different limit states for the same structure.

**b)** Predictions made by the design calculation models may contain biases and uncertainties. These aspects need to be taken into account when determining the safety margins introduced in the design.

### 1.5.3 Types of foundations

Foundations are classified as being either shallow foundations or deep foundations. This code deals with the design of direct
foundations as types of shallow foundations in Chapter 4 and the design of pile and column-type foundations in Chapters 5 and 6, respectively.

Remark 1. Foundations may be designed by classifying them as direct, pile, or column-type foundations. Foundations which are difficult to classify into any of the three classifications may be designed by combining design methods. The design of connected column-type foundations may be designed by referring to both Chapters 5 and 6 when appropriate.

2. The classifications for the design of deep and shallow foundations are usually distinguished by $L/D$, where $L$ is the effective embedded depth and $D$ is the width (diameter) of the foundation. Generally speaking, the foundations may be designed as shallow foundations if $L/D < 1/2 \sim 1$ and as deep foundations otherwise.

3. The body of a column-type foundation may be classified as either a shaft or a pile foundation from the viewpoint of load shearing.

1.6 VERIFICATION BY APPROACH A
Items concerning Approach A have been addressed in Section 0.6.

1.7 VERIFICATION BY APPROACH B
1.7.1 General
a) Items concerning Approach B have been addressed in Section 0.7.

b) Basic specific design codes or specific design codes are made on a design basis and are based on the performance design concept. They are made according to the specifications given for this design principle.

Remark When drafting basic specific design codes and/or specific design codes, the previously described design methods, namely, design by calculation, loading tests, model tests, the observational method, the observational construction control method, and the prescriptive method (deemed to satisfy solution), can be used singularly or in combination.

c) When drafting basic specific design codes and specific design codes for foundation designs, the partial factor format shall, in principle, be used when introducing sufficient safety margins against uncertainties for the various limit states.

d) The design by calculation verification method shall, in principle, be used in design codes for foundation structures classified as belonging to Geotechnical Categories 2 and 3.

Remark 1. The reason that this design method is considered to yield a more appropriate design compared to other methods is because it simulates and predicts the behavior of a structure and the occurrence of limit states based on more physical and mechanical principles.

2. In the case of design by calculation, when the model uncertainty is thought to be high, loading tests and model tests may be effective verification methods for checking the limit states.

3. The observational method and the observational construction control system are not considered to be alternative methods of design, but are to be used complementarily.

4. The prescriptive measures (deemed to satisfy solutions) may not be used when designing foundations in Geotechnical Category 2 or 3, except for unusual cases. Unusual cases may include designs against less elucidated phenomenon, matters concerned with experiences and traditions, the economy of the design, etc. The reason for this restriction is that this method tends to be more conservative.

5. Design details that cannot be solely determined by the design by calculation method can be added as structural details in these design codes.

e) It is important, however, to clarify the aims of such structural details so that it is clear which performance criteria are being added to satisfy which aims.

1.7.2 The partial factor format
a) Items concerning the partial factor format in Section 0.7.2 shall be addressed. In other words, items in Chapter 9 of ISO2394 shall be followed.

b) The partial factor format introduces adequate levels of safety margins with appropriate levels of reliability for the required
performances against various actions, geotechnical parameters, geometrical sizes, and the accuracy of the calculation models.

c) It is of vital importance during the design of foundations that the partial factor format be used to standardize procedures for the determination of the characteristic values of the geotechnical parameters in order to preserve homogeneous safety margins. The procedure for determining the characteristic values is specified in Chapter 2 entitled “Geotechnical Information.”

Reference The determination of partial factor values in the partial factor format are described in detail in Annex E of ISO2394, and are briefly summarized as follows:

1) Acceptable levels of risk may be determined based on background risks that actually exist in society (e.g., the risk of death due to a traffic accident).
2) Optimal safety levels may be determined by minimizing the expected total cost of a structure which is the sum of the initial construction cost and the expected cost of failure.
3) Safety margins shall be calibrated against limit states on the same level as those structures designed by conventional design codes. This method is termed “code calibration.”

d) The partial factor format is classified into two types, namely, the material factor approach and the resistance factor approach.

Material factor approach Partial factors are applied to the characteristic values of actions and the characteristic values of material properties. The values obtained after the application of the partial factor are termed “design values.”

Resistance factor approach Partial factors are applied to characteristic action effects and characteristic resistances. The approach is similar to the Load and Resistance Factor Design used in North America.

1.8 SEISMIC DESIGN

1.8.1 General In general, design situations such as persistent, extreme, and accidental situations should be considered in the seismic design of foundations along with the importance of the structure.

Remark 1. Foundations should be designed so as not to reach the serviceability limit state.
2. Foundations should be designed not to reach the reparability limit state or the ultimate limit state, due to extreme and/or accidental situations, according to the importance of the structure.

1.8.2 Seismic actions and seismic effects

a) The seismic actions and seismic effects on foundations are generally considered to be as follows:

1) Inertial forces
2) Seismic earth pressure
3) Seismic dynamic water pressure
4) Kinematic interaction forces due to soil deformation during earthquakes and especially under conditions of soft soil
5) Liquefaction of the ground at sites where there is a potential for liquefaction
6) Liquefaction-induced lateral flow of the ground at sites where there is a potential for liquefaction
7) Strength degradation of clay which is sensitive to cyclic loading

b) The load combinations in seismic designs should be specified by relating the seismic actions and seismic effects with other actions.

Remark It is not necessary to consider all the seismic actions at the same time. For example, the force of kinematic interaction is thought to be one of the major seismic actions in some subsoil conditions. However, foundations are often designed considering that the major seismic action is the inertial force of the superstructure and the kinematic interaction is a subsidiary seismic action.

1.8.3 Design principles and the estimation of responses

a) When foundations are designed for the serviceability limit state, they shall be designed without considering their ductility.
b) When foundations are designed for the reparability or the ultimate limit state, they shall be designed in such a way that the energy dissipation in the foundation is taken into account and the energy dissipation zones in the foundation are induced into specific relevant places. The foundation shall also be designed so that a brittle failure will not be induced, and the vibration mode of the total structure system will not become very complex because of the ductile behavior of the
foundation.

**Remark 1.** Even when foundations are designed for the reparability or the ultimate limit state, it is recommended that the ductility of the foundation not be taken into account.

2. When foundations are designed for the reparability limit state and the design takes into account the ductility of the foundation, resulting from damage to the structural elements of the foundation, the energy dissipation zones in the structural elements should be placed in areas that can be inspected and repaired easily in terms of the degree of damage resulting from earthquakes.

3. It is recommended that the energy dissipation zones in the structural elements of foundations be placed near the ground surface.

4. When ductility is considered in the design of foundations for the reparability or the ultimate limit state, relevant energy dissipation zones shall be specified. The design should ensure that the structural elements and areas other than the specified energy dissipation zones do not become plastic so that the energy dissipation zones can work as they were intended. Relevant margins of strength should be given between the designed energy dissipation zones and other elements, and between the designed ductile damage mode and other unexpected brittle, damaged modes, e.g., due to bending and shear.

5. The linear response of structures can be estimated using a pushover analysis in which the inertial force corresponding to the first vibration mode is relevantly applied to the structure, if the inertial force in the first vibration mode is predominant. When those structures become plastic, their ductile nonlinear response can also be estimated by applying the equivalent displacement method, the equivalent energy method, the nonlinear response spectrum method, etc. to a nonlinear load-displacement curve estimated with a nonlinear pushover analysis.

### 1.8.4 Modeling of structural elements and soil structure interaction

a) The nonlinearity in the structural elements of foundations and the nonlinear soil-structure interaction shall be considered. The soil-structure interaction should be modeled relevantly, considering the assumed load conditions, the stress or the strain level of the soil, the deformation level of the foundation, the size of the foundation, etc. since the soil-structure interaction can vary depending on those conditions.

**Remark** The soil resistance as a function of frequency and material nonlinearity is not well understood from the viewpoint of the code of practice. Therefore, the static or the pseudo-dynamic soil resistance can be applied in the pushover analysis.

b) Where there is a possibility of liquefaction, the soil resistance considered in the design shall be reduced to conform to the degree of potential for liquefaction.

c) When it comes to clay that is sensitive to cyclic loading, the soil resistance considered in the design shall be reduced to conform to the degree of sensitivity.

### 1.8.5 Verification

#### 1.8.5.1 Verification items and indices

a) The stability of the foundations against seismic actions shall be verified.

b) The strength and the deformation capacities of the foundation members against seismic actions shall be verified.

**Remark 1.** It shall be confirmed that the displacement of the foundation is less than or equal to the threshold displacement in order to ensure the performance of the superstructure.

2. The stability of the foundation may be evaluated, in general, by estimating the foundation responses at the top of the foundation to the base forces caused by the responses of the superstructure.

3. The sectional force and the deformation of the structural elements and the displacement as a total foundation system, obtained in the calculations for verifying the stability of the foundation, can also be used to verify the sectional force and the deformation of the structural elements and the displacement as a total foundation system.
1.8.5.2 Verification of the serviceability limit state

a) The foundation responses shall be verified to see that they remain within the elastic range so that the mechanical properties as a total foundation system can be presumed not to change significantly.

b) It shall be verified that the mechanical properties of the structural elements do not change significantly.

   Remark It shall be verified that the structural elements do not undergo any damage that may lead to a reduction in their durability.

c) The maximum and the residual displacements of the superstructure or the foundation top shall be evaluated; then it shall be verified that those displacements do not ruin the serviceability of the structure.

1.8.5.3 Verification of the reparability limit state

a) When the ductility of the foundation is not considered in the design, it shall be verified that the maximum displacement at the foundation top does not exceed the range in which the behavior of the foundation system becomes clearly nonlinear (nonelastic).

b) When the ductility of the foundation is considered in the design, it shall be verified that the maximum displacement at the foundation top is within the range in which a sufficient level of strength, as a foundation system, can be maintained.

c) When the ductility of the structural elements is considered in the design, it shall be verified that the degree of damage to the expected energy dissipation zones in the foundation’s structural elements is within the reparable range so that the zones can be repaired.

   Remark Although grouped-pile foundations are, statistically speaking, usually highly indeterminate, and local damage to the piles is not thought to strongly influence the foundation stability, a sufficient deformation capacity should be given to the piles. Even when deep under the ground, it is recommended that a sufficient level of deformation capacity be given to the piles, because the kinematic forces due to the distribution of soil vibration displacement versus the depth can make the piles deform and become plastic.

d) The shear strength of the structural elements shall be verified.

e) The maximum and the residual displacements of the superstructure or the foundation top shall be estimated, and then it shall be verified that the foundation can be repaired at a reasonable cost in order to restore the serviceability of the structure.

   Remark In the design of the reparable limit state, it is recommended that some options be given in the foundation structure design report for inspections and repair methods for the foundation in order to restore it after an earthquake.

1.8.5.4 Verification of the ultimate limit state

a) It shall be verified that a sufficient level of strength can be maintained as a total foundation.

b) It shall be verified that the foundation’s structural elements do not collapse.

c) It shall be verified that the displacement of the foundation does not cause the structure to collapse.

1.9 FOUNDATION STRUCTURE DESIGN REPORT

a) The chief designer shall report the results of the foundation design to the client or the owner in the form of a foundation structure design report.

b) The foundation structure design report shall include assumptions made during the design, a summary of the geotechnical information, actions, characteristic values, design calculation models, calculation procedures, and design verification methods for all limit states considered.

c) It is recommended that the foundation structure design report include, but not be limited to, the following items:
   1) Description of the site and the surrounding conditions
   2) Ground conditions
   3) Structural performance criteria and design situations
   4) Descriptions of site specific actions, e.g., earthquake action
   5) Characteristic values of the geotechnical parameters with a justification of the determination
6) Descriptions of the design codes and supporting documentation
7) Justification of the chosen foundation type
8) Structural risks and a justification of the safety margins against various limit states
9) Assumptions for the construction conditions
10) Calculations and drawings of the foundation structures
11) Descriptions of the required monitoring during construction and a check of the items for the maintenance of the structure

d) The geotechnical investigation report and the foundation structure design report shall be archived by the client or the owner for the entire service life of the structure.

References
CEN: Draft ENV 1997-3 Eurocode 7 Geotechnical Design Part 3 Design assisted by field testing, 1997.
The Institute of Structural Engineers: Eurocode 7 Toward Implementation, Oct. 1996.
2. GEOTECHNICAL INFORMATION

2.1 SCOPE

a) This chapter addresses the geotechnical investigation for the design of foundation structures (referred to as "the structure" or "the superstructure" hereinafter).

b) The geotechnical investigation shall include plans and implementations for modeling geotechnical loads (actions), subsurface structures, and relevant on-site constitutive relations as well as estimations of the geotechnical parameters used to describe the models applied in the design.

c) The purpose of the plans and implementations of the geotechnical investigation is to appropriately collect and interpret the geotechnical information. In particular, an evaluation of the geotechnical parameters is conducted in order to determine the "characteristic values".

d) A report on the geotechnical investigation shall be prepared as an official document which properly records all matters related to the geotechnical investigation.

2.2 GENERAL

2.2.1 Covering the geotechnical information

a) The geotechnical investigation shall cover sufficient information on the geology, the geomorphology, the seismology, the hydrology, etc. at the construction site. It shall also include information concerning background details on any artificial work that has been done or any changes in the natural environment that have occurred.

b) The following methods shall be combined, as relevant, in order to collect the geotechnical information:

1) Literature survey
2) Geological survey
3) Geophysical exploration and borehole logging
4) Drilling
5) Groundwater investigation and geotechnical investigation
6) Field testing and sounding
7) Trench investigation and exploratory tunnel investigation
8) Retrieval of samples (sampling) and laboratory testing
9) In-situ loading tests
10) Measurement and observation/monitoring during construction works
11) Decipherment of remote sensing and aerophotography

c) The geotechnical investigation shall be conducted in consideration of the construction methods and the performance requirements of the structure.

d) The geotechnical investigation shall be updated, as necessary, using the latest information. It shall accompany the progress of the geotechnical investigation prior to construction and the observations (monitoring) during construction.

e) The investigation, testing, and observations (monitoring) shall be executed and reported in accordance with the standards established by the Japanese Geotechnical Society (JGS) and/or the Japan Industrial Standards (JIS), etc., which are widely accepted in Japan.

Remark Standards that are acknowledged internationally can be applied if the need arises.

f) The range, the location, the items, and the extent of the geotechnical investigation shall be determined based on the geotechnical categories which are classified according to the importance of the structure and the difficulty of its design from the viewpoint of geotechnical engineering.

Remark It is recommended that the geotechnical conditions be classified as early in the process as possible since they are strongly associated with all geotechnical aspects of the design.

2.2.2 Designers and geotechnical investigators

a) The geotechnical investigation and the structural design with regard to the foundation design are closely related and form a sequence of processes. Therefore, the structural engineers, as designers, and the geotechnical engineers, as geotechnical
investigators, shall cooperate in order to produce an efficient design.

**Remark** While the design calculation model (for the foundation and the soil) and the estimation model (for possible earthquake motions) should be assumed for determining the items, the locations, the extent of the geotechnical investigation and testing, the local geological and geotechnical features obtained from the geotechnical investigation and testing are needed in order to assume the calculation and the estimation models. Hence, the structural designers and the geotechnical investigators are to be highly dependent on one other.

**Reference** See Appendix C.

a) The designers shall prepare the final resolution/approval and take responsibility for planning the geotechnical investigation and an assessment of the geotechnical aspects directly related to the design. The geotechnical investigators shall prepare the report on the geotechnical investigation and take responsibility for all such reports.

b) The designers and the investigators shall work together through meetings/discussions for their mutual benefit.

**Remark** The minutes of the meetings should be recorded and maintained as official documents. These documents should include reports on the investigation plans, the interim geotechnical investigation reports, and the final geotechnical investigation report.

**Reference** See Appendix C.

### 2.2.3 Investigators' qualifications

The investigators shall be geotechnical engineers who are familiar with the geology, the surrounding conditions, and the soil properties of the site, and have professional skills relevant to the geotechnical investigation.

**Remarks** 1. Geotechnical investigators should be familiar with the design of foundations.

2. It is recommended that the geotechnical engineers be qualified by an appropriate public organization.


### 2.3 GEOTECHNICAL INVESTIGATION

#### 2.3.1 General

a) All data concerning the local soil and groundwater conditions are surveyed in the geotechnical investigation. When the report on the geotechnical investigation is made, the geotechnical parameters used for the design calculations and their reliability shall be properly described.

b) The standard procedure for the geotechnical investigation is shown in Figure 3. The works executed by the investigators are delineated by solid lines, while the discussions/negotiations between the designers and the investigators are delineated by broken lines.

**Reference** See Appendix C.
c) The planning of the geotechnical investigation shall take into account the methods of construction, the performance objectives, the design calculation models, and so on.

d) A dual-stage geotechnical investigation is carried out; it is composed of a preliminary investigation stage and a detailed investigation stage. An investigation for the seismic design is also carried out as part of a series of geotechnical investigations.

e) The investigators shall compile the results of the preliminary investigation in the interim geotechnical investigation report and then send a copy of the report to the designers.

f) Based on the results of the preliminary investigation, the designers and the investigators shall discuss and plan a detailed investigation or decide to re-examine the existing detailed investigation plans.

Remark It is preferable that the detailed investigation be carried out step by step as the design progresses. Moreover, the designers and the investigators should have meetings to re-examine the prepared investigation plans at any appropriate occasion during the detailed geotechnical investigation.

g) The items and the extent of the geotechnical investigation shall be determined considering the geotechnical category and the current stage of the investigation within the total investigation plan.

h) Attention shall be paid to minimizing errors in the measurement data.

i) Careful consideration shall be made in choosing the investigation techniques, the testing methods, the type and the size of the equipment from among many techniques and methods, the locations and the depths of the measurement/testing/sampling, conditions and measurement/testing procedures, and the number of times each test is to be conducted.

j) When undisturbed samples are used as specimens in laboratory tests, the influence of sample disturbance on the test results should be minimized. Attention shall be paid to the sampling (sample retrieval), the transportation, the storage, and the preparation of the specimens.

k) When conducting field loading tests, such as plate loading tests and pressuremeter tests, efforts shall be made to minimize the
influence of the disturbance of the loading surface on the test results. Attention shall be paid to the preparation of the ground surface and the borehole surface to be loaded.

2.3.2 Preliminary geotechnical investigation The preliminary geotechnical investigation shall be conducted in order to collect the geotechnical information necessary to scrutinize the following items:

1) Feasibility of building the structure (e.g., general stability and possible construction locations)
2) Type and configuration of the foundation
3) Depth and area under the ground that may significantly influence the behavior of the structure
4) Plans for the detailed geotechnical investigation
5) Influence of the construction works on the surrounding environment
6) Magnitude of possible seismic motion at the site

Remark The preliminary investigation is principally comprised of published surveys and field trips. In addition, a basic geophysical exploration, borehole logging, a groundwater investigation, sounding, the retrieval of disturbed samples, and laboratory testing are performed if required.

2.3.3 Detailed geotechnical investigation

a) The investigators shall conduct a detailed geotechnical investigation prepared or re-examined by the designers based on the results of the preliminary investigation.

b) The detailed geotechnical investigation shall be conducted in order to collect sufficient information to examine alternatives for the design calculation model and the construction technique and to predict the performance of the foundation.

Remarks 1. In the detailed geotechnical investigation, the following items are to be clarified with attention given to the geological/geotechnical features of the area surrounding the site as well as the soil surrounding the foundation.

1) Geotechnical constituent masses/bodies and geological structural elements such as faults, cavities, and so on
2) Mass movement geomorphologies (e.g., landslides and pyroclastic flow deposits) and deformation geomorphologies (e.g., rock mass creep)
3) Physical and mechanical (deformation and strength) characteristics of the geomaterials
4) Hydrological characteristics of the groundwater and hydraulic characteristics of the ground
5) Topographical and characteristic features of the bedrock surface
6) Swelling or collapsible soils and rocks
7) Embedded or underground structures and objects
8) Existence and distribution of waste and artificial materials
9) Seismic characteristics of the ground (earthquake source characteristics, wave propagation characteristics, and deformation characteristics)

2. The detailed geotechnical investigation should be carefully conducted using reliable techniques, for example, a geophysical exploration and borehole logging, drilling, a groundwater investigation, in-situ tests, sounding, the retrieval of undisturbed samples, and laboratory testing. A trench investigation, exploratory tunnel investigations, and field loading tests may be conducted as required.

3. It is recommended that plans for the detailed geotechnical investigation be modified and augmented via the meetings among the project owners/clients, designers, and geotechnical investigators based on interim reports prepared by the geotechnical investigators.

2.3.4 Investigating the seismic design

a) An investigation of the seismic design of structures at Geotechnical Category 3 sites shall be performed to collect information on the soil properties, the seismic intensities, and so on.

b) To evaluate the ground amplification characteristics of seismic motions, the subsurface structure and the geotechnical characteristics shall be investigated.

c) When the subsurface structure is evaluated based on the linear elasticity theory, the S-wave velocity, the P-wave velocity,
density, the Q-value (or damping constant h), and the thickness of the subsoil layers shall be mainly investigated.

d) When the geotechnical characteristics of the subsoil layers are evaluated, the geotechnical investigation and the laboratory tests shall be selected in consideration of the target strain level in the ground.

Remarks 1. When the strain level of the soils becomes large, the nonlinear amplification characteristics to the base motions should be estimated considering the strain dependency of shear stiffness G and damping constant h of the soils.

2. The methods for estimating the seismic intensity and the return period can be classified into approaches based on information on past earthquakes (e.g., published surveys and observational records), approaches based on information on active faults, and approaches comprised of both of the above-mentioned approaches. The information on active faults is evaluated based on the results of aerial photograph analyses, geophysical explorations, trench investigations, and so on.

3. Possible seismic motions are evaluated with probabilistic seismic hazard analyses or deterministic seismic hazard analyses.

4. Probabilistic seismic hazard analyses take into account the risk of an earthquake occurrence at a target site, which has a target intensity for a target period in the future using the probability of occurrence or an equivalent index, and estimate the risk of using a probabilistic model. The seismic hazard analyses based on past earthquake data can be classified into two approaches, namely, 1) those that use the probabilistic model for the rate of earthquake occurrence and 2) those that use the statistical order of seismic motion intensities.

5. Deterministic seismic hazard analyses simulate earthquake motions through synthesisization by semi-empirical methods with assumed fault models corresponding to seismic sources. In order to assess the appropriate values for the parameters which describe the fault plane and the asperities, past earthquake records and their geological and geographical features should be sufficiently investigated.

6. When an important structure at a Ground Category 3 site is designed, it is necessary to conduct a separate geotechnical investigation specifically for the purpose of estimating the possible earthquake motions which are supposed to be the extremely strong motions of a Level 2 earthquake. The fault and its rupture mechanism, which can give the maximum considerable earthquake at the target site, are carefully assumed based on disaster records of past earthquakes, the latest trench investigation results for active faults, and the observed wave forms of small- and medium-scale earthquake motions that have occurred due to the assumed active fault. Therefore, as much relevant information as possible is collected in the geotechnical investigation. Even in regions where active subsurface faults are not found, the geotechnical investigation/testing is implemented regardless of the possibility, or apparent lack, of buried faults.

2.4 EVALUATING THE GEOTECHNICAL PARAMETERS

2.4.1 General

a) After collecting information by means of various investigations, laboratory tests, and observations (monitoring), and interpreting that information based on geotechnical knowledge, foundation-ground models are then made. Foundation-ground models are calculation models which present the responses of the foundation and the ground, and include the constitutive laws that account for the physical and the mechanical characteristics of the components in the calculation models.

Reference See Appendix C.

b) The geotechnical parameters shall be estimated based on Figure 4 which shows the modeling of the foundation and the ground. These parameters include the geometries of the components associated with the ground in the foundation-ground models (e.g., layer thickness and bedding inclination), the mechanical parameters used to express the foundation-ground interactions (e.g., bearing capacity and the coefficient of subgrade reaction), and the material properties applied to physically and mechanically characterize the geomaterials themselves (e.g., density, stiffness, and strength).
c) The design values of the geotechnical parameters should be obtained via the following four steps:
   1) Measure the values from the investigations, tests, observations, and monitoring.
   2) Derive the values for the geotechnical parameters.
   3) Determine the characteristic values of the geotechnical parameters.
   4) Derive the design values for the geotechnical parameters.

d) The geotechnical parameters shall be estimated via geological/geotechnical knowledge such as theories, empirical relationships, and correlations from the measured values that are obtained directly from each in-situ test, laboratory test, and observation (monitoring).

e) The characteristics of the seismic actions on the structure shall be determined by taking into account the earthquake source characteristics, the wave propagation characteristics, and the deformation characteristics of the ground. These models are also determined based on a proper interpretation of the results of the geotechnical investigation.

**Remark** Measured values are defined as the values that were measured during in-situ and/or laboratory tests or observations (monitoring). Examples of these values include the groundwater levels measured through a groundwater exploration, the N values measured through standard penetration tests, and stress and strain levels measured through triaxial compression tests.

### 2.4.2 Determining the derived values

a) The derived values for the geotechnical parameters are defined as the values that have been derived from the transformation of the measured values using the theoretical relationships, the empirical relationships, and correlations, for instance, Young’s modulus estimated from the N values in standard penetration tests, cohesion, and the internal friction angles estimated from Mohr circles in triaxial test results.

b) Prior to estimating the derived values for the geotechnical parameters, a preliminary assessment of the measured values may be conducted and adjusted, such as by the removal of values that are not considered to represent the characteristics of the soil/rock mass and the correction of data bias.

c) The derived values can be obtained as follows:
   - Directly regard the measured values as the derived values.
   - After a preliminary assessment, consider the measured values as the derived values.
   - Transform the measured values into the derived values for which the measured values and the derived values use different types of mechanical reasoning.

**Reference 1.** Measured values such as those for the density, the relative density, the degree of compaction, the shearing strength, and the ground stiffness are thought to be equivalent to the derived values.
2. Measured values in, for example, geophysical explorations, borehole logging, standard penetration tests, consolidation tests, and pressuremeter tests can be transformed into derived values using different types of mechanical reasoning from that used for the original measured values.

2.4.3 Determining the characteristic values

a) The characteristic values for the geotechnical parameters are defined as the representative values that have been cautiously estimated as the most appropriate values for the foundation-ground models in order to predict the limit states checked in the design.

b) When estimating the characteristic values, it is necessary to consider the harmony among the estimated characteristic values and other assumptions in the modeling of, for example, the mechanical properties, the shape, and the structure of the subsoil layers from the viewpoint of theories and past experience.

c) The characteristic value of a geotechnical parameter is principally thought of as the average (expected value) of the derived values. It is not a mere mathematical average, but also accounts for the estimation errors associated with statistical averaging. Moreover, the average value shall be carefully and comprehensively chosen considering data from past geologic/geotechnical engineering, experiences with similar projects, and relationships and consistencies among the results of different geotechnical investigations and tests.

Remarks 1. When the average value does not make sense in the design calculation model used to check the target limit states, the characteristic value should be estimated by considering the requirements of the design calculation model. For example, a representative value which can express the lower boundary in the distribution of derived values may be required in the case of weakest-link problems.

2. Variations which must be taken into account in the estimation of the characteristic values for geotechnical parameters include errors in the investigation techniques and testing methods as well as estimation errors in the derived values.

3. When the characteristic value of a geotechnical parameter is determined based on a frequency distribution of the derived values, which are generally considered to be scattered, the data shall firstly be carefully examined from the viewpoint of geological/geotechnical understanding and experience. The derived values that are not considered to represent the characteristics of the soil/rock mass, such as measurement defects, can then be removed. Finally, the sample mathematical average is calculated from the screened data and a characteristic value which can consider statistical errors in the estimation of the average value is obtained by the following equation (refer to Annex 2B):

\[ R_k = m_R \pm \frac{t_{\alpha,\nu} s_R}{\sqrt{n}} \]

where
\( R_k \): characteristic value
\( m_R \): sample average
\( s_R \): sample standard deviation
\( t_{\alpha,\nu} \): \( \alpha \)-percentile value of the \( t \)-distribution with \( \nu \) degrees of freedom
\( \nu = n-1 \) in which \( n \) is the number of samples. The \( \pm \) sign is chosen such that the design results are on the safe/conservative side based on the possible influence of the parameter for the total foundation performance.

4. Characteristic values should be reported in the geotechnical investigation report with derived values and their standard deviations or the values for the coefficients of variation.

5. For cases where one or more of the results of the geotechnical investigation are not available, characteristic values may be judged based on past experience with similar or closely related projects and geological/geotechnical knowledge.
2.4.4 Determining the design values

a) In the material factor approach, the design values for the geotechnical parameters are the ground properties substituted into the design calculation. They are obtained by multiplying the characteristic values by the relevant partial factors.

Remark In the resistance factor approach, design values for the geotechnical parameters do not exist.

b) The partial factors shall be determined from the fractile values, taking into account the credibility of the evaluation methods for setting the characteristics and the variability of the derived values. When selecting a partial value for the examined design value, it should be noted that it is necessary to consider whether each design value could mainly affect the resistance side or the action side.

Remark There are exceptions when the design values can be estimated directly from the derived values. Even in such cases, however, they are determined as fractile values in which the variation in derived values is based upon consideration of the following aspects:

1) Due to an insufficient number of samples, there is generally no choice but to assume the distribution type of parameters in order to estimate the design values.
2) The estimation of the probability in the tail region is vulnerable because of errors in the statistical estimations, for instance, an estimated probability value of 95%.
3) The estimation of the probability around the average is much more stable and reliable than that of the 95% probability value.

2.5 GEOTECHNICAL INVESTIGATION REPORT

The results of the geotechnical investigation shall be reported in a geotechnical investigation report and constitute an essential part of the report.

Remark In general, the geotechnical investigation report is comprised of the following two parts:

1) Presentation of the available information on the geological features and the site-related data
2) Statement of assumptions for interpreting the ground information including investigation/test/observation/measurement results

2.5.1 Presenting information concerning the ground Information concerning the original data on all the geotechnical investigations and testing as well as the investigation/testing methods performed as part of the geotechnical investigation shall be presented in the geotechnical investigation report.

Remarks 1. The following items are to be concretely included in the geotechnical investigation report as the ground information:

1) Objectives and scope of the geotechnical investigation
2) Plans of the geotechnical investigation
3) Methods of the geotechnical investigation and testing
   1.1) Items of the geotechnical investigation and testing
   1.2) Detailed methods, equipment, and procedure used in the geotechnical investigation
   1.3) Information on the positions in the soil/rock mass for which the geotechnical properties were examined, including locations, depths, and levels at which the measurements/tests/samplings were conducted
   1.4) Information related to sample quality, including the methods of sampling (sampling retrieval), transportation, and storage
   1.5) Dates and local circumstances that existed when the measurements/tests were carried out
   1.6) Technicians/operators
4) Results of the geotechnical investigation and testing
   4.1) Original data (e.g., measured values, observational records, and photos)
   4.2) Primary processed data (e.g., geologic maps and boring logs)
5) Minutes of the meetings on the geotechnical investigation among investigators, designers, and client/owner

2. The geotechnical investigation report should contain relevant tables and figures to help all involved parties
interpret the data.

3. When a special test is performed at a Geotechnical Category 3 site, the geotechnical investigation report shall describe the test procedure and explain the test results. Moreover, relevant reference materials on special tests performed shall be included in the geotechnical investigation report.

2.5.2 Evaluating information concerning the ground

a) An evaluation of the information concerning the ground shall be conducted in order to interpret the geotechnical investigation and the test results.

b) The decision process regarding the foundation-ground models and the geotechnical parameter values assumed in the design shall be described in the design report as an interpretation of the geotechnical investigation results.

c) The following items shall be included in the evaluation of information concerning the ground:

1) If the related data is reviewed by means of various investigations, tests, and measurements/observations, and it is limited or partial data, it shall be described. If the data contains any faults, or if it is improper, insufficient, or low in accuracy, those facts shall also be shown as well as the original data, and the causes shall be carefully examined and determined in order that those facts can be seen as either reflecting a property of the soil/rock mass or as being the result of errors in the investigation, the tests, the measurements, or the observations.

3) A proposal for additional geotechnical investigations should be submitted, if needed, with comments on their necessity. A detailed plan of the composition and the extent of the requested investigations should also be attached to the proposal.

d) The geotechnical parameters shall be estimated considering the relationships among the results of the investigation, the tests, the observations, and the measurements regarding the construction ground as well as past experience.

**Remarks 1.** An estimation of the information on the construction site and ground should be carried out in terms of related items including the following:

1) A diagram summarizing the results of various investigations, tests, and measurements/observations related to the construction requirements, and if necessary, a histogram showing the range and the distribution of the data with the closest relationship

2) A description concerning the determination of the groundwater level and its seasonal variations

3) A detailed description of the modeling of the structure showing the geological features of the ground

4) A detailed description, including a physical description, and transformation and strength characteristics

5) The presence and an explanation of any irregularities such as caves or pockets

6) A presentation of a created group of derived values for the geotechnical parameters.

2. An estimation of the geotechnical parameters should be conducted by taking into account the mechanical initial and boundary conditions of the structure and the ground to be designed, such as:

1) Initial stress conditions

2) Level and path of the effective stress

3) Strain level and shearing damage level

4) Hydraulic conditions (e.g., drain conditions, permeability, and groundwater level)

5) Anisotropy (inherent and induced)

6) Time effect (e.g., rate of shearing, creep and/or relaxation, aging effect, and diagenesis)

7) Stress/strain history (e.g., effect of over-consolidation)

8) Influence of submergence and desiccation (e.g., saturation ratio, swelling, and free and/or trapped water)

9) Discontinuities (e.g., joints and failure planes)

10) Heterogeneity and nonuniformity of the ground (e.g., intervening thin layers)

11) Influence of freezing and thawing

12) Size of the foundation

13) Boundary conditions between the foundation and the ground.

3. When undisturbed samples are used as specimens for laboratory tests, the sample disturbance, the heterogeneity
and the discontinuity in the samples, the scale effect, and so on should be considered when estimating the
geotechnical parameters.

4. When grading controlled samples or when using samples containing crushable particles as specimens for
laboratory tests, attention should be paid to the influence of the particle grading on the preparation of the samples.

5. When geotechnical parameters obtained from back analyses are applied in the geotechnical investigation results,
a careful examination of the assumptions on the back-analysis models (structural model and material (constitutive)
model) should be made when estimating the geotechnical parameters used for the design.

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Related standards:

[Japanese Industrial Standards (JIS)]
JIS A1219  Method for standard penetration test
JIS A1220  Method for Dutch double-tube cone penetration test
JIS A1221  Method for Swedish weight sounding test

[Japanese Geotechnical Society Standards (JGS)]
JGS 1121  Method for Electrical Logging
JGS 1122  Method for Seismic Velocity Logging
JGS 1221  Method for Obtaining Soil Samples using Thin-walled Tube Sampler with Fixed Piston
JGS 1222  Method for Obtaining Soil Samples using Rotary Double-tube Sampler with Fixed Piston
JGS 1223  Method for Obtaining Soil Samples using Rotary Triple-tube Sampler with Fixed Piston
JGS 1224  Method for Obtaining Samples using Double-tube Sampler with Sleeve
JGS 1231  Method for Obtaining Soil Block Samples
JGS 3211  Method for Obtaining Soft Rock Samples using Rotary Tube Sampler
JGS 1411  Method for Field Vane Shear Test
JGS 1421  Method for Pressure Meter Test in Borehole
JGS 1431  Method for Portable Cone Penetration Test
JGS 1433  Method for Portable Dynamic Cone Penetration Test
JGS 1435  Method for Electric Cone Penetration Test
JGS 1311  Method for Measuring Groundwater Level in Borehole
JGS 1312  Method for Measuring Groundwater Level in Well
JGS 1313  Method for Measuring Pore Water Pressure using Electric Transducer
JGS 1314  Method for Determination of Hydraulic Properties of Aquifer in Single Borehole
JGS 1315  Method for Pumping Test
JGS 1316  Method for Determination of Hydraulic Conductivity of Compacted Fill
JGS 1317  Method for Flow Layer Logging by Tracer
JGS 1321  Method for Determination of Hydraulic Properties of Rock Mass using Instantaneous Head Recovery
Technique in Single Borehole
JGS 1322  Method for Determination of Hydraulic Conductivity of Rock Mass using Injection Technique in Single
Borehole
JGS 1323  Method for Lugeon Test
JGS 1521  Method for Plate Load Test on Soil Ground
JGS 3521  Method for In-Situ Rigid Plate Load Test on Rocks
JGS 3511  Method for In-Situ Direct Shear Test on Rocks
JGS 1613  Method for Measuring In-Situ Soil Density using Core Cutter
JGS 1614  Method for Measuring In-Situ Soil Density using Nuclear Gauge
3. DESIGN OF SHALLOW FOUNDATIONS

3.1 SCOPE
This chapter addresses the design of shallow foundations. The stipulations described herein shall be fully understood and correctly applied when designing shallow foundations.

Remarks 1. The types of shallow foundations to which this chapter is applicable are single footings, continuous-multiple footings, composite footings, and mat foundations.
2. Shallow foundations consist of members such as footings or foundation slabs, footing beams, etc.

3.2 OBJECTIVES
a) The objectives are the reasons for building a shallow foundation. They shall be expressed in nontechnical terms.

b) Since a shallow foundation constitutes part of an entire superstructure, the objectives of the shallow foundation are to coincide with those of the entire structure.

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

3.3 PERFORMANCE REQUIREMENTS
The performance requirements are statements on the functions that need to be provided by a shallow foundation in order to achieve the objectives. In other words, the performance requirements describe the required functions of the shallow foundation for each item given in the objectives. The performance requirements shall be expressed in nontechnical terms.

Remark The performance requirements of shallow foundations shall include, but not be limited to, safety, serviceability, reparability, workability, and cost (refer to Section 1.3).

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”.

3.4 PERFORMANCE CRITERIA
3.4.1 Design working life The design working life of shallow foundations shall be determined based on the definition for the design working life of the superstructure presented in Section 0.4.1.

3.4.2 Limit states
a) The limit states, which must be considered in the design of shallow foundations, should be determined by the performance requirements for shallow foundations and are to coincide with the performance criteria of the superstructure presented in Section 1.4.2.

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

Serviceability limit state The serviceability limit state is the limit state in which damage to the shallow foundation 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 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 shallow foundation 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 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 shallow foundation 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 limit 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.

3.4.3 Actions and design situations

a) The types and combinations of actions which must be taken into account in the design of shallow foundations shall be determined by considering the frequency and the simultaneity of the loads that have been predicted to act on the foundation during the design working life of the superstructure.

Remark Generally speaking, the following actions shall be given consideration in the design of a shallow foundation:

1) Weight of the superstructure
2) Variable loads acting on the superstructure (e.g., live loads, inertial forces during earthquakes, loads due to wave pressure, etc.)
3) Self-weight of the shallow foundation structure (including the weight of backfill)
4) Inertial forces of the foundation structure during earthquakes
5) Buoyancy
6) Earth pressure and water pressure
7) Other external loads

b) The loads assumed in the design of a shallow foundation shall be classified based on their characteristics by referring to the stipulations described in Section 1.4.3.

c) Design conditions which require a combination of actions to be considered in the design of a shallow foundation shall be determined by referring to the stipulations described in Section 1.4.3.

3.4.4 Importance of the superstructure and the performance criteria

In designing shallow foundations, the relationship between the importance of the superstructure and its performance requirements shall be determined by referring to the stipulations of Section 0.4 and Figure 2 in Chapter 0, namely, “Performance matrix concepts.”

Remark The performance criteria for shallow foundations shall be determined based on the safety margins of the limit values for settlement and dip angles, bearing capacity, sliding, overturning, etc., depending on the limit states of the objects of the verification.

Reference The limit states should be determined by considering the characteristics of the shallow foundation and of the superstructure under the conditions which existed during construction.

3.5 INVESTIGATING THE GROUND AND THE SURROUNDING CONDITIONS

a) Prior to the design of shallow foundations, a geotechnical investigation and a survey of the surrounding conditions shall be performed. The type of shallow foundation, the bearing layer, and the construction method shall be selected based on the results of these studies.

b) The types of geotechnical investigations and the methods available for performing them, as well as the evaluation methods available for performing the survey of the surrounding conditions, shall be in accordance with Chapter 2.

Remarks 1. The investigations required in the design of a shallow foundation shall be classified as, but not limited to, the following items:

1) Investigation to determine the ground parameters
   1.1) Unit weight of the soil
   1.2) Shear strength properties
   1.3) Groundwater level and the presence of artesian conditions
   1.4) Geological stratification and geological age
   1.4.1) Presence of unconsolidated layers

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1.4.2) Presence of permeable layers and sandy aquifers
1.4.3) Inclination of the bearing layer and geotectonic folds/dips
1.4.4) Extent of weathering, cracking, and faults when the pile bearing layer is bedrock
1.4.5) Landslides

2) Survey of the surrounding conditions
2.1) Topography of the construction site
2.2) Nearby structures
2.3) Traffic conditions and transportation routes
2.4) Presence of buried matter and industrial waste
2.5) Water table level and quality of the well water

2. The procedures used in the geotechnical investigation and the soil tests shall be determined by referring to relevant Japanese Industrial Standards (JIS) or the Japanese Geotechnical Society (JGS) standards.

3.6 ITEMS TO BE CONSIDERED IN THE DESIGN OF SHALLOW FOUNDATIONS

a) The following items shall be considered in the design of shallow foundations:
   1) Topographical and geological conditions
   2) Characteristics of the structure
   3) Construction conditions
   4) Environmental conditions

   Remark Shallow foundations shall be designed based on investigations of the following items (see (1) and (2)):
   1) Stability of the ground
   2) Bearing capacity failure
   3) Overturning and sliding of the foundation
   4) Subsidence and inclination of the foundation
   5) Failure of or damage to foundation members

   (1) When investigating the limit states, some of the above-mentioned items may be omitted.
   (2) For some types of superstructures, it is necessary to examine the horizontal displacement of the foundation.

b) In the design of shallow foundations, careful consideration shall be given to the following matters:
   1) As a general rule, the bearing layer must be a soil layer with a low probability of liquefaction during earthquakes. In cases where liquefaction is possible, measures shall be taken to improve the soil or pile foundations must be considered.
   2) When a shallow foundation is going to be constructed on a sloping ground or near a cliff, the stability of the entire ground shall be confirmed, and its effect on the bearing capacity and the displacement of the foundation shall be considered.
   3) In cases where the subsoil layer which supports the foundation is bedrock, the effects of discontinuity planes and weathered layers shall be considered.
   4) The base of the shallow foundation should be constructed at a depth where the soil is unaffected by freezing and where scour, caused by rainwater, is unlikely to occur.

c) The objectives and the performance requirements of the structure shall be discussed with the client or the owner before beginning the design process.

Remark Prior to the design process, the design method which will be applied to estimate the behavior of the shallow foundation shall be discussed with the client or the owner.

d) A qualified chief designer shall assume responsibility for the management of the design process (refer to Sections 0.6.2 and 0.7.3).
3.7 PREDICTING THE BEHAVIOR OF SHALLOW FOUNDATIONS

3.7.1 Vertical bearing capacity

a) The vertical bearing capacity of shallow foundations can be estimated by the following methods:

   Remarks 1. Calculation method
   1) The use of a design model that considers both geotechnical parameters and actual examples is recommended.
   2) A model based on the rigid-plastic theory is generally used as the design model.
   3) The method used to establish the ground constants in the calculation method is closely related to the partial factors considered in the design verification. Therefore, a method which establishes the ground constants for use in examining the partial factors is applied.

b) Other methods
   1) If the vertical bearing capacity of the ground can be estimated semi-empirically, based on nearby construction works or similar case histories with identical ground conditions, it is not necessary to predict the foundation behavior by the calculation method.
   2) When considering plate loading test results, an adequate study must be conducted with regard to the effect of the dispersion of the ground and the difference in the dimensions of the loading plate and the actual foundation.

b) The scale effect must be considered when calculating the vertical bearing capacity of a shallow foundation.

c) In cases where the load is inclined or eccentric, the effect of these conditions shall be considered.

   Remark The following are cases in which a load is inclined or eccentric:
   1) The position of the action of a vertical load is eccentric.
   2) A horizontal force is acting on the foundation due to eccentric soil pressure.
   3) A horizontal force or an overturning moment is acting on the structure due to an earthquake, high wind, wave pressure, etc.

d) When considering a sloping ground or a ground near a cliff, the vertical bearing capacity must be reduced in relation to the slope angle, the distance from the top of the slope, the soil properties, the depth, etc.

e) When soft cohesive soil lies underneath the bearing layer, the bearing capacity of the cohesive soil layer shall be examined.

f) When a thin weak stratum exists between the foundation bed surface and the bearing layer, the possibility that the soil may be forced out must be considered.

3.7.2 Sliding resistance The sliding resistance of shallow foundations shall be investigated when necessary.

   Remark The following elements of resistance shall be considered when estimating the sliding resistance of a shallow foundation:
   1) Frictional resistance of the foundation bed surface
      The frictional resistance of the foundation bed surface must be calculated considering the ground conditions as well as the form and the construction of the foundation bed surface.
   2) Passive resistance of the embedment
      The passive resistance of a foundation embedment shall be considered using the passive resistance in front of the foundation. It should be noted that a large horizontal displacement is required in order to obtain adequate passive resistance.
   3) Passive resistance of brace projections
      Projections or braces shall be used to improve the sliding resistance of the foundation base.

3.7.3 Settlement An investigation of the settlement of shallow foundations shall be performed for both initial and consolidation settlements. When a cohesive soil layer is present immediately under the shallow foundation or under the bearing layer, it is important to examine the long-term consolidation settlement.

   Remarks 1. One or a combination of the following methods shall be applied when estimating the initial settlement of a shallow foundation:
   1) Calculation method according to the elasticity theory
1.1) When applying the elasticity theory, the method for estimating the deformation modulus (or shearing rigidity ratio) of the ground is significant.

1.2) When estimating the deformation modulus of the ground, a geophysical investigation, in-situ tests, or laboratory soil tests using sample materials shall be conducted.

1.3) Appropriate ground constants shall be established for all limit states considering the respective stress and strain levels of the ground.

2) Method based on plate loading tests

When using plate loading test results to calculate the settlement, differences in the dimensions of the plate and the foundation shall be considered.

2. A calculation method based on the consolidation theory can be applied when estimating the consolidation settlement of a shallow foundation. In calculating the consolidation settlement, consolidation tests on sample materials are important.

3. The target depth used in calculating the settlement shall be determined based on the size and the shape of the foundation, variations in the ground stiffness in the vertical direction, the distance between foundations, etc.

4. When investigating the settlement, the unequal settlement and the distortion angle (1) or the inclination angle of the foundation shall be estimated in addition to the total settlement.

Note: (1) The distortion angle is equal to the displacement (or deflection) of a foundation member divided by the span length, whereas the displacement is the unequal settlement minus the inclination of the rigid body.

5. The stiffness of a superstructure can greatly affect the occurrence of unequal settlement and/or the distortion angle of the foundation.

3.8 VERIFYING THE DESIGN OF SHALLOW FOUNDATIONS

3.8.1 Limit states and verification

3.8.1.1 Performance criteria The performance criteria shall consist of a combination of the limit states for shallow foundations specified according to the importance of the structure and its design conditions, namely, load conditions and a combination of loads considering the design working life.

Reference Specifications for the performance criteria are described in Section 3.4.4.

3.8.1.2 Verifying the serviceability limit state The maximum and the residual displacements of the superstructure and its foundation shall be estimated to confirm that they lie within a range that satisfies the serviceability requirements.

Remarks 1. In some cases, the safety allowance for the bearing capacity of the ground, as well as that for the sliding and/or the overturning of the foundation, shall be examined to confirm that the allowance lies within a range that satisfies the serviceability requirements.

2. It shall be confirmed that the calculated member stress levels will not alter the dynamic performance of the structure or cause a decline in its durability.

3.8.1.3 Verifying the reparability limit state

a) The reparability limit state shall be verified by confirming that the calculated residual displacements of the superstructure and its foundation lie within a range in which repairs that would restore the structure to the required level of serviceability are possible.

b) The safety allowance for the bearing capacity of the ground, as well as that for the sliding and/or the overturning of the foundation, shall be examined to confirm that the allowance lies within a range in which repairs are possible.

c) The calculated stress levels of the foundation members shall be examined to confirm that they lie within a range in which repairs are possible.

Remark For cases in which the plastic deformation capacity of the foundation members is considered in the design, based on a combination of loads that are assumed to occur during a large-scale earthquake, it shall be confirmed that the deformation of the foundation lies within a range in which repairs are possible.
3.8.1.4 Verifying the ultimate limit state

a) The safety allowance for the bearing capacity of the ground, as well as that for the sliding and/or the overturning of the foundation, shall be examined to confirm that the shallow foundation will not reach an unstable state.

b) Large foundation displacements may cause the failure and/or the collapse of the structure even if the safety and the bearing capacity requirements of the ground have been satisfied. For large foundation displacements, therefore, it is necessary to confirm that such conditions will not cause the structure to fail and/or collapse.

Reference  The ability of the foundation to withstand a sudden collapse must be verified in some cases by considering the plasticity of the ground and the rotation of the foundation based on a combination of loads that is assumed to occur during a large-scale earthquake. In these cases, it shall be confirmed that the calculated rotation of the foundation lies within the limits specified by the allowable deformability of the ground and of the superstructure.

3.8.1.5 Verifying equations

3.8.1.5.1 Vertical bearing capacity

The vertical bearing capacity of the foundation shall be verified by the following equation:

\[ F_{sd} \leq R_{sd} \]

where

- \( F_{sd} \): vertical ground reaction or the stress at the base of the shallow foundation due to the design load
- \( R_{sd} \): design vertical bearing capacity or the limit of the design stress at the base of the shallow foundation in each limit state.

Remarks 1. Two methods are available for calculating the design vertical bearing capacity of the ground, namely, one which divides the characteristic value of the design vertical bearing capacity by the partial factor and the other which multiplies the ground constant by the material factor and calculates the vertical bearing capacity.

2. When applying the method in which the characteristic value of the design vertical bearing capacity is divided by the partial factor, the design bearing capacity can be determined using the following formula:

\[ R_{sd} = R_{sk} / \gamma_d \]

where

- \( R_{sd} \): design vertical bearing capacity at the base of the shallow foundation in each limit state
- \( R_{sk} \): characteristic value of the vertical bearing capacity at the base of the shallow foundation
- \( \gamma_d \): partial factor for the vertical bearing capacity at the base of the shallow foundation in each limit state.

3. When applying the method in which the ground constant is multiplied by the material factor using the rigid-plastic theory, the characteristic value of the vertical bearing capacity is generally estimated as follows:

\[ R_{sk} = C_c N_c + C_\gamma N_\gamma + C_q N_q \]

where

- \( R_{sk} \): characteristic value of the vertical bearing capacity of the shallow foundation
- \( N_c, N_\gamma, N_q \): bearing capacity coefficients
- \( C_c, C_\gamma, C_q \): correction coefficients for the shape of the foundation, the embedded depth, the load eccentricity, and the inclination.

In this case, the design vertical bearing capacity is evaluated using the following equation:

\[ R_{sd} = C_c N_c / \gamma_c + C_\gamma N_\gamma / \gamma_\gamma + C_q N_q / \gamma_q \]

where

- \( \gamma_c, \gamma_\gamma, \gamma_q \): partial factors in each limit state.

3.8.1.5.2 Sliding resistance

The following condition must be satisfied in order to verify the sliding resistance of the foundation:

\[ F_{sd} \leq R_{sd} \]
where

$F_{sd}$: horizontal ground reaction at the base of the shallow foundation due to the design load

$R_{sd}$: design sliding resistance of the shallow foundation in each limit state.

**Remark**

Two methods are available for calculating the design sliding resistance of the ground, namely, one which divides the characteristic value of the sliding resistance by the partial factor and the other which multiplies the ground constant by the material factor and calculates the sliding resistance.

### 3.8.1.5.3 Settlement

The following condition must be satisfied in order to verify the settlement of the foundation:

$$E_{sd} \leq C_{sd}$$

where

$E_{sd}$: settlement, the unequal settlement, or the inclination angle

$C_{sd}$: design value for the settlement, the unequal settlement, or the inclination angle at the base of the shallow foundation in each limit state.

**Remark**

If the performance requirements for the structure have been satisfied with respect to the stress levels acting on both the superstructure and the foundation members, the investigation of the uneven settlement can be omitted.

### 3.8.1.5.4 Stress acting on the foundation members

The following condition must be satisfied in order to verify the safety of the foundation members with respect to damage and failure:

$$F_{sd} \leq R_{sd}$$

where

$F_{sd}$: section force or the stress acting on the shallow foundation members due to the design load

$R_{sd}$: design sectional yield strength or the limit of the design stress of the shallow foundation members in each limit state.

**Remark**

Two methods are available for calculating the limit stress of the foundation members, namely, one which divides the characteristic value of the resistance force by the partial factor, and the other which multiplies the material constant by the material factor and calculates the vertical bearing capacity.

### 3.8.1.5.5 Bearing stratum and the deformability of the foundation

The possible overturning of the foundation shall be verified in some cases when the plasticity of the ground and the rotation of the foundation are considered for a combination of loads due to a large-scale earthquake.

**Remarks 1.** In this case, the following condition is applied:

$$E_{rd} \leq C_{rd}$$

where

$E_{rd}$: rotation of the base of the shallow foundation due to the design load

$C_{rd}$: rotation limit of the shallow foundation in each limit state.

2. The rotation of the foundation must be estimated with a sufficient safety margin considering the plasticity of the ground and the deformation of the foundation.

3. The limit value of the rotation must be set with a sufficient safety margin considering the plastic deformability of the ground and the stiffness of the foundation.

### 3.9 DESIGN REPORT FOR SHALLOW FOUNDATIONS

**a)** The chief designer shall submit a design report on the shallow foundation to the client or owner.

**b)** The design report on the shallow foundation shall include, but not be limited to, the following information in order that the design parameters, the survey on the surrounding environment, the design calculations, and the verification of the design may be obtained:

1) Design conditions
2) Design results
3) Procedure for verifying the design (methods used to estimate the design parameters are based on the results of the geotechnical investigation, details of the verification methods, the referenced design standards, the references, the literature, etc.)
4) Results of the geotechnical investigation (locations, dates, and the results of the survey on the surrounding environment)
5) Results of the loading tests, if performed (sites, dates, and test results)
6) Construction conditions specified in the design
7) Construction management items
8) Surveys deemed necessary during construction

3.10 CONSTRUCTION
a) The construction of shallow foundations shall be performed so as to fulfill the conditions specified in the design.
   Remarks 1. To ensure that a shallow foundation fulfills the performance requirements specified in the design, the construction should be conducted using established control items, control methods, and control values or allowable values. Since performance requirements differ, depending on the type of structure, the control criteria shall be determined based on their applicability to the structure under consideration.
2. The method of excavation should be selected according to the geological conditions, the surrounding conditions, and environmental issues. A test excavation should be conducted in advance to confirm that the construction method can satisfy the design performance requirements and that the excavation is performable.
3. The excavation should be carried out carefully so as not to cause ground instability due to subsurface water and/or rainwater and so as not to damage any surfaces during curing.
4. In order to confirm the bearing stratum, a visual inspection should be conducted by comparing the geotechnical investigation report and sample materials.
   The following tests are useful for confirming the bearing stratum:
   1) Geotechnical soil tests on samples gathered from the formation surface
   2) Loading tests
5. Material such as rubble, gravel, and leveling concrete used in ground works shall satisfy the specifications stated in the design.
6. If backfill is considered to be an element that prevents the sliding of the foundation, the contractor should then be asked to confirm the passive resistance of the backfill materials by performing density tests, compaction tests, and/or loading tests.

b) Care shall be used during construction with regard to the following environmental issues, and investigations shall be conducted whenever deemed necessary.
   1) Water pollution
   2) Noise
   3) Ground vibrations
   4) Settlement/heaving of the surrounding ground and the associated displacement/deformation of nearby structures
   5) Treatment and/or disposal of excavated materials

c) The chief designer shall be responsible for confirming that the installation of the shallow foundation has been performed as specified in the design and shall submit records of the construction to the client or owner.

Related standards:
[Japanese Industrial Standards (JIS)]
JIS A1219 Method for standard penetration test
JIS A1220  Method for Dutch double-tube cone penetration test
JIS A1221  Method for Swedish weight sounding test
[Japanese Geotechnical Society Standards (JGS)]
JGS 1121  Method for Electrical Logging
JGS 1122  Method for Seismic Velocity Logging
JGS 1221  Method for Obtaining Soil Samples using Thin-walled Tube Sampler with Fixed Piston
JGS 1222  Method for Obtaining Soil Samples using Rotary Double-tube Sampler with Fixed Piston
JGS 1223  Method for Obtaining Soil Samples using Rotary Triple-tube Sampler with Fixed Piston
JGS 1224  Method for Obtaining Samples using Double-tube Sampler with Sleeve
JGS 1231  Method for Obtaining Soil Block Samples
JGS 3211  Method for Obtaining Soft Rock Samples using Rotary Tube Sampler
JGS 1411  Method for Field Vane Shear Test
JGS 1421  Method for Pressuremeter Test in Borehole
JGS 1431  Method for Portable Cone Penetration Test
JGS 1433  Method for Portable Dynamic Cone Penetration Test
JGS 1435  Method for Electric Cone Penetration Test
JGS 1311  Method for Measuring Groundwater Level in Borehole
JGS 1312  Method for Measuring Groundwater Level in Well
JGS 1313  Method for Measuring Pore Water Pressure using Electric Transducer
JGS 1314  Method for Determination of Hydraulic Properties of Aquifer in Single Borehole
JGS 1315  Method for Pumping Test
JGS 1316  Method for Determination of Hydraulic Conductivity of Compacted Fill
JGS 1317  Method for Flow Layer Logging by Tracer
JGS 1322  Method for Determination of Hydraulic Conductivity of Rock Mass using Injection Technique in Single Borehole
JGS 1323  Method for Lugeon Test
JGS 1521  Method for Plate Load Test on Soil Ground
JGS 3521  Method for In-Situ Rigid Plate Load Test on Rocks
JGS 3511  Method for In-Situ Direct Shear Test on Rocks
JGS 1613  Method for Measuring In-Situ Soil Density using Core Cutter
JGS 1614  Method for Measuring In-Situ Soil Density using Nuclear Gauge
4. DESIGN OF PILE FOUNDATIONS

4.1 SCOPE
This chapter addresses the design of pile foundations. The stipulations described herein shall be fully understood and correctly applied when designing pile foundations.

Remarks 1. Pile foundations are foundations that consist of one or more piles and the members that connect the respective piles.
2. Piles are slender members driven into the ground.
3. In cases where base bending moment resistance can be disregarded, the provisions in this chapter are also applicable to column-type foundations.
4. An appropriate investigation shall be performed when designing a pile foundation that is going to be constructed on a slope so that it will be designed properly.
5. The resistance characteristics of caisson-type pile foundations are similar to those of column-type foundations; therefore, the effects of such characteristics shall be considered when designing caisson-type pile foundations.

Reference It is possible to consider laterally-loaded members as slender members even though they behave as infinitively long members.

4.2 OBJECTIVES
a) The objectives are the reasons for building a pile foundation. They shall be expressed in nontechnical terms.
b) Since a pile foundation constitutes part of an entire superstructure, the objectives of the pile foundation are to coincide with those of the entire structure.

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

4.3 PERFORMANCE REQUIREMENTS
a) The performance requirements are statements on the functions that need to be provided by a pile foundation in order to achieve the objectives. In other words, the performance requirements describe the required functions of the pile foundation for each item given in the objectives. The performance requirements shall be expressed in nontechnical terms.

Remark The performance requirements of pile foundations shall include, but not be limited to, safety, serviceability, reparability, workability, and cost (refer to Section 1.3).

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) Loads from the superstructure shall be transmitted to the surrounding ground by piles driven deep into the ground, using the strength and the stiffness of the piles, with no loss in the functions of the structure.

Remark Since it is generally difficult to diagnose the failure state of a pile foundation, and it is more difficult and time consuming to repair a damaged pile foundation than a damaged superstructure, pile foundations may require higher safety factors than the superstructure itself.

4.4 PERFORMANCE CRITERIA

4.4.1 Design working life The design working life of pile foundations shall be determined based on the definition for the design working life of the superstructure presented in Section 0.4.1.

4.4.2 Limit states
a) The limit states, which must be considered in the design of pile foundations, should be determined by the performance requirements for pile foundations and are to coincide with the performance criteria of the superstructure presented in Section 1.4.2.
b) In principle, the following three limit states shall be specified for pile foundations, although other limit states are not
Serviceability limit state  The serviceability limit state is the limit state in which damage to the pile foundation 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 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 pile foundation 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 pile foundation 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. 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.

4.4.3  Actions and design situations

a)  The types and combinations of actions which must be taken into account in the design of pile foundations shall be determined by considering the frequency and the simultaneity of the loads that have been predicted to act on the foundation during the design working life of the superstructure.

Remarks 1. Generally speaking, the following actions shall be given consideration in the design of a pile foundation:

1)  Loads imposed by the superstructure, including surcharges
2)  Variable loads acting on the superstructure (for example, surcharges, inertial forces during earthquakes, and wave forces)
3)  Self-weight of the pile foundation
4)  Buoyancy
5)  Water pressure and action/reaction from the subsoil
6)  Other external loads

2.  One of the following two forces shall be applied when considering the action caused by the deformation of the surrounding ground. The interaction between the pile foundation and the ground shall be taken into consideration in this case.

1)  Forced displacement caused by ground displacement
2)  Forces acting on the pile body due to the deformation of the ground

3.  In cases where piles are set in or on a ground where settlement is likely to occur, for example, in or on reclaimed land or ground with a compressive layer, negative skin friction should be considered in the design.

b)  The loads assumed in the design of a pile foundation shall be classified based on their characteristics by referring to the stipulations described in Section 1.4.3.

c)  Design conditions which require a combination of actions to be considered in the design of the pile foundation shall be determined by referring to the stipulations described in Section 1.4.3.

4.4.4  Importance of the superstructure and the performance criteria

a)  In designing pile foundations, the relationship between the importance of the superstructure and its performance requirements shall be determined by referring to the stipulations in Section 0.4 and Figure 2 in Chapter 0, namely, "Performance matrix concepts."

b)  The structural performance of pile foundations shall be evaluated by factors such as displacement, stress acting on its members,
durability, remaining strength after damage, and remaining rigidity after damage.

Remarks 1. The displacements considered in the design of a superstructure shall be vertical, horizontal, and rotational.

2. To satisfy the performance requirements, pile foundations shall be designed to meet the specified performance criteria, bearing in mind the following points:
   1) The loads imposed on the ground via the pile foundation must not be excessive.
   2) The strength of the pile foundation members must be sufficient.
   3) Adequate consideration must be given to the strength of the piles and their connections, as well as to the buckling strength of the piles.
   4) The displacement and the deformation of the pile foundation must be sufficiently small.

Reference The limit states should be determined by considering the characteristics of the pile foundation and of the superstructure under the conditions which existed during their construction.

4.5 INVESTIGATING THE GROUND AND THE SURROUNDING CONDITIONS

a) Prior to the design of pile foundations, a geotechnical investigation and a survey of the surrounding conditions shall be performed. The structural type of foundation and the construction method shall be selected based on the results of these studies.

b) The types of geotechnical investigations and the methods available for performing them, as well as the evaluation methods available for performing the survey of the surrounding conditions, shall be in accordance with Chapter 2.

Remarks 1. Reference should be made to case histories of construction and other investigations conducted near the proposed construction site.

2. The investigations required in the design of a pile foundation shall be classified as, but not limited to, the following items:
   1) Investigation to determine the design parameters
      1.1) Unit weight of the soil
      1.2) Shear strength properties
      1.3) Groundwater table and the presence of artesian conditions
      1.4) Geological stratification and geological age
         1.4.1) Presence of unconsolidated layers
         1.4.2) Ground settlement
         1.4.3) Presence of permeable layers and sandy aquifers
         1.4.4) Inclination of the pile bearing layer and folding/dip angle of the geological strata
         1.4.5) Extent of weathering, cracking, and faults when the pile bearing layer is bedrock
         1.4.6) Landslides
         1.4.7) Particle size of the gravel
   2) Survey of the surrounding conditions
      2.1) Topography of the construction site
      2.2) Nearby structures
      2.3) Traffic conditions and transportation routes
      2.4) Presence of buried matter and industrial waste
      2.5) Possibility of toxic gas release due to the construction
      2.6) Methods for the treatment and/or the disposal of surplus soil and industrial waste
      2.7) Groundwater conditions, including the state and the flow velocity of the confined groundwater
      2.8) Water table level and the quality of the well water
      2.9) Scouring

c) The geotechnical investigation shall be conducted for factors that may affect the performance of the pile foundation, and should include the bearing capacity of the ground, stability against sliding, and settlement properties.

Remark 1. The content of the geotechnical investigation (type, interval, number, and depth) shall be determined by giving consideration to the possible types of foundations to be used and the complexity of the soil conditions.
2. The procedures used in the geotechnical investigation and the soil tests shall be determined by referring to the relevant Japanese Industrial Standards (JIS) or the Japanese Geotechnical Society (JGS) standards.

3. The geotechnical investigation should be performed to the depth at which the bearing layer exhibits the required bearing capacity.

4. In investigating bedrock, a macroscopic study should be made to determine the presence and the overall state of any faults and/or cracks.

5. The possibility that the properties of the surrounding ground may be altered by the installation of piles shall be considered.

6. The design values can be obtained directly from loading tests. Generally speaking, the geotechnical data should be determined by means of a geotechnical investigation, because the loading test results are evaluated from a geotechnical viewpoint.

Reference: The characteristic design values for the axial bearing capacity shall be estimated from the average value of the geotechnical data in each layer along the axis of the pile. The chief designer should consider the fact that spatial variations in the parameters can be reduced if this technique is used. The reason for this phenomenon is that the variance in the moving average of a random field is smaller than the variance in the original random field, and the reduction of the variance depends on the distance of the autocorrelation in the random field.

4.6 ITEMS TO BE CONSIDERED IN THE DESIGN OF PILE FOUNDATIONS

4.6.1 General items

a) The following items shall be considered in the design of pile foundations:
   - Topographical and geological conditions
   - Characteristics of the structure
   - Construction conditions
   - Environmental conditions

b) In the design of pile foundations, the deformation of the ground, the reaction force of each pile top, and the deformation of the piles caused by the loads (or actions) imposed by the superstructure and/or the surrounding ground should be evaluated.

c) The type and the dimensions of the piles should be determined after considering the functions of the superstructure, the geological conditions, the ease of construction, and the bearing mechanism of the foundation.

Remark: In cases where liquefaction of the surrounding ground during an earthquake is a possibility, caution is required in the design of the pile foundation.

Reference 1. Pile foundations shall be designed based on investigations of the following items:
   - Overall stability and deformation of the ground
   - Displacement and deformation of the pile foundation
   - Damage to and failure of the pile foundation

2. The design of pile foundations shall be prepared in accordance with the items specified below:
   - In cases where the subsoil layer which supports the foundation consists of bedrock, the effects of discontinuity planes and weathered layers shall be considered.
   - Even when the piles are to be embedded into a firm, good-quality subsoil layer, the effect of the foundation on the bearing capacity and the settlement should be studied particularly in cases where the layer is thin or it overlies a weak or unconsolidated soil layer.
   - To prevent differential settlement and the inclination of the foundation, the arrangement of the piles should be planned so as to support equivalent long-term loads.
   - Depending on the design model employed, the ground surface should be properly assumed in the design.
   - The pile pitch should be selected after considering the environment of the construction site and the ease of construction.
   - The stress acting on the piles while they are being driven into the ground should be considered.

d) The objectives and the performance requirements of the structure shall be discussed with the client or the owner before
beginning the design process.

**Reference** Prior to the design process, the design method which will be applied to estimate the behavior of the pile foundation shall be discussed with the client or the owner.

e) A qualified chief designer shall assume responsibility for the management of the design process (refer to Sections 0.6.2 and 0.7.3).

### 4.6.2 Individual items

#### 4.6.2.1 Footings

In cases where the majority of the piles are going to be used as friction piles, footings, pile caps, and base slabs will greatly affect the bearing capacity of the pile foundation.

#### 4.6.2.2 Pile foundations using pile groups

When the pile foundation consists of a group of piles, the forces acting perpendicular to the major axis, due to horizontal loading and/or the axial force caused by horizontal loading, shall be considered.

**Remark 1.** The estimation of the bearing capacity of a pile foundation must consider the effect of using a pile group, because the bearing capacity of a pile group may be less than the sum of the bearing capacity of each single pile, depending on the center-to-center distance between the piles.

1. In cases where the center-to-center distance between the piles is small, the estimated bearing capacity of the pile foundation should be reduced. Depending on the construction method, there are limitations on the center-to-center distance between piles in pile foundations.
2. In cases where the bearing strata are thin and weak and compressible strata underlie the bearing strata, a reduction in the bearing capacity is conceivable. It follows, therefore, that the settlement of a pile group may be greater than that of the sum of the single piles.
3. Since the forces perpendicular to the major axis assigned to each pile in a pile group will vary depending on the pile spacing and/or the deflection of the pile, pile spacing and deflection should be taken into consideration.

**Reference 1.** The effect of grouping piles on the axial bearing capacity may be small when the center-to-center distance between the piles is greater than 2.5 times the pile diameter.

2. To avoid differential settlement, the arrangement of the piles is frequently defined by the equivalent division of the axial component of the self-load.
3. The estimation of the settlement of the pile foundation should consider the effects of grouping, because the settlement of a pile group differs from that of the sum of the single piles, depending on the pile spacing.
4. In cases where the superstructure has high rigidity, the pile foundation can be designed based on the assumption that the undercapacity of some piles will be covered by other piles if certain piles have a lower bearing capacity.

#### 4.6.2.3 Negative skin friction

a) In cases where piles penetrate through compressible strata, the effect of negative skin friction shall be taken into consideration when estimating the behavior of pile foundations.

**Remark 1.** Skin friction in a sandy stratum between compressible strata, or a stratum overlying compressible strata, can be considered as a cause of negative skin friction.

1. The arrangement of the piles and the characteristics of the negative friction acting on the individual piles should be taken into account when considering the negative skin friction acting on a pile group.
2. The effect of reduced negative skin friction, due to pile settlement, may be taken into consideration when estimating the effect of skin friction.
3. In compressible strata, batter piles are subject to bending stress.
4. As negative skin friction is thought to be mobilized by the relative movement between the piles and the ground, the relative movement between the piles and the ground should be estimated when calculating the negative skin friction.
b) Differential settlement may occur at points where the type of foundation has changed and/or at the points of change between a structure and the surrounding ground surface. The effect of differential settlement on the performance and the safety of the superstructure should be taken into consideration.

4.6.2.4 Open-ended piles  The effect of pile diameter, pile length, subsoil conditions, construction conditions, and plugging conditions shall be considered when estimating the pile capacity.

Remark  The mechanism associated with plugging the pile ends is not well understood. A decrease in the pile base capacity is conventionally thought to be a decrease in the reliable base area. However, the plugging effect may be thought of as the result of the skin friction of the pile inner surface.

Reference  The compressive failure of piles in bearing strata is conceivable when using steel pipe piles.

4.6.2.5 Slenderness ratio  When the pile is significantly long and the length/diameter ratio (slenderness ratio) is large, the pile capacity may be reduced, depending on the accuracy of the pile construction.

Remark  The mechanism which mobilizes the shaft friction for long piles differs from that for short piles due to the compressibility of the piles. This effect should be considered.

4.6.2.6 Effect of connections  The connection points of prefabricated piles may be the weakest points of the piles. Since the performance of the in-situ connections is usually complicated, control of the construction process may be inadequate.

Remark  Giving consideration to the effect of the connections is important in tension-loaded piles.

4.6.2.7 Batter piles  Differences in the structural characteristics of different types of foundations, for example, the combined use of batter piles and vertical piles, should be taken into consideration.

4.7 PREDICTING THE BEHAVIOR OF PILE FOUNDATIONS

4.7.1 General

a) Any combination of the three methods listed below shall be used to evaluate the behavior of pile foundations:

Loading tests  Standard pile loading test method proposed by the Japanese Geotechnical Society (JGS)

Calculation method  Calculation model verified by a knowledge of soil mechanics or by data on actual structures

Other methods  It may not be necessary to perform loading tests or calculations if references to the results of a nearby construction or similar case histories show that no possibility of failure exists.

Reference  At present, there are no methods available which can estimate the load-settlement relationship of piles with high accuracy.

b) The following items shall be considered when evaluating the behavior of pile foundations with any combination of the above-mentioned methods:

1) Load characteristics
2) Differences between test piles and actual piles
3) Effects of the pile construction
4) Accuracy of the geotechnical investigation

Remark 1. In cases where the design is performed by the calculation method and/or other methods, pile loading tests are recommended in order to verify the design.

2. The load-settlement relationship should be evaluated since the settlement of pile foundations can be affected by the differences in loading characteristics (especially the duration of loading) and variations in construction methods.

c) The characteristics of piles that are loaded perpendicular to the major axis shall be considered when estimating the bearing capacity with respect to loads perpendicular to the major axis.

Remark 1. When estimating the characteristics of piles loaded perpendicular to the major axis of the piles, the piles are initially assumed to be infinitely long piles. If the piles are not thought to be infinitely long, however, the
effect of short piles must then be taken into consideration.

2. It is difficult to accurately determine the yield and the ultimate load of piles loaded perpendicular to the major axis. Thus, the maximum load perpendicular to the major axis supported by the piles may be defined by the displacement perpendicular to the major axis.

4.7.2 Evaluating the piles by loading tests

a) Pile loading tests should be planned after considering the load characteristics, the degree of pile displacement, and the characteristics of the design model. The type of loading test and the sample size chosen should be defined according to the specifications of the loading tests (1)(2).

Reference 1. Several types of pile loading tests are available; they are categorized by loading speed (static, rapid, or dynamic) and loading point (pile top or tip).

2. The standards proposed by the Japanese Geotechnical Society (JGS) can be employed for reference when selecting the type of pile loading test.

Notes (1) Loading test results are simulated for static loading test results regardless of which test method is used. This is because design loads are simulated for static loads in virtually all pile foundation designs, and the majority of the loading tests have been static loading tests.

(2) A method for applying test results under different loading speeds to static loading test results has been studied for axial pile loading tests.

b) A geotechnical investigation shall be performed at the site where the loading tests are to be performed.

Remark 1. It is preferable to perform the pile loading tests at a location representative of the actual site.

2. The representative location should be determined by taking into consideration the site investigation results and the importance of the structure. Differences in the test sites and the actual locations will affect the safety margin of the design.

c) The reliability of the loading tests is affected by the type and the number of tests conducted (1).

Remark The number of piles to be tested should be determined after considering the following points:

1) How the loading tests reflect the design
2) Type of loading test
3) Importance of the structure
4) Number of piles required in the foundation
5) Existence of the results of tests on piles used under similar ground conditions

Notes (1) The merit of pile loading tests is their applicability to performance predictions for single piles based on tests conducted on piles installed under the same conditions as the actual piles. Therefore, it is possible to predict the bearing capacity of piles at the actual site.

d) The loading test results shall be evaluated from a geotechnical viewpoint.

Remark 1. When the ground behavior is evaluated by loading tests, the safety factor of the piles should be sufficient to estimate the bearing capacity of the piles up to ground failure.

2. Even if the purpose of the loading tests is to verify the design assumptions, the test load should be larger than the load being considered in the design.

3. In cases where liquefaction of a stratum is possible, the stratum should be improved to eliminate the possibility of liquefaction. Otherwise, the design must consider the effects of liquefaction.

4. It is generally difficult to estimate the pile performance under long-term loading conditions from loading test results. Therefore, the pile performance shall be estimated through calculations.

5. If the effect of the loading speed and/or the loading history during an earthquake can be taken into consideration, dynamic loading test results can be directly applied to the design.

6. In order to use the geotechnical parameters provided by the loading test results, the design should be performed considering how the loading test results may be affected by the ground conditions, the maximum load, the pile diameter, the pile length, the stiffness ratio of the pile and the ground, and the loading history.
7. If the behavior of a pile loaded perpendicular to its major axis is to be estimated from the results of loading tests, the effect of the loading height and the fixity of the pile head should be taken into consideration.

8. If the behavior of a pile loaded perpendicular to its major axis is to be estimated from the results of loading tests, the effect of the pile length should be taken into consideration, since the pile tip will not be fixed if the pile length is insufficient.

Reference 1. When loading tests are conducted to verify the design assumptions, the test load should be limited based on the safety margin of the piles. The safety margin of the ground conditions cannot be estimated in such cases.

2. The effect of the residual stress on the piles should be considered when the pile loading test results are evaluated.

3. Long piles are piles whose behavior is not affected by differences in the embedded length.

4. The classification of a pile as a long pile cannot be determined merely by the pile and the ground conditions, but must also consider the load level, since both the pile and the ground have nonlinear properties.

4.7.3 Estimating the pile behavior through the calculation method The calculation method shall follow the principles of soil mechanics.

Remarks 1. The calculation method can be used to evaluate and to support the loading test results.

2. The limitations of the calculation method should be considered.

Reference 1. The design may be continued without performing loading tests if the cost of conducting such tests would be economically prohibitive. In such cases, however, the calculation method should be corroborated by objective evidence.

2. Loading tests are performed to verify the design which the calculation method supports.

3. When the behavior of a pile loaded perpendicular to its major axis is estimated with the calculation method, the pile can be modeled as a beam in an elastic medium.

4.7.4 Evaluating the piles by other methods Piles should principally be designed by loading tests and/or the calculation method.

Remarks 1. In some cases, experience with established pile construction methods under similar conditions eliminates the necessity for loading tests or the calculation method.

2. Piles can be designed based solely on experience only if the foundation is small in size and few safety problems are anticipated. However, such cases are very rare.

3. The design of pile foundations based solely on previous results is not appropriate. It is very important to rationally interpret the data on past experiences and to apply such data to the design with care.

4.8 VERIFYING THE DESIGN OF PILE FOUNDATIONS

4.8.1 Limit states and verification

4.8.1.1 Performance criteria The performance criteria shall consist of a combination of the limit states for pile foundations, specified according to the importance of the structure, and its design conditions, namely, load conditions and a combination of loads considering the design working life.

Reference Specifications for the performance criteria are described in Section 4.4.4.

4.8.1.2 Verifying the serviceability limit state The maximum and the residual displacements of the superstructure and its foundation shall be estimated to confirm that they lie within a range that satisfies the serviceability requirements.

Remarks 1. The following two items shall be verified for the foundation body of a pile foundation:

1) There have been no significant changes in the characteristics of the structure.

2) No damage has been done which would reduce the long-term durability of the structure.

2. The stability of the foundation shall be verified by satisfying above-mentioned items 1) and 2).

Reference In general, the vertical settlement of structures which are supported by pile foundations is small. If the settlement of the surrounding ground is excessive, however, the structure may experience a pull-out effect.
4.8.1.3 Verifying the reparability limit state  The reparability limit state shall be verified by confirming that the calculated residual displacements of the superstructure and its foundation lie within a range in which repairs that would restore the structure to the required level of serviceability are possible.

Remarks 1. Verification of the reparability of the foundation
   1) It shall be confirmed that no damage has been done which would reduce the long-term durability of the structure.
   2) The residual carrying capacity of all members shall be verified.
   2. The stability of the foundation shall be verified by satisfying above-mentioned items 1) and 2).

4.8.1.4 Verifying the ultimate limit state  In verifying the ultimate limit state, the stability of the foundation shall be verified.

Remarks 1. The following two items shall be verified:
   1) The foundation has not experienced failure due to the failure of the surrounding ground which supports the pile foundation.
   2) The foundation has not experienced failure due to stress on the members of the pile foundation which exceeds the capacity of the members.
   2. It shall be verified that the superstructure will not collapse due to the displacement of the foundation.

4.8.2 Verifying equations  The following shall be verified for each limit state, as required.

4.8.1.1 Vertically-loaded single piles
a) In verifying the design of vertically-loaded piles, the following equation shall be satisfied for each limit state:

\[ F_{pd} \leq R_{pd} \]

where
- \( F_{pd} \): design axial load at the pile top or design axial stress for each design situation
- \( R_{pd} \): design axial resistance at the pile top or design allowable stress for each limit state

Remark  The force exerted by the pile shall also be confirmed.

b) If axial displacement of the piles is anticipated, the following equation shall be satisfied for each limit state:

\[ E_{pd} \leq C_{pd} \]

where
- \( E_{pd} \): design axial displacement at the pile top for each design situation
- \( C_{pd} \): design allowable axial displacement at the pile top for each limit state

Reference 1. The bearing capacity of each axially-loaded pile is normally assumed to be a combination of shaft resistance and base resistance. This assumption is expressed by the following equation:

\[ R_{pk} = R_{pok} + R_{psk} \]

where
- \( R_{pk} \): characteristic value of the total pile resistance due to ground failure
- \( R_{pok} \): characteristic value of the base resistance due to ground failure
- \( R_{psk} \): characteristic value of the shaft resistance due to ground failure

2. When using this assumption, the design bearing capacity can be estimated using the following equation. In this case, the values for rb and rs should be determined by considering the bearing mechanism of the piles and the design model.

\[ R_{pd} = R_{pok} / \gamma_{pt} + R_{psk} / \gamma_{ps} \]
where
\( \gamma_{pt} \): partial safety factor of the shaft resistance due to the ground failure in each limit state
\( \gamma_{ps} \): partial safety factor of the pile base resistance due to the ground failure in each limit state

3. It is normally assumed that the tensile bearing capacity of the pile is due only to the shaft resistance. This assumption is expressed by the following equation:

\[
R_{pk} = R_{pk}^\delta
\]

4. When using the above assumption, the design tensile bearing capacity can be estimated using the following equation. In this case, the value of \( \gamma_{ps} \) should be determined by considering the bearing mechanism of the piles and the design model.

4.8.1.2 Single piles loaded perpendicular to the major axis of the pile

When piles are loaded perpendicular to the major axis of the piles, the deflection and the stress acting on the piles shall be verified as part of the design verification.

Remarks 1. In verifying the design of piles loaded perpendicular to the major axis of the piles, the deflection perpendicular to the major axis shall be verified for each limit state by the following equation:

\[
E_{pd} \leq C_{pd}
\]

where
\( E_{pd} \): estimated pile deflection perpendicular to the major axis for each design situation
\( C_{pd} \): allowable pile deflection perpendicular to the major axis for each design limit state

2. The following equation must be satisfied for each limit state when verifying the stress acting on the piles:

\[
F_{pd} \leq R_{pd}
\]

where
\( F_{pd} \): force acting perpendicular to the major axis of the piles for each design situation
\( R_{pd} \): resistance of the piles perpendicular to the major axis of the piles for each design limit state

4.8.1.3 Foundations supported by multiple piles

The forces or the amounts of stress acting on each part of the foundation and the displacements of the pile foundation shall be verified as part of the design verification for the pile foundation.

Remarks 1. The safety of the pile foundation shall be verified by the following equation:

\[
F_{pgd} \leq R_{pgd}
\]

where
\( F_{pgd} \): force or stress acting on each part of the foundation for each design situation
\( R_{pgd} \): design resistance value or design allowable stress of each part of the foundation for each design limit state

2. When verifying the displacement/deformation of pile foundations, the following equation shall be satisfied for each design limit state:

\[
E_{pgd} \leq C_{pgd}
\]

where
\( E_{pgd} \): estimated displacement/deformation of each element for each design situation
\( C_{pgd} \): design allowable displacement/deformation of each element for each design limit state

3. The plasticity ratio may be taken into consideration in Remark 2 of Section 4.8.1.4 entitled “Verifying the ultimate limit state.”
4.9 DESIGN REPORT FOR PILE FOUNDATIONS
The chief designer shall submit a design report on the pile foundation to the client or the owner.
The design report on the pile foundation shall include, but not be limited to, the following information in order that the design parameters, the design of the foundation, and the verification of the design may be obtained:

1) Design conditions
2) Design results
3) Procedure for verifying the design (methods used to estimate the design parameters are based on the results of the geotechnical investigation, details of the verification methods, etc.)
4) Results of the geotechnical investigation (locations, dates, and test results)
5) Results of the loading tests, if performed (sites, dates, test results, and pile details)
6) Construction conditions specified in the design
7) Construction management items
8) Surveys deemed necessary during construction

4.10 CONSTRUCTION

a) The construction of pile foundations shall be performed so as to fulfill the conditions specified in the design.

Remarks 1. It may be necessary to conduct an investigation to confirm that the conditions specified in the design are appropriate and are being met.

2. It shall be confirmed that the construction was performed in such a way that the pile foundation fulfills the performance requirements.

3. To ensure that the pile foundation fulfills the performance requirements, care shall be used during construction with regard to the following points:
   1) Quality control of the materials
   2) Construction procedure
   3) Spillage of toe consolidation liquid/stabilizing liquid, depending on the groundwater conditions
   4) Verticality of the construction machinery on soft grounds
   5) Densification of loose fine sand layers

b) Care shall be used during construction with regard to the following environmental issues, and investigations shall be conducted whenever deemed necessary:
   1) Water pollution
   2) Noise
   3) Ground vibrations
   4) Settlement/heaving of the surrounding ground and the associated displacement/deformation of nearby structures
   5) Treatment and/or disposal of excavated materials

c) The chief designer shall be responsible for confirming that the installation of the pile foundation has been performed as specified in the design and shall submit records of the construction to the client or the owner.

Related standards:

[Japanese Industrial Standards (JIS)]
JIS A1219 Method for standard penetration test
JIS A1220 Method for Dutch double-tube cone penetration test
JIS A1221 Method for Swedish weight sounding test

[Japanese Geotechnical Society Standards (JGS)]
JGS 1121 Method for Electrical Logging
JGS 1122 Method for Seismic Velocity Logging
JGS 1221 Method for Obtaining Soil Samples using Thin-walled Tube Sampler with Fixed Piston
| JGS 1222 | Method for Obtaining Soil Samples using Rotary Double-tube Sampler with Fixed Piston |
| JGS 1223 | Method for Obtaining Soil Samples using Rotary Triple-tube Sampler with Fixed Piston |
| JGS 1224 | Method for Obtaining Samples using Double-tube Sampler with Sleeve |
| JGS 1231 | Method for Obtaining Soil Block Samples |
| JGS 3211 | Method for Obtaining Soft Rock Samples using Rotary Tube Sampler |
| JGS 1411 | Method for Field Vane Shear Test |
| JGS 1421 | Method for Pressuremeter Test in Borehole |
| JGS 1431 | Method for Portable Cone Penetration Test |
| JGS 1433 | Method for Portable Dynamic Cone Penetration Test |
| JGS 1435 | Method for Electric Cone Penetration Test |
| JGS 1311 | Method for Measuring Groundwater Level in Borehole |
| JGS 1312 | Method for Measuring Groundwater Level in Well |
| JGS 1313 | Method for Measuring Pore Water Pressure using Electric Transducer |
| JGS 1314 | Method for Determination of Hydraulic Properties of Aquifer in Single Borehole |
| JGS 1315 | Method for Pumping Test |
| JGS 1316 | Method for Determination of Hydraulic Conductivity of Compacted Fill |
| JGS 1317 | Method for Flow Layer Logging by Tracer |
| JGS 1322 | Method for Determination of Hydraulic Conductivity of Rock Mass using Injection Technique in Single Borehole |
| JGS 1323 | Method for Lugeon Test |
| JGS 1521 | Method for Plate Load Test on Soil Ground |
| JGS 3521 | Method for In-Situ Rigid Plate Load Test on Rocks |
| JGS 3511 | Method for In-Situ Direct Shear Test on Rocks |
| JGS 1613 | Method for Measuring In-Situ Soil Density using Core Cutter |
| JGS 1614 | Method for Measuring In-Situ Soil Density using Nuclear Gauge |
| JGS 1811 | Method for Static Axial Compressive Load Test of Single Piles |
| JGS 1812 | Method for Static Pile-Toe Load Test of Single Piles |
| JGS 1813 | Method for Static Axial Tensile Load Test of Single Piles |
| JGS 1814 | Method for Static Axial Reciprocal Load Test of Single Piles |
| JGS 1815 | Method for Rapid Load Test of Single Piles |
| JGS 1816 | Method for Dynamic Load Test of Single Piles |
5. DESIGN OF COLUMN-TYPE FOUNDATIONS

5.1 SCOPE
This chapter addresses the design of column-type foundations. The stipulations described herein shall be fully understood and correctly applied when designing column-type foundations.

Remarks 1. Column-type foundations are foundations that are modeled as single column bodies for design purposes. They include caisson foundations, steel-pipe-sheet pile foundations, and diaphragm wall foundations.
2. An appropriate investigation shall be performed when designing a column-type foundation that is going to be constructed on a slope so that it will be designed properly.
3. The resistance characteristics of shallow-embedded column-type foundations are similar to those of spread foundations; therefore, the effects of such characteristics shall be considered when designing shallow-embedded column-type foundations.
4. The resistance characteristics of deeply-embedded column-type foundations are similar to those of pile foundations; therefore, the effects of such characteristics shall be considered when designing deeply-embedded column-type foundations.

5.2 OBJECTIVES
a) The objectives are the reasons for building a column-type foundation. They shall be expressed in nontechnical terms.
b) Since a column-type foundation constitutes part of an entire superstructure, the objectives of the column-type foundation are to coincide with those of the entire structure.

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

5.3 PERFORMANCE REQUIREMENTS
a) The performance requirements are statements on the functions that need to be provided by a column-type foundation in order to achieve the objectives. In other words, the performance requirements describe the required functions of the column-type foundation for each item given in the objectives. The performance requirements shall be expressed in nontechnical terms.

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

Reference Each item included in the performance requirements should be described separately.
b) When a column-type foundation is constructed, the main body shall be embedded and its bottom surface shall be placed on the subsoil layer so that loads from the superstructure are transmitted to the surrounding ground, by the strength and the stiffness of the main body, with no loss in the functions of the structure.

Remark Since it is generally difficult to diagnose the failure state of a column-type foundation, and it is more difficult and time consuming to repair a damaged column-type foundation than a damaged superstructure, column-type foundations may require higher safety factors than the superstructure itself.

5.4 PERFORMANCE CRITERIA
5.4.1 Design working life The design working life of column-type foundations shall be determined based on the definition for the design working life of the superstructure presented in Section 0.4.1.
5.4.2 Limit states

a) The limit states, which must be considered in the design of column-type foundations, should be determined by the performance requirements for column-type foundations and are to coincide with the performance criteria of the superstructure presented in Section 1.4.2.

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

Serviceability limit state  The serviceability limit state is the limit state in which damage to the column-type foundation 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 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 column-type foundation 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 column-type foundation 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.

5.4.3 Actions and design situations

a) The types and combinations of actions which must be taken into account in the design of column-type foundations shall be determined by considering the frequency and the simultaneity of the loads that have been predicted to act on the foundation during the design working life of the superstructure.

Remarks 1. Generally speaking, the following actions shall be given consideration in the design of a column-type foundation.

1) Loads imposed by the superstructure, including surcharges
2) Variable loads acting on the superstructure (for example, live loads, inertial forces during earthquakes, and wave forces)
3) Self-weight of the column-type foundation
4) Inertial force during earthquakes
5) Buoyancy
6) Water pressure and earth pressure
7) Other external loads

2. One of the following two forces shall be applied when considering the action caused by the deformation of the surrounding ground. The interaction between the column-type foundation and the ground shall be taken into consideration in this case.

1) Forced displacement caused by ground displacement
2) Forces acting on the column body due to the deformation of the ground

3. In cases where piles are set in or on a ground where settlement is likely to occur, for example, in or on reclaimed land or a ground with a compressive layer, negative skin friction should be considered in the design.

b) The loads assumed in the design of a column-type foundation shall be classified based on their characteristics by referring to the stipulations described in Section 1.4.3.

c) Design conditions which require a combination of actions to be considered in the design of a column-type foundation shall be
determined by referring to the stipulations described in Section 1.4.3.

5.4.4 Importance of the superstructure and the performance criteria

a) In designing column-type foundations, the relationship between the importance of the superstructure and its performance requirements shall be determined by referring to the stipulations in Section 0.4 and Figure 2 in Chapter 0, namely, “Performance matrix concepts.”

b) To satisfy the performance requirements, column-type foundations shall be designed to meet the specified performance criteria, bearing in mind the following points:
1) The loads imposed on the ground via the column-type foundation must not be excessive.
2) The strength of the column-type foundation members must be sufficient.
3) Adequate consideration must be given to the strength of the columns and the joints between the structural members.
4) The displacement and the deformation of the column-type foundation must be sufficiently small.

Reference The limit states should be determined by considering the characteristics of the column-type foundation and of the superstructure under the conditions which existed during their construction.

5.5 INVESTIGATING THE GROUND AND THE SURROUNDING CONDITIONS

a) Prior to the design of column-type foundations, a geotechnical investigation and a survey of the surrounding conditions shall be performed. The structural type of foundation and the construction method shall be selected based on the results of these studies.

b) The types of geotechnical investigations and the methods available for performing them, as well as the evaluation methods available for performing the survey of the surrounding conditions, shall be in accordance with Chapter 2.

Reference 1. Reference should be made to case histories of construction and other investigations conducted near the proposed construction site.

2. The investigations required in the design of a column-type foundation shall be classified as, but not limited to, the following items:
   1) Investigation to determine the design parameters
      1.1) Unit weight of the soil
      1.2) Shear strength properties
      1.3) Groundwater table and the presence of artesian conditions
      1.4) Geological stratification and geological age
         1.4.1) Presence of unconsolidated layers
         1.4.2) Presence of permeable layers
         1.4.3) Inclination of the subsoil layer
         1.4.4) Geotectonic folds/dips
         1.4.5) Extent of weathering, cracking, and faults when the subsoil layer is bedrock
         1.4.6) Ground settlement
         1.4.7) Landslides
         1.4.8) Presence of aquifer sand layers
         1.4.9) Particle size of the gravel
   2) Survey of the surrounding conditions
      2.1) Topography of the construction site
      2.2) Nearby structures
      2.3) Traffic conditions and transportation routes
      2.4) Presence of buried matter and industrial waste
      2.5) Possibility of toxic gas release due to the construction
      2.6) Methods for the treatment and/or the disposal of surplus soil and industrial waste
      2.7) Groundwater conditions, including the state and the flow velocity of the confined groundwater
2.9) Scouring

c) The geotechnical investigation shall be conducted for factors that may affect the performance of the column-type foundation, and should include the bearing capacity, stability against sliding, and settlement properties.

Remarks 1. The content of the geotechnical investigation (type, plane dimensions, and depth) shall be determined by giving consideration to the possible types of foundations to be used and the complexity of the soil conditions.

2. The procedures used in the geotechnical investigation and the soil tests shall be determined by referring to the relevant Japanese Industrial Standards (JIS) or the Japanese Geotechnical Society (JGS) standards.

3. The geotechnical investigation should be performed to the depth at which the bearing layer exhibits the required bearing capacity.

4. In investigating bedrock, a macroscopic study should be made to determine the presence and the overall state of any faults and/or cracks.

5. The possibility that the properties of the surrounding ground may be altered by the construction of the column body shall be considered.

Reference The characteristic design values for the vertical bearing capacity around the column body shall be estimated from the average value for the depth of a single layer. The chief designer should consider the fact that spatial variations in the parameters can be reduced if this technique is used.

5.6 ITEMS TO BE CONSIDERED IN THE DESIGN OF COLUMN-TYPE FOUNDATIONS

a) The following items shall be considered in the design of column-type foundations:
1) Topographical and geological conditions
2) Characteristics of the structure
3) Construction conditions
4) Environmental conditions

b) In the design of column-type foundations, the deformation of the ground, the reaction force of each pile top, and the deformation of the column bodies caused by the loads (or actions) imposed by the superstructure and/or the surrounding ground should be evaluated. The members shall be designed to withstand the calculated resultant stress.

c) The type and the dimensions of the column bodies should be determined after considering the functions of the superstructure, the geological conditions, the ease of construction, and the bearing mechanism of the foundation.

Remarks 1. Column-type foundations shall be designed based on investigations of the following items:
1) Ground displacement and bearing-strength failure
2) Movement and sliding failure of the foundation
3) Displacement and deformation of the column-type foundation
4) Damage to and failure of the column-type foundation

2. The design of column-type foundations shall be prepared in accordance with the items specified below:
1) A subsoil layer with sufficient strength and stiffness shall be selected.
2) In cases where the subsoil layer which supports the foundation consists of bedrock, the effects of discontinuity planes and weathered layers shall be considered.
3) Even when the piles are to be embedded in a firm, good-quality subsoil layer, the effect of the foundation on the bearing capacity and the settlement should be studied particularly in cases where the layer is thin or it overlies a weak or unconsolidated soil layer.
4) When a column-type foundation is going to be constructed on a sloping ground, the stability of the entire ground shall be confirmed and its effect on the bearing strength and the displacement of the foundation shall be considered.
5) When an embankment is to be constructed adjacent to a column-type foundation, the effects of the lateral motion of the ground shall be considered.
6) When a column-type foundation is set to pass through a ground that may be consolidated, the effects of
negative skin friction shall be considered in order to evaluate the behavior of the column body.

7) The handling of the joints of column-type foundations requires a detailed study.

8) The joints between the side walls and the upper slab of caisson and diaphragm wall foundations, and the joints of the steel pipes and the upper slabs of steel-pipe-sheet pile foundations must be designed with care to ensure that the joints have enough strength to transmit the load from the superstructure to the ground.

9) Diaphragm wall foundations shall be designed to secure sufficient strength among the joints linking the foundation elements in order that the side walls can behave as integrated units.

10) In the design of caisson foundations, a study on the construction requirements shall be conducted to ensure that the foundation can subside during construction.

11) In the design of caisson and steel-pipe-sheet pile foundations, the members shall be verified during construction.

d) The objectives and the performance requirements of the structure shall be discussed with the client or the owner before beginning the design process.

Reference Prior to the design process, the design method which will be applied to estimate the behavior of the column-type foundation shall be discussed with the client or the owner.

e) A qualified chief designer shall assume responsibility for the management of the design process (refer to Sections 0.6.2 and 0.7.3).

5.7 PREDICTING THE BEHAVIOR OF COLUMN-TYPE FOUNDATIONS

5.7.1 General The behavior of column-type foundations shall basically be predicted by the calculation method.

Remark The calculation method should contain a design calculation model that has been verified based on the geotechnical investigation and past similar cases.

Reference 1. When preparing the design, it is not necessary to predict the foundation behavior of column-type foundations by the calculation method if it can be assumed that referring to nearby works or similar projects will not result in any problems.

2. In principle, column-type foundations should be designed by a calculation-based method. When a column body design has been constructed many times under similar conditions, however, it may not be necessary to design the foundation by this method.

5.7.2 Degree of displacement and subgrade reaction The displacement of column-type foundations and the subgrade reaction shall be estimated after thoroughly considering the characteristics of the foundation and the ground surrounding the structure.

Remarks 1. In calculations carried out to estimate the behavior of a column body subjected to horizontal force, the column may be modeled as a beam and the subgrade reaction characteristics may be modeled as soil springs.

2. If the embedding ratio of the column-type foundation is small, the column body may be treated as a rigid body.

3. When a column body is analyzed as a beam and the subgrade reaction characteristics are analyzed as soil springs, the ground can be evaluated as the coefficient of subgrade reaction. However, the fact that the said coefficient is dependent on the loading width must be considered.

4. The nonlinearity of the ground should be considered in the relationship between the displacement and the coefficient of subgrade reaction.

5. In the case of caisson foundations, the coefficient of subgrade reaction should be evaluated based on a modulus of deformation that considers the looseness of the surrounding ground due to the construction. However, in cases where the surrounding ground is going to be strengthened by grouting following the construction of the caisson, it is not necessary to consider such looseness.

6. In the case of steel-pipe-sheet pile foundations, the analysis must take the shear distortion deformation into account if it is large.

5.7.3 Vertical bearing capacity The vertical bearing behavior of column-type foundations shall be estimated after thoroughly considering the characteristics of the foundation and the ground surrounding the structure.
Remarks 1. It may be assumed that a column-type foundation resists vertical loads with the vertical subgrade reaction of the ground at its bottom surface and with the vertical shear subgrade reaction at its skin surface.

2. It is possible to estimate the vertical bearing force of caisson foundations based on the rigid-plastic theory, as in the case of spread foundations. When calculating the vertical bearing capacity, the effects of load eccentricity and inclination should be considered.

Reference 1. Since caisson foundations can disrupt the ground, it may be assumed that such foundations resist vertical loads only with the vertical reaction force of the ground at the bottom surface of the foundation.

2. In the case of steel-pipe-sheet pile or diaphragm wall foundations, it is possible to consider the vertical shear subgrade reaction of the ground around the foundation under vertical load conditions.

3. In the case of caisson foundations, the vertical bearing capacity against the total shear failure is not necessarily related to the degree of settlement; rather, an upper limit should be set to prevent the excessive subsidence of the foundation.

4. The vertical bearing capacity per single steel-pipe lagging can be obtained by performing loading tests, as in the case of pile foundations.

5. The vertical bearing capacity of diaphragm wall foundations may be set in accordance with the vertical bearing capacity of cast-in-place piles.

5.7.4 Horizontal bearing capacity The horizontal bearing behavior of column-type foundations shall be estimated after thoroughly considering the characteristics of the foundation and the ground surrounding the structure.

Remarks 1. In principle, it may be assumed that column-type foundations resist horizontal loads with the horizontal subgrade reaction of the ground at its front surface and with the vertical subgrade reaction and shear subgrade reaction of the ground at the bottom surface of the foundation.

2. The sliding resistance of the base of a column-type foundation can be obtained from the adhesion between the foundation base and the ground and the product of the vertical subgrade reaction and the friction coefficient.

3. The horizontal resistance of the ground in front of a column-type foundation can be obtained from the passive resistance. The passive resistance should consider the effects of a 3-dimensional expansion.

5.8 VERIFYING THE DESIGN OF COLUMN-TYPE FOUNDATIONS

5.8.1 Limit states and verification

5.8.1.1 Performance criteria The performance criteria shall consist of a combination of the limit states for column-type foundations specified according to the importance of the structure and its design conditions, namely, load conditions and a combination of loads considering the design working life.

Reference Specifications of the performance criteria are described in Section 5.4.4.

5.8.1.2 Verifying the serviceability limit state The maximum and the residual displacements of the superstructure and its foundation shall be estimated to confirm that they lie within a range that satisfies the serviceability requirements.

Remarks 1. The following two items shall be verified for the foundation body of a column-type foundation:

1) There have been no significant changes in the mechanical properties of the structural members.
2) The structural members have been protected from damage that would reduce their durability

2. Items 1) and 2) are generally sufficient for verifying the stability of a column-type foundation.

5.8.1.3 Verifying the reparability limit state The reparability limit state shall be verified by confirming that the calculated residual displacements of the superstructure and its foundation lie within a range in which repairs that would restore the structure to the required level of serviceability are possible.

Remarks 1. The following two items shall be verified for the foundation body of a column-type foundation:

1) No difficult-to-repair damage has been done which would reduce the long-term durability of the structure.
2) The residual bearing capacity of all structural members
2. The stability of the foundation shall be verified by satisfying above-mentioned items 1) and 2).

5.8.1.4 Verifying the ultimate limit state

a) In verifying the ultimate limit state, the stability of the foundation shall be verified.

b) The displacement of the foundation shall be verified by confirming that the superstructure has not been damaged by the displacement of the foundation.

5.8.2 Verification equations

a) The safety of the vertical bearing at the base shall be verified by the following equation:

$$F_{hd} \leq R_{hd}$$

where

- $F_{hd}$: vertical subgrade reaction or stress intensity at the base of the column-type foundation due to the design load
- $R_{hd}$: limit value of the design vertical bearing capacity or the design stress intensity at the base of the column-type foundation in each limit state

b) The bottom surface sliding supports shall be verified by the following equation:

$$F_{hd} \leq R_{hd}$$

where

- $F_{hd}$: shear subgrade reaction at the base of the column-type foundation due to the design load
- $R_{hd}$: limit value of the design shear subgrade resistance at the base of the column-type foundation in each limit state

c) The horizontal bearing capacity of the ground in front of the column-type foundation shall be verified by the following equation:

$$F_{hd} \leq R_{hd}$$

where

- $F_{hd}$: horizontal subgrade reaction at the front surface of the column-type foundation due to the design load
- $R_{hd}$: limit value of the design horizontal subgrade resistance at the front surface of the column-type foundation in each limit state

d) The displacement or the deformation of the column-type foundation shall be verified by the following equation:

$$E_{hd} \leq C_{hd}$$

where

- $E_{hd}$: displacement or deformation of the hypothetical member of the column-type foundation due to the design load
- $C_{hd}$: limit value of the design displacement or the deformation of the hypothetical member of the column-type foundation in each limit state

e) The resultant stress acting on the column body of the column-type foundation shall be verified by the following equation:

$$F_{hd} \leq R_{hd}$$

where

- $F_{hd}$: internal force of each member of the column-type foundation due to the design load
- $R_{hd}$: limit value of the design resistance force of each member of the column-type foundation in each limit state

Reference The design value of the above-mentioned bearing capacity or the resistance may be obtained by one of two
methods, in other words, by eliminating a fraction of the partial factors from the characteristic values of the bearing capacity or the resistance obtained with an appropriate design calculation model based on characteristic values such as the geotechnical parameters, or by eliminating a fraction of the material factors from the characteristic values to be input into the design calculation model.

5.9 DESIGN REPORT FOR COLUMN-TYPE FOUNDATIONS

a) The chief designer shall submit a design report on the column-type foundation to the client or owner.

b) The design report on the column-type foundation shall include, but not be limited to, the following information in order that the design parameters, the design of the foundation, and the verification of the design may be obtained:

1) Design conditions
2) Design results
3) Procedure for verifying the design (methods used to estimate the design parameters are based on the results of the geotechnical investigation, details of the verification methods, the referenced design standards, references, literature, etc.)
4) Results of the geotechnical investigation (locations, dates, test results, and the results of the survey on the surrounding environment)
5) Results of the loading tests, if performed (sites, dates, test results, and details of the foundation)
6) Construction conditions specified in the design
7) Construction management items
8) Surveys deemed necessary during construction

5.10 CONSTRUCTION

a) The construction of column-type foundations shall be performed so as to fulfill the conditions specified in the design.

Remarks 1. It may be necessary to conduct an investigation to confirm that the conditions specified in the design are appropriate and are being met.

2. It shall be confirmed that the construction was performed in such a way that the column-type foundation fulfills the performance requirements.

3. To ensure that caisson foundations fulfill the performance requirements, care shall be used during construction with regard to the following points:

1) Quality control of the materials
2) Construction procedure
3) Control of the embedding depth
4) Settlement management and control of the movement, the inclinations, and the rotations of the caissons during the settlement
5) In the case of open caissons, the stability of the bottom surface of the excavation
6) Prevention of heaving and boiling
7) In the case of pneumatic caissons, control of the air pressure inside the work chamber

4. To ensure that steel-pipe-sheet pile foundations fulfill the performance requirements, care shall be used during construction with regard to the following items:

1) Quality control of the materials
2) Construction procedure
3) Control of the embedding depth
4) Control of the driving accuracy of the steel pipe lagging when the driving method is used
5) Stability of the bottom surface of the excavation within the cofferdam
6) Prevention of heaving and boiling
7) Control of the performance of the upper slab joints

5. To ensure that diaphragm wall foundations fulfill the performance requirements, care shall be used during construction with regard to the following items:
1) Quality control of the materials
2) Construction procedure
3) Control of the embedding depth
4) Minimizing irregularities in skin and bearing strata and the prevention of heaving and boiling before pouring the concrete
5) Stability of the shaft wall and the processing slurry inside the shaft and the processing slime
6) Discharge of the stabilization fluid, depending on the groundwater conditions, and control of the performance of the element joints

b) Care shall be used during construction with regard to the following environmental issues, and investigations shall be conducted whenever deemed necessary:
   1) Water pollution
   2) Noise
   3) Ground vibrations
   4) Settlement/heaving of the surrounding ground and the associated displacement/deformation of nearby structures
   5) Treatment and/or disposal of excavated materials
c) The chief designer shall be responsible for confirming that the installation of the column-type foundation has been performed as specified in the design and shall submit records of the construction to the client or owner.

Related standards:

[JIS]
JIS A1219 Method for standard penetration test
JIS A1220 Method for Dutch double-tube cone penetration test
JIS A1221 Method for Swedish weight sounding test

[JGS]
JGS 1121 Method for Electrical Logging
JGS 1122 Method for Seismic Velocity Logging
JGS 1221 Method for Obtaining Soil Samples using Thin-walled Tube Sampler with Fixed Piston
JGS 1222 Method for Obtaining Soil Samples using Rotary Double-tube Sampler with Fixed Piston
JGS 1223 Method for Obtaining Soil Samples using Rotary Triple-tube Sampler with Fixed Piston
JGS 1224 Method for Obtaining Samples using Double-tube Sampler with Sleeve
JGS 1231 Method for Obtaining Soil Block Samples
JGS 3211 Method for Obtaining Soft Rock Samples using Rotary Tube Sampler
JGS 1441 Method for Field Vane Shear Test
JGS 1421 Method for Pressuremeter Test in Borehole
JGS 1431 Method for Portable Cone Penetration Test
JGS 1433 Method for Portable Dynamic Cone Penetration Test
JGS 1435 Method for Electric Cone Penetration Test
JGS 1311 Method for Measuring Groundwater Level in Borehole
JGS 1312 Method for Measuring Groundwater Level in Well
JGS 1313 Method for Measuring Pore Water Pressure using Electric Transducer
JGS 1314 Method for Determination of Hydraulic Properties of Aquifer in Single Borehole
JGS 1315 Method for Pumping Test
JGS 1316 Method for Determination of Hydraulic Conductivity of Compacted Fill
JGS 1317 Method for Flow Layer Logging by Tracer
JGS 1322 Method for Determination of Hydraulic Conductivity of Rock Mass using Injection Technique in Single Borehole
JGS 1323 Method for Lugeon Test
JGS 1521 Method for Plate Load Test on Soil Ground
JGS 3521 Method for In-Situ Rigid Plate Load Test on Rocks
JGS 3511 Method for In-Situ Direct Shear Test on Rocks
JGS 1613 Method for Measuring In-Situ Soil Density using Core Cutter
JGS 1614 Method for Measuring In-Situ Soil Density using Nuclear Gauge
6. DESIGN OF RETAINING STRUCTURES

6.1 SCOPE

a) This chapter addresses the design of retaining structures. The stipulations described herein shall be fully understood and correctly applied when designing retaining structures.

Remarks 1. Retaining structures are structures that use walls and/or support systems to prevent the collapse of embankments and cut slopes, consisting of geomaterials such as soil, rock, backfill, and water, by resisting the earth pressure exerted by these embankments and cut slopes that cannot maintain stability by themselves.

2. Structures for temporary use are, in principle, outside the scope of this section. Thus, the design of temporary bracings shall not be discussed herein.

b) Retaining structures shall be classified into three categories, namely, “retaining structures with shallow foundations” that mobilize resistance due to the bearing capacity (including resistance against base sliding) of the subsoil at the base of structures and their shallowly-embedded portions, “retaining structures with deep foundations” that mobilize resistance due to the bearing capacity of the subsoil at the deeply-embedded foundations of structures, and “combined-type retaining structures” that mobilize combined resistance due to the above two mechanisms. It should be noted that other structural types also exist, such as anchored walls, braced walls with struts, and reinforced soil-retaining walls, which cannot be classified into any of the above three categories.

6.2 OBJECTIVES

a) The objectives are the reasons for building a retaining structure. They shall be expressed in nontechnical terms.

b) Since a retaining structure constitutes part of an entire superstructure, the objectives of the retaining structure are to coincide with those of the entire structure.

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

Note There are several cases for the application of retaining structures which include using the retained ground for a certain purpose (e.g., a combination of embankments and retaining structures), using the space in front of the retaining structures that is created by their construction (e.g., a combination of cut slopes and retaining structures, and excavations and bracings), and using the retaining structures themselves (e.g., quay walls and the port facilities above them).

c) The ground supported by a retaining structure is designated in this chapter as a “retained ground”.

6.3 PERFORMANCE REQUIREMENTS

a) The performance requirements are statements on the functions that need to be provided by a retaining structure in order to achieve the objectives. In other words, the performance requirements describe the required functions of the retaining structure for each item given in the objectives. The performance requirements shall be expressed in nontechnical terms.

Remark The performance requirements of retaining structures shall include, but not be limited to, safety, serviceability, reparability, workability, and cost (refer to Section 1.3).

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 objectives be “the structure”.

6.4 PERFORMANCE CRITERIA

6.4.1 Design working life The design working life of retaining structures shall be determined based on the definition for the design working life of the superstructure presented in Section 0.4.1.

6.4.2 Limit states

a) The limit states, which must be considered in the design of retaining structures, should be determined by the performance
requirements for retained grounds and/or retaining structures and are to coincide with the performance criteria of the superstructure presented in Section 1.4.2.

b) In principle, the following three limit states shall be specified for retaining 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 retaining structure or the retained ground 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 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 retained ground and/or the retaining 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 retained ground and/or the retaining 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.

6.4.3 Actions and design situations

a) The types and combinations of actions which must be taken into account in the design of retaining structures shall be determined by considering the frequency and the simultaneity of the loads that have been predicted to act on the structure during the design working life of the superstructure.

Remark Generally speaking, the following actions shall be given consideration in the design of a retaining structure:
1) Earth pressure and water pressure exerted from the retained ground, including surcharges
2) Self-weight of the retaining structure
3) Inertial forces during earthquakes
4) Other external loads.

b) The loads assumed in the design of a retaining structure shall be classified based on their characteristics by referring to the stipulations described in Section 1.4.3.

c) Design conditions which require a combination of actions to be considered in the design of a retaining structure shall be determined by referring to the stipulations described in Section 1.4.3.

6.4.4 Importance of the superstructure and the performance criteria

In designing retaining structures, the relationship between the importance of the superstructure and its performance requirements shall be determined by referring to the stipulations described in Section 0.4 and Figure 2 in Chapter 0, namely, “Performance matrix concepts.”

Remarks 1. The performance requirements of retaining structures and/or retained grounds shall be described in terms of their displacement and/or deformation, stress that is mobilized in the structural parts, etc.

2. To satisfy the performance requirements, retaining structures and/or retained grounds shall be designed to meet the specified criteria, bearing in mind the following points:
1) The retaining structure and/or the retained ground shall possess a sufficient safety allowance against damage and/or failure.
2) The displacement and the deformation of the retaining structure and/or the retained ground must be sufficiently small.

3) The strength of the retaining structure and/or the retained ground members must be sufficient.

Reference  The limit states should be determined by considering the characteristics of the retaining structure and/or the retained ground and of the superstructure under the conditions which existed during their construction.

6.5 INVESTIGATING THE GROUND AND THE SURROUNDING CONDITIONS

a) Prior to the design of retaining structures, a geotechnical investigation and a survey of the surrounding conditions shall be performed. The type of retaining structure and its foundation shall be selected based on the results of these studies.

Reference  Reference should be made to case histories of construction and other investigations conducted near the proposed construction site.

b) The types of geotechnical investigations and the methods available for performing them, as well as the evaluation methods available for performing the survey of the surrounding conditions, shall be in accordance with Chapter 2.

Remark  The investigations required in the design of a shallow foundation shall be classified as, but not limited to, the following items:

1) Investigation to determine the design parameters
   1.1) Unit weight of the soil
   1.2) Shear strength properties
   1.3) Groundwater table and the presence of artesian conditions
   1.4) Geological stratification and geological age
       1.4.1) Presence of unconsolidated soil layers
       1.4.2) Ground settlement
       1.4.3) Presence of permeable soil layers and saturated sand layers
       1.4.4) Inclination of the subsoil layers which support the retaining structure and the folding or the inclination of the geological strata
       1.4.5) Extent of weathering, cracking, and faults when the subsoil layers consist of bedrock
       1.4.6) Landslides
   2) Survey of the surrounding conditions
       2.1) Topography of the construction site
       2.2) Nearby structures
       2.3) Traffic conditions and transportation routes
       2.4) Presence of buried matter and industrial waste
       2.5) Possibility of toxic gas release due to the construction
       2.6) Methods for the treatment and/or the disposal of surplus soil and industrial waste
       2.7) Groundwater conditions, including the state and the flow velocity of the confined ground water
       2.8) Water table level and the quality of the well water
       2.9) Scouring.

c) The geotechnical investigation shall be conducted for factors that may affect the performance of the retaining structure and its foundation, and should include the bearing capacity of the ground, stability against sliding, and settlement properties. Special attention shall be paid to the extent of the retained ground, since it also affects the area of the geotechnical investigations.

Reference 1. The content of the geotechnical investigation (type, interval, number, and depth) shall be determined by giving consideration to the possible types of retaining structures and foundations to be used and the complexity of the soil conditions.
2. The procedures used in the geotechnical investigation and the soil tests shall be determined by referring to the relevant Japanese Industrial Standards (JIS) or the Japanese Geotechnical Society (JGS) standards.

3. The geotechnical investigation should be performed to the depth at which the bearing layer exhibits the required bearing capacity.

4. In investigating bedrock, a macroscopic study should be made to determine the presence and the overall state of any faults and/or cracks.

5. The possibility that the properties of the surrounding ground may be altered by the construction of the retaining structure and its foundation shall be considered.

6. In evaluating the passive resistance of the bearing layer located in front of an embedded retaining structure, the level of the ground surface should be set by considering the possibilities of future excavations, scouring, and/or erosion.

6.6 ITEMS TO BE CONSIDERED IN THE DESIGN OF RETAINING STRUCTURES

6.6.1 General items

a) The following items shall be considered in the design of retaining structures:
   1) Topographical and geological conditions
   2) Characteristics of the structure
   3) Construction conditions
   4) Environmental conditions.

b) In the design of retaining structures, the overall stability against sliding, overturning, the loss of bearing capacity, and the failure of the structural parts shall be considered.

Reference In the design of a retaining structure, the overall stability of the structure shall generally be confirmed, followed by an evaluation of the bearing capacity of structural parts based on the results of an overall stability analysis.

Remarks 1. In the design of retaining structures, the following procedure is recommended in terms of the ultimate and the reparability limit states:
   1) Evaluate the overall failure.
   2) Evaluate the overall displacement and deformation.
   3) Evaluate the failure of the structural parts.

2. In the design of retaining structures, the following procedure is recommended in terms of the serviceability limit state:
   1) Evaluate the margin of overall failure.

(Footnote on 1): In cases where it is difficult to evaluate the deformation of the retaining structure, the margin of the overall failure shall traditionally be employed in the design.

   2) Evaluate the overall displacement and deformation.
   3) Evaluate the margin to failure of the structural parts.

c) In cases where liquefaction of the surrounding ground during earthquakes is a possibility, either the design of the retaining structure should be conducted with caution or the liquefiable soil layer should be improved so as to eliminate the possibility of liquefaction.

d) The design of retaining structures shall be prepared in accordance with the items specified below:
   1) In cases where the subsoil layer which supports the structure consists of bedrock, the effects of discontinuity planes and weathered layers should be considered.
   2) Even when the structure is to be embedded into a firm, good-quality subsoil layer, the effect of the structure on the bearing capacity and the settlement should be studied particularly in cases where the layer is thin or it overlies a weak or unconsolidated soil layer.
   3) Depending on the design model employed, the ground surface should be properly assumed in the design.
e) The objectives and the performance requirements of the structure shall be discussed with the client or the owner before beginning the design process.

**Reference** Prior to the design process, the design method which will be applied to estimate the behavior of the retaining structure and/or the retained ground shall be discussed with the client or the owner.

f) A qualified chief designer shall assume responsibility for the management of the design process (refer to Sections 0.6.2 and 0.7.3).

### 6.6.2 Individual items

#### 6.6.2.1 Evaluating earth pressure

a) Attention shall be paid when evaluating the earth pressure acting on the retaining structure or the retained ground. The pressure cannot be evaluated as a single characteristic value, as it is affected by and greatly varies depending on the following conditions:

1) Displacement mode of the retaining structure

**Remarks 1.** The amplitude, the distribution, and the direction of the earth pressure levels vary depending on whether the retaining structure moves away from the retained ground (earth pressure on the active side) or toward the retained ground (earth pressure on the passive side).

2. The amplitude, the distribution, and the direction of the earth pressure levels depend on whether or not the retaining structure rotates and on the direction of the rotation.

3. The amplitude, the distribution, and the direction of the earth pressure levels are also affected by the flexibility of the retaining structure.

2) Strain level mobilized in the retained ground

**Remarks 1.** Earth pressure values vary depending on the strain level mobilized in the retained ground.

2. Limiting values should be employed for earth pressure values when the strain level has reached failure, while intermediate values should be employed for earth pressure values when the strain level has not yet reached failure.

3. At-rest values should be applied for the earth pressure when the retaining structure does not move, since no strain is being mobilized in the retained ground.

3) Interface condition between the retaining structure and the retained ground

**Remark** Earth pressure levels vary depending on the interface friction and the adhesion that exist between the retaining structure and the retained ground.

b) The following factors should be considered when evaluating the earth pressure levels:

1) The shape of the retained ground, such as the inclination of the surface and the back face of the retaining structure

2) The soil type and the condition of the retained ground, such as the density and the degree of saturation

3) Any external load applied to the retained ground, such as surcharges, wind-induced loads, and earthquake-induced loads.

#### 6.6.2.2 Evaluating water pressure

a) Water pressure exerted from the retained ground to the retaining structure, which acts during and after the excavation, shall be evaluated by monitoring the pore water pressure in the retained ground before the excavation, understanding the artesian pressure levels acting on each stratum.

**Note** The water and the earth pressure levels are occasionally evaluated without first separating them.

b) When the groundwater level in the retained ground changes rapidly, the design and the verification of the retaining structure shall be performed for both the transient condition, which occurs immediately after the rapid change in groundwater level considering the effects of the seepage force, and the static situation, which is eventually achieved after the rapid change in groundwater level.
6.7 PREDICTING THE BEHAVIOR OF RETAINING STRUCTURES

The behavior of retaining structures shall be estimated by properly evaluating their foundations based on the provisions specified in Chapters 3 through 5 for shallow foundations, pile foundations, and column-type foundations, respectively, while paying attention to the items that are shown in Section 6.6 as those intrinsic to retaining structures.

6.8 VERIFYING THE DESIGN OF RETAINING STRUCTURES

6.8.1 Limit states and verification

6.8.1.1 Performance criteria

The performance criteria shall consist of a combination of the limit states for retaining structures and/or retained grounds specified according to the importance of the structure and its design conditions, namely, load conditions and a combination of loads considering the design working life.

Reference: At the time of the verification, each performance specification is generally called “verification of *** limit state”.

Remark: Specifications for the performance criteria are described in Section 6.4.4.

6.8.1.2 Verifying the serviceability limit state

a) The maximum and the residual displacement/deformation of the retaining structures and the verification of the displacement/deformation of the retained ground and/or the retaining structures shall be estimated to confirm that they lie within a range that satisfies the serviceability requirements.

b) The following two items shall be verified for the structural parts of the retaining structure and/or the retained ground:
   1) There have been no significant changes in the characteristics of the structure.
   2) No damage has been done which would reduce the long-term durability of the structure.

6.8.1.3 Verifying the reparability limit state

a) The reparability limit state shall be verified by confirming that the calculated residual displacement/deformation of the superstructure, the retained ground, and/or the retaining structures lie within a range in which repairs that would restore the structure to the required level of serviceability are possible.

b) The following two items shall be verified for the structural parts of the retaining structure and/or the retained ground:
   1) No damage has been done which would reduce the long-term durability of the structure.
   2) The residual bearing capacity of all structural members.

6.8.1.4 Verifying the ultimate limit state

a) In verifying the overall failure of retaining structures, the stability of the structure shall be verified.

b) It shall be verified that the structure has not experienced any excessive displacement/deformation that may cause the collapse of the retained ground and/or the retaining structure.

c) It shall be verified that local failure of the structural members, inducing the overall failure of the entire system, has not occurred by confirming that the structural members which affect the overall stability and excessive displacement/deformation of the whole system have not failed.

6.8.2 Verifying equations

a) The following equation shall be employed to verify retaining structures with shallow foundations:

\[ F_{rd} \leq R_{rd} \]

where:

- \( F_{rd} \): force and overturning moment that act on the base and the embedded part of the retaining structure due to the design loads
- \( R_{rd} \): design resistance values of force (i.e., resistance against sliding and bearing capacity) and the overturning moment that are mobilized on the base and the embedded member of the retaining structure for each limit state.
b) In the case of the overall stability of the subsoil supporting the retaining structure, verification shall be made with respect to the relevant failure mode (e.g., sliding along a circular failure plane).

c) In the case of the internal forces/stress acting on the structural members, verification shall be made by employing the following equation:

\[ F_{id} \leq R_{id} \]

where

- \( F_{id} \): force/stress acting on the structural members due to the design loads
- \( R_{id} \): design capacity or design limit stress of the structural members for each limit state.

d) In the case of the displacement/deformation of the retaining structure, verification shall be made by employing the following equation:

\[ E_{id} \leq C_{id} \]

where

- \( E_{id} \): displacement/deformation of the structural members due to the design loads
- \( C_{id} \): design displacement or the limit value of the structural members for each limit state.

Remark

For gravity types of structures, in particular, it is important to verify the settlement of the subsoil supporting them.

Reference 1. Refer to Chapter 3 for structures with shallow foundations.

2. Refer to Chapters 4 and 5 for structures with deep foundations.

6.9 DESIGN REPORT FOR RETAINING STRUCTURES

a) The chief designer shall submit a design report on the retaining structure to the client or owner.

b) The design report on the retaining structure shall include, but not be limited to, the following information in order that the design parameters, the design of the retaining structure, and the verification of the design may be obtained:

1) Design conditions
2) Design results
3) Procedure for verifying the design (methods used to estimate design parameters are based on the results of the geotechnical investigation, details of the verification methods, etc.)
4) Results of the geotechnical investigation (locations, dates, and test results)
5) Results of the loading tests, if performed (locations, dates, test results, and details of the foundation)
6) Construction conditions specified in the design
7) Construction management items
8) Surveys deemed necessary during construction.

6.10 CONSTRUCTION

a) The construction of retaining structures shall be performed so as to fulfill the conditions specified in the design.

Reference

It may be necessary to conduct an investigation to confirm that the conditions specified in the design are appropriate and are being met.

b) It shall be confirmed that the construction was performed in such a way that the retaining structure fulfills the performance requirements.

c) To ensure that the retaining structure fulfills the performance requirements, care shall be used during construction with regard to the following points:

1) Quality control of backfill materials and their compaction, if the retaining structure is backfilled
2) Quality control of the wall materials
3) Construction procedure
4) Items described in Chapter 3, if shallow foundations are employed
5) Items described in Chapters 4 and 5, if deep foundations are employed.
d) Care shall be used during construction with regard to the following environmental issues, and investigations shall be conducted whenever deemed necessary:

1) Water pollution
2) Noise
3) Ground vibrations
4) Settlement/heaving of the surrounding ground and the associated displacement/deformation of nearby structures
5) Treatment and/or disposal of excavated materials.

e) The chief designer shall be responsible for confirming that the installation of the retaining structure has been performed as specified in the design and shall submit records of the construction to the client or owner.

Related standards:

[Japanese Industrial Standards (JIS)]
JIS A1219  Method for standard penetration test
JIS A1220  Method for Dutch double-tube cone penetration test
JIS A1221  Method for Swedish weight sounding test

[Japanese Geotechnical Society Standards (JGS)]
JGS 1121  Method for Electrical Logging
JGS 1122  Method for Seismic Velocity Logging
JGS 1221  Method for Obtaining Soil Samples using Thin-walled Tube Sampler with Fixed Piston
JGS 1222  Method for Obtaining Soil Samples using Rotary Double-tube Sampler with Fixed Piston
JGS 1223  Method for Obtaining Soil Samples using Rotary Triple-tube Sampler with Fixed Piston
JGS 1224  Method for Obtaining Samples using Double-tube Sampler with Sleeve
JGS 1231  Method for Obtaining Soil Block Samples
JGS 3211  Method for Obtaining Soft Rock Samples using Rotary Tube Sampler
JGS 1411  Method for Field Vane Shear Test
JGS 1421  Method for Pressuremeter Test in Borehole
JGS 1431  Method for Portable Cone Penetration Test
JGS 1433  Method for Portable Dynamic Cone Penetration Test
JGS 1435  Method for Electric Cone Penetration Test
JGS 1311  Method for Measuring Groundwater Level in Borehole
JGS 1312  Method for Measuring Groundwater Level in Well
JGS 1313  Method for Measuring Pore Water Pressure using Electric Transducer
JGS 1314  Method for Determination of Hydraulic Properties of Aquifer in Single Borehole
JGS 1315  Method for Pumping Test
JGS 1316  Method for Determination of Hydraulic Conductivity of Compacted Fill
JGS 1317  Method for Flow Layer Logging by Tracer
JGS 1322  Method for Determination of Hydraulic Conductivity of Rock Mass using Injection Technique in Single Borehole
JGS 1323  Method for Lugeon Test
JGS 1521  Method for Plate Load Test on Soil Ground
JGS 3521  Method for In-Situ Rigid Plate Load Test on Rocks
JGS 3511  Method for In-Situ Direct Shear Test on Rocks
JGS 1613  Method for Measuring In-Situ Soil Density using Core Cutter
JGS 1614  Method for Measuring In-Situ Soil Density using Nuclear Gauge
7. DESIGN OF TEMPORARY STRUCTURES

7.1 SCOPE
This chapter addresses the design of temporary structures. The stipulations described herein shall be fully understood and correctly applied when designing temporary structures.

Remarks 1. Temporary structures are structures that are installed to ensure the safe and smooth construction of main structures and then are removed, or simply not used, after the main structures have been completed.

2. This chapter describes temporary structures that are used to prevent the sides and the bottom of excavations from collapsing and water from inflowing (referred to as “earth-retaining structures” hereinafter), by installing temporary walls and/or supports, when a ground is being vertically excavated, when a ground with a high groundwater level is going to be excavated, or when a ground is going to be excavated across a river.

3. Earth-retaining structures include free-standing earth-retaining structures, which resist soil pressure and water pressure from the back only with the bearing capacity of the excavated bottom into which the earth-retaining structure is embedded, and supported earth-retaining structures, which are supported by the bearing capacity of the excavated bottom and braces, ground anchors, etc.

7.2 OBJECTIVES
a) The objectives are the reasons for building a temporary structure. They shall be expressed in nontechnical terms.

b) Temporary structures are built for the purpose of ensuring the safe and smooth construction of the entire superstructure. This includes a safe excavation and the prevention of adverse effects on adjacent structures. Since a temporary structure constitutes part of an entire structure, the objectives of the temporary structure are to coincide with those of the entire structure.

Remark This chapter uses the term “retained ground” to refer to the section of a ground to be supported by a temporary structure. The effects on adjacent structures and on the underground water level are also included in a retained ground.

7.3 PERFORMANCE REQUIREMENTS
The performance requirements are statements on the functions that need to be provided by a temporary structure in order to achieve the objectives. In other words, the performance requirements describe the required functions of the temporary structure for each item given in the objectives. The performance requirements shall be expressed in nontechnical terms.

Remark The performance requirements of temporary structures shall include, but not be limited to, safety, serviceability, reparability, workability, and cost (refer to Section 1.3).

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”.

7.4 PERFORMANCE CRITERIA
7.4.1 Design working life The design working life of temporary structures shall be determined based on the definition for the design working life of the superstructure presented in Section 0.4.1.

7.4.2 Limit states
a) The limit states, which must be considered in the design of temporary structures, should be determined by the performance requirements for temporary structures and are to coincide with the performance criteria of the superstructure presented in Section 1.4.2.

b) In principle, the following three limit states shall be specified for temporary 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 temporary 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 is possible, without repairs, and no excessive displacement or deformation has occurred.

**Reparability limit state**  The reparability limit state is the limit state in which damage to the temporary 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 temporary 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.

**Note**  The reparability and the ultimate limit states, which consider variable and accidental loads that occur very infrequently during the design service period, can sometimes be omitted based on structural details determined from past experiences.

### 7.4.3 Actions and design situations

**a)**  The types and combinations of actions which must be taken into account in the design of temporary structures shall be determined by considering the frequency and the simultaneity of the loads that have been predicted to act on the structure during the design working life of the superstructure.

**Remark**  Generally speaking, the following actions shall be given consideration in the design of a temporary structure:

1)  Permanent loads
   1.1)  Dead load
   1.2)  Soil pressure and water pressure
   1.3)  Other external loads
2)  Variable loads
   2.1)  Live loads
   2.2)  Impacts
   2.3)  Effects of changes in temperature
   2.4)  Effects of earthquakes

**b)**  The loads assumed in the design of a temporary structure shall be classified based on their characteristics by referring to the stipulations in Section 1.4.3.

**c)**  Design conditions which require a combination of actions to be considered in the design of a temporary structure shall be determined by referring to the stipulations described in Section 1.4.3.

**Remark**  Variable and accidental loads that occur very infrequently during the design service period can sometimes be omitted based on structural details determined from past experiences.
7.4.3.1 Importance of the superstructure and the performance criteria

a) The importance of a temporary structure shall be determined by forming a mutual consensus among the planning agency, the owner/client of the project, and/or the executor and the third parties (owners of adjacent structures, etc.) and by considering the possibility of injury to people or damage to the superstructure and/or to nearby structures at and/or near the site caused by damage to the structure, the work process, repair expenses, etc.

b) The performance requirements shall be determined by referring to the stipulations described Section 0.4 and Figure 2 in Chapter 0, namely, “Performance matrix concepts”.

7.5 INVESTIGATING THE GROUND AND THE SURROUNDING CONDITIONS

a) Prior to the design of temporary structures, a geotechnical investigation and a survey of the surrounding conditions shall be performed.

Reference Reference should be made to case histories of construction and other investigations conducted near the proposed construction site.

b) The types of geotechnical investigations and the methods available for performing them, as well as the evaluation methods available for performing the survey of the surrounding conditions, shall be in accordance with Chapter 2.

Reference 1. The investigations required in the design of a temporary structure shall be classified as, but not limited to, the following items:

1) Investigation to determine the design parameters
   1.1) Unit weight of the soil
   1.2) Shear strength properties
   1.3) Groundwater table and the presence of artesian conditions
   1.4) Geological stratification and geological age
       1.4.1) Presence of unconsolidated soil layers
       1.4.2) Ground settlement
       1.4.3) Presence of permeable soil layers and saturated sand layers
       1.4.4) Inclination of the bearing stratum as well as folding and inclination of the strata
       1.4.5) Extent of weathering, cracking, and faults of the bearing natural ground
       1.4.6) Landslides

2) Survey of the surrounding conditions
   2.1) Topography of the construction site
   2.2) Nearby structures
   2.3) Underground structures
   2.4) Risk of ground settlement
   2.5) Groundwater conditions
   2.6) Noise and vibrations
   2.7) Methods for the treatment and/or the disposal of sediment and industrial waste
   2.8) Traffic conditions and transportation routes
   2.9) Scouring

2. The procedures used in the geotechnical investigation and the soil tests shall be determined by referring to the relevant Japanese Industrial Standards (JIS) or the Japanese Geotechnical Society (JGS) standards.

c) Soil surveys shall be conducted in areas where earth-retaining structures are expected to show a horizontal bearing capacity, where large depths are needed in order for the excavated bottom surface to be stable, and areas affected by the installation of earth-retaining structures.

d) The content of the soil survey (kind, intervals, number, and depth) shall be determined by giving consideration to the scale and the importance of the temporary structure and the complexity of the ground.

Remarks 1. The possibility that earth-retaining structures may cause scouring and result in changes in the height of the back
ground must be taken into consideration.

2. Care must be taken during the installation of earth-retaining structures as the installation may cause adverse effects on the surrounding ground, such as the cutting off of the flow of underground water.

3. Consideration must be given to the installation of earth-retaining walls and piles for scaffold boards as the installation may cause adverse effects on the surrounding ground, such as vibrations and noise.

7.6 ITEMS TO BE CONSIDERED IN THE DESIGN OF TEMPORARY STRUCTURES

7.6.1 General items

a) The following items shall be considered in the design of temporary structures:

1) Topographical and geological conditions
2) Characteristics of the structure
3) Construction conditions
4) Environmental conditions

Remark In the design of temporary structures, the following points shall be examined:

1) Stability of the entire surrounding ground including the earth-retaining structure
2) Stability of the excavated bottom
3) Internal stability
4) Displacement and deformation of the earth-retaining structure
5) Sectional force of the members

b) Temporary structures shall be designed by keeping the following items in mind:

1) Generally speaking, when asymmetrical pressure acts on an earth-retaining structure, the earth-retaining structure inclines toward one side. This behavior should be considered in the design process.
2) The ground surface assumed in the design should be selected appropriately depending on the model chosen.

c) The objectives and the performance requirements of the temporary structure shall be discussed with the client or the owner and, when necessary, with the owner(s) of any adjacent structures which may be affected by damage to the temporary structure.

Reference Prior to the design process, the design method which will be applied to estimate the behavior of the temporary structure shall be discussed with the client or the owner and, when necessary, with the owner(s) of any adjacent structures which may be affected by damage to the temporary structure.

d) A qualified chief engineer shall assume responsibility for the management of the design process (refer to Sections 0.6.2 and 0.7.3).

7.6.2 Individual items

7.6.2.1 Evaluating earth pressure

a) Attention shall be paid when evaluating the earth pressure acting on the earth-retaining structure. The pressure cannot be evaluated as a single characteristic value, as it is affected by and greatly varies depending on the following conditions:

1) Displacement mode of the earth-retaining structure

Remark The amplitude, the distribution, and the direction of the earth pressure levels vary depending on whether the earth-retaining structure moves away from the retained ground (earth pressure on the active side) or toward the retained ground (earth pressure on the passive side).

2) Strain level mobilized in the retained ground

Remarks 1. Earth pressure values vary depending on the strain level mobilized in the retained ground.
2. The limiting values should be employed for the earth pressure values when the strain has reached failure, while the intermediate values should be employed for the earth pressure values when the strain level has not yet reached failure.
3. At-rest values for the earth pressure should be applied when the earth-retaining structure does not move, such as before excavation when it is not displaced and since no strain is being mobilized in the retained ground.
3) Interface condition between the earth-retaining structure and the ground

Remark
Earth pressure levels vary depending on the interface friction and the adhesion that exist between the earth-retaining structure and the ground. Generally speaking, the effect is large on the excavation side (the side where the structure is pushing on the ground).

b) The following factors should be considered when evaluating the earth pressure levels:
   1) Inclination of the ground surface
   2) Geological state of the ground
   3) Loads acting on the ground surface
   4) Other factors (such as the loads of nearby structures)

7.6.2.2 Evaluating water pressure

a) Water pressure exerted from the retained ground to the temporary structure, which acts during and after the excavation, shall be evaluated by monitoring the pore water pressure before the excavation, understanding the artesian pressure levels acting on each stratum, and considering the following point:
   1) Water pressure in the sandy soil layer

Reference 1. When the lower end of the earth-retaining structure is in an aquifer, underground water seeps from the back side to the excavated side, and the pore water pressure is likely to be equal in the back and on the excavated sides at the lower end.
   2. When there is a clayey layer (aquiclude) beneath the excavated surface, the increments in water pressure along the depth direction are similar in the back and on the excavated sides.
   3. The water pressure in a confined sandy soil layer, lower than the excavated surface, is usually smaller on the excavated sides than in the back even when there is a lower or upper clayey layer.

   1) Water pressure in clayey soil

Reference 1. Since clayey soil is little pervious, it is recommended that the lateral pressure be estimated; it is the sum of the water pressure and the earth pressure and it is obtained from the values monitored in similar soils.
   2. Special care must be taken when there are sandy layers with high pore water pressure above and/or beneath a clayey layer, such as in a laminated ground, since water is supplied to the boundary between the clayey soil and the earth-retaining structure, producing water pressure that may exceed the estimated lateral pressure. This effect is especially large in self-standing clayey soil.

b) When evaluating the water pressure, the following points should be considered:
   1) Pore water pressure of each layer before the excavation
   2) States of the aquifers and the aquicludes (position, thickness, and permeability of each)
   3) States of the artesian pressure

7.7 PREDICTING THE BEHAVIOR OF TEMPORARY STRUCTURES

7.7.1 General

a) The behavior of temporary structures shall be predicted with one or more of the following methods:

Calculation method Calculation model verified by soil mechanics analyses and by comparing the analyzed and the measured values

Other methods Simple and common calculation methods can be used to estimate the behavior of temporary structures when the methods cannot quantitatively evaluate the behavior, but are judged as being able to roughly predict the behavior based on past experiences under similar conditions.

Reference There may be no need to predict the behavior of small-scale structures when designing a structure using data on nearby or similar construction projects which show that no problems are likely to occur.

b) The following items shall be considered when evaluating the behavior of temporary structures using one of the above-mentioned methods:

1) Load characteristics
2) Calculation model
3) Effects of the construction
4) Accuracy of the soil survey

7.7.2 Estimating the behavior of temporary structures through the calculation method

a) The calculation method chosen shall be in conformity with soil mechanics and its reproducibility must have been verified by comparing the analyzed and the measured values.

   Reference 1. Care must be given to the application limits of the calculation method.

   2. The correction of calibrations used in similar cases to the design coefficients derived from soil surveys is an effective way to improve reproducibility.

   3. Complicated in-situ conditions can be simplified in order to prepare the calculation models, but the reliability must have been confirmed based on facts.

7.7.3 Estimating the behavior of temporary structures by other methods

Calculation methods that have been verified by soil mechanics analyses and a comparison between analyzed and measured values are not necessary when the scale of the temporary structure is small or when many structures have already been constructed under similar conditions.

Remarks 1. Simple and common calculation methods can be used to estimate the behavior of temporary structures, although the methods cannot quantitatively evaluate such behavior as displacement when the methods are judged effective for being able to roughly predict the behavior based on past experiences.

2. It is not necessary to estimate the behavior of small-scale structures when the design uses data from nearby or similar construction projects and shows it unlikely to cause any problems, provided that the applicability of the projects referenced have been thoroughly examined.

3. Although data on past projects alone are insufficient for designing temporary structures, a rational interpretation of and a reference to the data are effective.

7.8 VERIFYING THE DESIGN OF TEMPORARY STRUCTURES

7.8.1 Limit states and verification

7.8.1.1 Performance criteria

a) The performance criteria shall consist of a combination of limit states for temporary structures specified according to the importance of the structure and its design conditions, namely, load conditions and a combination of loads considering the design working life.

   Reference Specifications for the performance criteria are described in Section 7.4.4.

b) The performance requirements of a temporary structure are evaluated by the displacements and deformations of the temporary structure, the retained ground, and the sectional force of the structural members.

c) The performance requirements must be determined during the design working life by considering the following points in order for the temporary structure to meet the requirements:

   1) The temporary structure must have sufficient strength against failure and collapse.

   2) The displacements and deformation of the temporary structure and/or the retained surface must be small.

   3) Structural members must be sufficiently strong.

   4) The temporary structures must be easy to maintain, to inspect, and to repair (or it must be easy to detect damage by inspections and to repair any damage found).

   Reference Checking the states of very infrequent variable loads and accidental loads during the design service period can sometimes be omitted based on the structural details that have been empirically determined.
7.8.1.2 Verifying the serviceability limit state

a) The maximum and the residual displacements and the deformation of the temporary structure shall be estimated to confirm that they lie within a range that satisfies the serviceability requirements.

Remark The maximum displacement and the deformation of an earth-retaining structure shall be estimated by calculating the internal displacement, the general stability of the surrounding ground, including the earth-retaining structure itself, and the stability of the excavated bottom surface.

b) Verifying the serviceability of members constituting the temporary structure Structural members shall be checked to confirm that their mechanical properties do not change greatly, and that they are free of serious damage which may cause a decrease in durability.

c) Verifying the internal stability of the earth-retaining structure Earth-retaining structures shall be checked to confirm that there are elastic regions in the embedded sections.

Remark Verification that there has been neither a failure nor a collapse of an entire temporary structure is usually satisfied when a), b), and c) have all been fulfilled.

7.8.1.3 Verifying the reparability limit state

a) The reparability limit state shall be verified by confirming that the calculated residual displacement and the deformation of the temporary structure and the foundation lie within a range in which repairs that would restore the structure to the required level of serviceability are possible.

Note The stability of the entire surrounding ground, including the earth-retaining structure and the excavated bottom, shall be considered as well as the calculation of the internal displacement for the estimation of the maximum displacement and the deformation of the earth-retaining structure.

b) Verifying the serviceability of members constituting the temporary structure Structural members shall be checked to confirm that no damage has occurred which would be difficult to repair or might cause a decrease in the durability of the structure. The strength of the members shall also be checked.

c) Verifying the internal stability of the earth retaining structure Earth-retaining structures shall be checked to verify that there are elastic regions in the embedded sections.

Reference Verification that there has been neither a failure nor a collapse of an entire temporary structure is usually satisfied when a), b), and c) have all been fulfilled.

Remark Checking the repair limit states giving consideration to very infrequent variable loads and accidental loads during the design service period can sometimes be omitted based on structural details that have been empirically determined.

7.8.1.4 Verifying the ultimate limit state

a) Verifying against the risk of the failure and the collapse of the entire temporary structure The temporary structure shall be checked to verify that it is stable.

b) Verifying the displacement and the deformation of the temporary structure and the retained ground It shall be confirmed that no excessive displacement or deformation that may cause a collapse of the back ground has been generated.

Reference The stability of the entire surrounding ground, including the earth-retaining structure and the excavated bottom, shall be considered as well as the calculation of the internal displacement for the estimation of the maximum displacement and the deformation of the earth-retaining structure.

c) Verifying the effects of the destruction of the structural members of a temporary structure on the entire structure The members shall be checked to confirm that no damage has occurred which might cause the destruction, the excessive displacement, or the deformation of the temporary structure.

Reference Checking the ultimate limit states, giving consideration to very infrequent variable loads and accidental loads during the design service period, can sometimes be omitted based on structural details that have been empirically determined.
7.8.2 Verifying equations

a) In verifying the limit states, the displacement generated in the earth-retaining structure must satisfy the following equation:

\[ E_{td} \leq C_{td} \]

where

- \( E_{td} \): displacement or deformation of each part of the earth-retaining structure under the design load
- \( C_{td} \): design displacement or design deformation limit of the members of the earth-retaining structure at each limit state.

**Remark** The stability of the entire surrounding ground, including the earth-retaining structure and the excavated bottom, shall be considered as well as the calculation of the internal displacement for the estimation of the displacement of the members of the earth-retaining structure.

b) In checking of the limit states, the sectional forces of the members constituting the earth-retaining structure must satisfy the following equation:

\[ F_{td} \leq R_{td} \]

where

- \( F_{td} \): sectional force or stress of each member of the earth-retaining structure under the design load
- \( R_{td} \): design section force or the design limit stress of the members of the earth-retaining structure at each limit state.

c) When the earth retaining wall receives load along the lining, the following equation must be satisfied:

\[ F_{td} \leq R_{td} \]

where

- \( F_{td} \): vertical reaction from the ground acting on the earth-retaining structure under the design load
- \( R_{td} \): design vertical bearing capacity of the earth-retaining structure or the design limit vertical ground reaction at each limit state.

7.9 DESIGN REPORT FOR TEMPORARY STRUCTURES

a) The chief designer shall submit a design report on the temporary structure to the client or owner.

b) The design report on the temporary structure shall include, but not be limited to, the following information in order that the design parameters, the design of the structure, and the verification of the design may be obtained:

1) Design conditions
2) Design results
3) Procedure for verifying the design (methods used to estimate the design parameters are based on the results of the geotechnical investigation, details of the verification methods, etc.)
4) Results of the geotechnical investigation (locations, dates, and test results)
5) Construction conditions specified in the design
6) Construction management items
7) Surveys deemed necessary during construction

7.10 CONSTRUCTION

a) The construction of temporary structures shall be performed so as to fulfill the conditions specified in the design.

**Reference 1.** It may be necessary to conduct an investigation to confirm that the conditions specified in the design are appropriate and are being met.

b) It shall be confirmed that the construction was performed in such a way that the temporary structure fulfills the performances requirements.

c) To ensure that the earth-retaining structure fulfills the performance requirements, care shall be used during construction with regard to the following points:

1) Quality control of the materials
2) Precision of the installation of the earth-retaining structure
3) Control of the joints
4) Control of the embedded depth
5) Disturbance of the ground caused by the excavation
6) Excessive excavation
7) Stability of the excavated bottom
8) Loosening of the support(s) during installation
9) Control of the pre-roads

d) Care shall be used during construction with regard to the following environmental issues, and investigations shall be conducted whenever deemed necessary:
1) Water pollution
2) Noise
3) Ground vibrations
4) Settlement/heaving of the surrounding ground and the associated displacement/deformation of nearby structures
5) Treatment and/or disposal of excavated materials
6) Damming up and drops in the level of underground water

e) The chief designer shall be responsible for confirming that the installation of the temporary structure has been performed as specified in the design and shall submit records of the construction to the client or owner.

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Related standards:

[Japanese Industrial Standards (JIS)]
JIS A 1219   Method for standard penetration test
JIS A 1220   Method for Dutch double-tube cone penetration test
JIS A 1221   Method for Swedish weight sounding test

[Japanese Geotechnical Society Standards (JGS)]
JGS 1121   Electrical Logging of the Ground
JGS 1122   Seismic Velocity Logging of the Ground
JGS 1221   Sampling of Soil Specimens using Stationary Piston Type Thin-walled Sampler
JGS 1222   Sampling of Soil Specimens using Rotary Double-tube Sampler
JGS 1223   Sampling of Soil Specimens using Rotary Triple-tube Sampler
JGS 1224   Sampling of Soil Specimens using Rotary Double-tube Sample Equipped with Sleeves
JGS 1231   Block Sampling of Soil Specimens
JGS 3211   Sampling of Soft Rock Specimens using Rotary Tube Sampler
JGS 1411   In-situ Vane Shearing Test
JGS 1421   Lateral Boring Test in Borehole
JGS 1431   Portable Cone Penetration Test
JGS 1433   Simple Dynamic Cone Penetration Test
JGS 1435   Electric Static Cone Penetration Test
JGS 1311   Measurement of Underground Water Level in the Sandy and Gravel Ground using Borehole
JGS 1312   Measurement of Underground Water Level in the Sandy and Gravel Ground in Observation Well
JGS 1313   Measurement of Pore Water Pressure using Electric Piezometer Installed in Bore Hole
JGS 1314   Permeability Test using a Single Borehole
JGS 1315   Pumping Test
JGS 1316   Permeability Test of Compacted Ground
JGS 1317   Logging of Ground Water Flow Layers using Tracer
JGS 1321   Rock Permeability Test by Monitoring Water Level Recovery in Borehole
JGS 1322   Rock Permeability Test by Flooding
JGS 1323   Lugeon Test
JGS 1521   Plate Loading Test of the Ground
JGS 3521   Plate Loading Test of the Ground using Rigid Loading Plates
JGS 3511  Rock Shearing Test
JGS 1613  Soil Density Test using Core Cutter
JGS 1614  Soil Density Test using Nuclear Gauge
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