

**TENTATIVE ENGLISH TRANSLATION
OF
A PROPOSAL FOR
EARTHQUAKE RESISTANT DESIGN METHODS
PWRI TECHNICAL MEMORANDUM NO. 1 5 3 5**

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ABOUT TENTATIVE ENGLISH TRANSLATION

This publication presents a tentative English translation of design methods in Part I and Part II of "A Proposal For Earthquake Resistant Design Methods" based on the PWRI Technical Memorandum No. 1185. Their explanations and design methods in Part III are provided exclusively.

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PREFACE

The proposed method of earthquake-resistant design has been studied and developed to achieve the objective of developing a more rational method of earthquake-resistant design for structures, basing upon the research results from 20 themes from 6 studies on the "Development of New Method of Earthquake-Resistant Design", one of the overall technical development projects being conducted by the Ministry of Construction, as well as previous research by academic circles, research institutes and private organizations.

The proposed design method consists of three parts; Part I describes fundamental requirements common to the earthquake-resistant design for both civil engineering structures and building structures; and Parts II and III show the actual method of earthquake resistant design for each of civil engineering and building structures basing upon the fundamental requirements given in Part I.

The following objectives were established in preparing this design method:

- (1) Establishment of fundamental requirements common to various structures

The method of earthquake-resistant design generally used at present has been gradually formed as a result of the successive utilization of information concerning the damage occurring to structures caused by past earthquakes, the results of analyses on earthquake ground motions triggered by strong motion observation network, and of the progress of the seismic response analysis procedures. Thus, the analytical procedure of earthquake-resistant design for structures varies depending upon the types and usages of the structures, and the method of earthquake-resistant design itself has become more complicated as a result of the development of new types of structures.

To cope with such circumstances, various current methods of earthquake resistant-design for individual structures were thoroughly reviewed, and common portions for both civil engineering and architecture were selected and compiled to establish the fundamental requirements.

(2) Clarification of design procedure

Engineers were apt to be unaware of the basic procedure of earthquake-resistant design since conventional methods of structural calculations had been so widely practiced for earthquake-resistant design purposes up to now.

According to the proposed design method, special attention is paid to checking the characteristics of seismic force, various structural characteristics and the degree of safety instead of carelessly following the conventional method of practice, and the design procedure has been clarified to allow the proper earthquake-resistant designing practice.

(3) Rationalization of design procedure

It is desired to provide appropriate procedures of seismic design method corresponding to the ground and structural characteristics. Thus, this design method provides guidance to engineers in selecting a particular kind of calculating method for the earthquake-resistant design based on the latest technical knowledge in order to achieve the rationalization of design practice without being bothered by excessively complicated calculating methods.

PART I. FUNDAMENTAL REQUIREMENTS

1. Scope of Application

This method of earthquake resistant design shall be applied to civil engineering structures and building structures.

2. Definitions of Technical Terms

The technical terms used for this method of earthquake-resistant design are defined as follows:

(1) Method of earthquake-resistant design

The term method of earthquake-resistant design is the generic term for various design processes for designing earthquake-proof structures.

(2) Method of seismic design calculations

This is the major design process in earthquake-resistant design, and specifications of structures and others are mainly determined during this process. Also, a safety check is normally included in this process.

(3) Ground characteristics

Dynamic characteristics of the ground that affect the earthquake resistance of a structure.

(4) Structural system

Generic term for both the major portion of the structure and its supporting ground.

(5) Seismic response

Behavior of the structural system resulting from earthquake ground motions.

(6) Seismic load

Earthquake force evaluated on the basis of engineering for use in seismic design calculations.

(6) Seismic coefficient method

A method of seismic design calculations where the seismic load is statically applied to the structure.

(8) Modified seismic coefficient method

A method of seismic design calculations where the seismic load is determined by considering the seismic response characteristics of the structure and ground.

(9) Seismic deformation method

A calculation method in which behavior of the structure during earthquake is, in the analysis, considered to be governed by the displacement and deformation of the surrounding subsoils.

(10) Dynamic response analysis

A calculating method in which dynamic models of structure and ground will be used for the analysis.

(11) Structural requirements

A generic term for structural provisions and regulations which are determined to secure the performance of structure.

(12) Designing in conformity with structural requirements

Designing where specifications and materials of structure will be determined in accordance with the structural requirements.

(13) Intensity of earthquake ground motion

A generic term for the intensity of ground motion during an earthquake as an index to show the magnitudes of acceleration, velocity and displacement.

(14) Design horizontal seismic coefficient

Horizontal seismic coefficient to be used for seismic design calculations. This coefficient is equal to the horizontal seismic load divided by weight of structure being considered when this seismic load is being applied to a horizontal plane at a given height of the structure, and the weight of the structure is assumed to be concentrated on that horizontal plane.

(15) Standard design horizontal seismic coefficient

Standard value of the horizontal seismic coefficient to be used for the seismic design calculations.

(16) Base shear coefficient

Value derived by dividing the sum of seismic load being applied to a horizontal plane above the ground surface of a structure by the weight of the structural portion above the ground surface.

(17) Types of ground

Types of ground evaluated from an engineering point of view in response to the ground characteristics.

(18) Seismic activity

Frequency of earthquake occurrence and intensity of earthquakes within a particular area.

(19) Strong-motion records

Records of ground motion obtained with engineering strong motion seismograph.

(20) Simulated seismic wave

Artificial seismic wave produced by taking the ground condition at the construction site, seismic activities, structural characteristics concerned, etc. into consideration.

(21) Yield strength of member

Ultimate yield strength of a structural member.

(22) Liquefaction

Losing of shear strength of saturated sandy ground and occurrence of liquefaction failure of earth structure due to a sudden rise of pore water pressure during earth.

3. Basic Policies in Earthquake-Resistant Design

In making earthquake-resistant design, various structural characteristics, usage, type, scale and site conditions of the structure concerned, and past experience of earthquake damage to ground and similar structures shall be taken into consideration, and the safety of structure shall be checked by using the method of seismic design calculations indicated in this method of earthquake-resistant design.

3.1 Basic procedure of earthquake-resistant design

Earthquake-resistant design shall be principally conducted in accordance with the following procedure:

- 1) Establishing engineering intensity of earthquake ground motion considering regional characteristics.
- 2) Establishing the seismic load considering the ground condition at the construction site and seismic response of the structural system.
- 3) Determining specifications of the structure.
- 4) Checking the safety.

For the steps within the procedure shown above, usage, type, scale and the site condition of structure concerned, and past experience on earthquake damage to ground and similar structures shall be taken into consideration as necessary.

3.2 Methods of seismic design calculations

3.2.1 Kinds of methods of seismic design calculations

Seismic design calculations utilizing this method of earthquake resistant design shall be principally made by either one of the following methods or a combination thereof:

- i) Seismic coefficient method
- ii) Modified seismic coefficient method
- iii) Seismic deformation method
- iv) Dynamic response analysis
 - a) Response spectrum method
 - b) Time-history response analysis method

3.2.2 Selection of method of seismic design calculations

In the process of structural design, the usage, type, scale and site condition of the structure concerned, experience of past earthquake damage to ground and similar structures, analytical procedure, state of refinement of structural requirements, precision of the construction work and so forth shall be considered, and a particular method of seismic design calculations shown in Paragraph 3.2.1 shall be selected. However, design shall be performed only by conforming to the structural requirements if it is clear that the required earthquake resistance can be obtained only by using the structural requirements.

3.2.3 Precautions for seismic design calculations

In the process of the seismic design calculations, the following items shall be taken into consideration in addition to the provisions of the calculation method concerned:

- i) Special characteristics associated with the structural type of a particular structure concerned.

- ii) Deformation performance of a particular structure concerned.
- iii) Working direction of the seismic load.

3.3 Checking of safety

For checking the safety in the process of calculations in conformity with the method of seismic design calculations shown in Paragraph 3.2, allowable stress, allowable displacement, ultimate yield strength, ultimate displacement, etc. shall be used. However, structural requirements may be used if it is apparent that the required earthquake resistance is guaranteed by using such structural requirements.

4. Standard Design Earthquake Ground Motion and Seismic Load

4.1 Previous earthquakes

When determining the intensity of earthquakes in an area near the construction site, it is necessary to consider the previous occurrence of earthquakes in the area.

4.2 Engineering characteristics of earthquake ground motion

4.2.1 Determination of engineering characteristics of earthquake ground motion

Engineering characteristics of earthquake ground motion shall be determined by considering the records of strong ground motions.

4.2.2 Regional characteristics of intensity of earthquake ground motion

The regional characteristics of the engineering intensity of earthquake ground motion shall be represented by the seismic zone coefficient in consideration of earthquake activities.

4.2.3 Engineering intensity of earthquake ground motion construction site

When determining the engineering intensity of earthquake ground motion at the construction site, the ground condition at the site and in nearby areas shall as a rule be taken into consideration in addition to the seismic zone coefficient stated in Paragraph 4.2.2.

4.3 Seismic load to be considered for designing

4.3.1 General

Seismic load to be considered for structural design shall be determined depending upon the methods of seismic design calculation, in conformity with the procedures shown in this section.

4.3.2 Design seismic coefficient to be used for the seismic coefficient method

The design seismic coefficient to be used for the seismic coefficient method shall be determined by the following equation:

$$K_H = \Delta_1 \cdot \Delta_2 \cdot \Delta_3 \cdot K_0 \quad (4.3.1)$$

where

K_H : Design horizontal seismic coefficient

K_0 : Standard design horizontal seismic coefficient

Δ_1 : Seismic zone coefficient prescribed in Paragraph 4.2.2.

Δ_2 : Ground condition coefficient

Δ_3 : Other coefficient

4.3.3 Design seismic coefficient to be used for modified seismic coefficient method

Design seismic coefficient to be used for the modified seismic coefficient method shall be determined by the following equation:

$$K = \Delta_1 \cdot \Delta_2 \cdot \Delta_4 \cdot \Delta_5 \cdot \Delta_6 \cdot K_0 \quad (4.3.2)$$

where

- K : Design horizontal seismic coefficient or base shear coefficient.
- K_0 : Standard design horizontal seismic coefficient or standard base shear coefficient.
- Δ_1 : Seismic zone coefficient prescribed in Paragraph 4.2.2.
- Δ_2 : Ground condition coefficient
- Δ_4 : Coefficient dependent on response characteristics of structure in accordance with ground condition.
- Δ_5 : Coefficient for structural characteristics.
- Δ_6 : Other coefficient

4.3.4 Amplitude to be used for seismic deformation method

Amplitude to be used for the seismic deformation method shall be determined by the ground displacement during earthquake.

4.3.5 Earthquake ground motion to be used for dynamic response analysis

i) Earthquake ground motion to be used for dynamic response analysis shall be determined in accordance with Section 4.2.

ii) Design seismic coefficient to be used for the response spectrum method shall be determined from values of the response spectrum corresponding to natural frequency, natural mode, and participation factor.

iii) Input earthquake ground motion to be used for the time-history response analysis method shall be a combination of some of the past strong-motion records suited to ground conditions of the construction site or modification of such past records, or some appropriate simulated seismic waves. However, the lower limit of the elastic response of the relevant structure for the seismic waves employed shall, if the minimum value has been prescribed for each structure of various types, be no smaller than such a minimum value prescribed.

5. Investigation of Subsurface Ground Condition and Earthquake-Resistance of Ground

5.1 General

i) In performing earthquake-resistant design for the structures, previous observations on the dynamic properties and the earthquake-resistance of subsurface ground shall be investigated and, if required, investigation of characteristics of the relevant ground and properties of the soil comprising the ground and structure shall be performed. Seismic load shall be established based on the results of such investigation, and seismic design calculations shall be made accordingly.

ii) Ground supporting the structure shall be capable of safely supporting the dead load and assuring the stability of the structure during earthquake.

5.2 Soil investigation

5.2.1 General

Investigation and testing to find the dynamic characteristics of soil shall be conducted as necessary in addition to ordinary soil investigation and soil tests of the ground at the construction site. Dynamic soil properties to be used for earthquake-resistant design shall be properly determined from an overall point of view after examining the results of the investigations and tests.

5.2.2 Tests for finding dynamic soil properties

Tests for finding dynamic soil properties shall be conducted by referring to the results of previous research and by using an appropriate method which takes test results, soil conditions and field conditions into consideration.

5.3 Investigation of subsurface ground condition

5.3.1 General

For examining earthquake-resistance of structures, the dynamic characteristics of the ground shall be investigated, as necessary, in addition to ordinary investigation of subsurface ground condition.

5.3.2 Investigation of the dynamic characteristics of the ground

Investigation of the dynamic characteristics of the ground shall be principally conducted by selecting appropriate items from the list indicated below.

- i) Preliminary investigation by using existing data.
- ii) Ordinary subsurface ground investigation and boring investigation.
- iii) Dynamic investigation on ground surface and within bore holes.
- iv) Sampling
- v) In-situ test for liquefaction
- vi) Other investigations and tests

5.3.3 Dynamic analysis of ground

Dynamic analysis of ground shall be conducted when it is specially needed by considering the earthquake ground motion prescribed in Paragraph 2.3.5 and by employing the method that is capable of properly finding the behavior of the ground during earthquake.

5.3.4 Investigation on ground types

Investigation on ground types shall be principally performed in accordance with subsurface ground investigation described in this section. In this case, judgement shall be made after making an overall analysis considering ground characteristics such as geologic configuration, shear wave velocity, and frequency characteristics of ground.

5.4 Seismic stability of ground

5.4.1 General

For soil layer that may greatly lose shearing resistance during earthquake, bearing resistance capacity is not usually expected for earthquake-resistant design. In addition, if there is a possibility of the occurrence of sliding during earthquake, safety of structure shall be checked also by considering such influence.

5.4.2 Investigation on stability of sandy soil

Investigation on the stability of sandy soil shall be conducted, as a rule, in accordance with one of the following investigation methods for liquefaction:

- i) Simple method of investigation for liquefaction
- ii) Detailed method of investigation for liquefaction

5.4.3 Investigation on stability of cohesive soil

Investigation on the stability of cohesive soil shall be conducted in accordance with the proper method of test and survey.

6. Earthquake-Resistant Performance of Concrete Members

6.1 Material characteristics of concrete and steel

6.1.1 Concrete

Concrete shall have the required strength and endurance. The stress-strain relation and elastic modulus of concrete which are to be used for design calculations shall be determined depending upon the concrete quality and purpose of earthquake-resistant calculations.

6.1.2 Reinforcing bars and PC steel rods

Reinforcing bars and PC steel rods shall have required tensile strength, yield strength, and deformation performance (elongation, bending, etc.).

Stress-strain relation, elastic constants, etc. of reinforcing bars and PC steel rods which are to be used for design calculations shall be determined depending upon the quality of reinforcing bars and PC steel rods and the purpose of the seismic calculations.

6.2 Earthquake-resistant performance of civil engineering structural members of reinforced concrete

6.2.1 General

In designing civil engineering structural members of reinforced concrete, it is generally required to provide necessary strength and function against constantly applied load and also to provide necessary strength and function against earthquake. However, structural members may be designed simply in conformity with the structural requirements if it is obvious that the required earthquake resistance can be assured by such requirements.

6.2.2 Basic design precautions

The following items shall be taken into consideration when designing the civil engineering use structural members of reinforced concrete:

- i) Stress of each section of members shall not exceed the prescribed value during earthquake.
- ii) Yield strength for shear which is sufficient in comparison with the yield strength for bending shall be provided.
- iii) Structure shall be subjected to as little twisting as possible.
- iv) Harmful cracks or permanent residual deformation shall not be caused by earthquake.
- v) If influence by the surrounding soil cannot be ignored, the conditions of such soil shall be taken into consideration.

6.2.3 Yield strength and deformation performance

In designing civil engineering structural members of reinforced concrete, it is required to maintain the ductility in order to prevent brittle failure until the inherent yield strength is fully utilized, when checking the safety of members against the seismic load shown in Paragraph 4.3, and when determining the specifications for members and their reinforcement.

6.3 Earthquake-resistant performance of structural members of reinforced concrete buildings

6.3.1 General

Structural members of reinforced concrete buildings shall have necessary strength and functions against constantly applied load and also have the necessary strength and deformation performance against earthquake.

6.3.2 Basic precautions to be considered for designing

When designing the structural members for reinforced concrete buildings, the following items shall be taken into consideration:

i) Shear failure and bond failure shall not occur in column and beam members before the occurrence of bending failure of these members.

ii) Connecting portions between beams and columns shall have sufficient surplus strength when beams or columns connected to such portions reach their ultimate state.

iii) Columns, beams and their connecting portions shall have the deformation performance that is capable to maintain their yield strength within the required amount of deformation.

iv) Shear wall shall have sufficient deformation performance without causing shear failure under the condition of the yield strength which is to be determined by considering the behavior of

structural plane containing such shear wall.

v) Structural members composing the floor and their connecting portions shall have sufficient rigidity and strength against forces caused within the floor during earthquake.

6.3.3 Yield strength and deformation performance

In designing structural members of reinforced concrete buildings, it is required to maintain the ductility in order to prevent brittle failure until the inherent yield strength is fully utilized, when checking the safety of members against the seismic load shown in Paragraph 4-3 and when determining the specifications for members and their reinforcement.

6.4 Earthquake-resistant performance of structural members of reinforced concrete and steel buildings

6.4.1 General

Structural members of reinforced concrete and steel buildings shall have necessary strength and functions against constantly applied load have necessary strength and deformation performance against influence caused by earthquake.

6.4.2 Basic precautions to be considered for designing

When designing the structural members for reinforced concrete and steel buildings, the following precautions shall be taken into consideration:

i) Shear failure and bond failure shall not occur in column and beam members before the occurrence of bending failure of these members.

ii) Connecting portions between beams and columns shall have sufficient surplus strength when beams or columns connected to such portions reach their ultimate state.

iii) Columns, beams and their connecting portions shall have the deformation performance that is capable to maintain their yield strength within the required amount of deformation.

iv) Shear wall shall have sufficient deformation performance under the condition of the yield strength which is to be determined by considering the behavior of structural plane containing such shear wall.

v) Structural members composing the floor and their connecting portions shall have sufficient rigidity and strength against forces caused within the floor during earthquake.

6.4.3 Yield strength and deformation performance

In designing structural members of reinforced concrete and steel buildings, it is required to maintain the ductility in order to prevent brittle failure until the inherent yield strength is fully utilized, when checking the safety of members against the seismic load shown in Paragraph 4.3 and when determining the specifications for members and the reinforcement.

6.5 Earthquake-resistant performance of structural members of prestressed concrete buildings

6.5.1 General

Structural members of prestressed concrete buildings shall have necessary strength and functions against constantly applied load and have necessary strength and deformation performance against influence caused by earthquake.

6.5.2 Basic precautions to be considered for designing

When designing the structural members for prestressed concrete buildings, the following precautions shall be taken into consideration:

i) Brittle failure such as shear failure shall not occur in column and beam members before the occurrence of bending failure of these members.

ii) Connecting portions between beams and columns shall have sufficient surplus strength when beams or columns connected to such portions reach their ultimate state.

iii) Columns, beams and their connecting portions shall have the deformation performance that is capable to maintain their yield strength within the required amount of deformation.

iv) Shear wall shall have sufficient deformation performance under the condition of the yield strength which is to be determined by considering the behavior of structural plane containing such shear wall.

v) Structural members composing the floor and their connecting portions shall have sufficient rigidity and strength against forces caused within the floor during earthquake.

6.5.3 Yield strength and deformation performance

In designing structural members of prestressed concrete buildings, it is required to maintain the ductility in order to prevent brittle failure until the inherent yield strength is fully utilized, when checking the safety of members against the seismic load given in Paragraph 4.3 and when determining the specifications for members and their reinforcement.

7. Earthquake-Resistant Performance of Steel Members

7.1 Characteristics of steel materials

Steel materials for steel structure for which earthquake-resistant design is being made shall have satisfactory mechanical properties needed such as yield point, tensile strength, brittle strength, fatigue strength, deformation performance, and so forth.

7.2 Earthquake-resistant performance of structural steel members for civil engineering structure

7.2.1 General

In the earthquake-resistant design of structural steel members for civil engineering structures, required strength and functions shall be provided against the seismic load.

7.2.2 Basic precautions to be considered for designing

In the earthquake-resistant design for the structural steel members for civil works, two critical states such as working limit and ultimate limit must be generally satisfied. In this case, it is desired to pay full attention to the characteristics of the members and structural system.

7.2.3 Yield strength and deformation performance

i) Working limit of structural steel members for civil engineering structures shall be set in the zone where the elastic behavior of structures is expected, as a rule. In this case, the state of the working shall be checked and determined by assuming that the structure has elastic performance.

ii) The yield point or buckling strength shall be principally used as the ultimate limit of structural steel members for civil engineering structures. In addition, if the amount of deformation of structural system creates a special problem, the displacement may be set to the ultimate limit. Checking of such an ultimate limit shall be performed by assuming that the structure has elastic performance.

iii) For structure having thick-plate as major components or having high redundancy in the case of Paragraph ii) stated above, the safety factor during earthquake for ordinary steel structure for civil engineering structures may be reduced or the ultimate limit may be set to the plastic range only when all conditions shown from a) to c) below are satisfied.

a) If major components have stable yield strength and deformation performance even after yielding or buckling.

b) If rigidity of a member reduced due to yielding or buckling does not badly affect the yield strength and stability of the whole structure.

c) If supports and splices of the structure which tend to become weak portions are able to maintain stable functions even after yielding or buckling of the members.

7.3 Earthquake-resistant performance of structural steel members of buildings

7.3.1 General

Structural steel members of steel buildings shall have the necessary strength and functions against constantly applied load and also have the necessary strength and deformation performance against seismic load.

7.3.2 Basic precautions to be considered for designing

In the design of structural steel members for steel building, the following items shall be considered:

i) Columns, beams and braces shall have the necessary strength and deformation performance.

ii) Connecting portions for columns and beams shall not cause any local deformation or brittle failure before columns or beams connected to such portions begin flexural yielding and shall have sufficient surplus strength and deformation performance after such flexural yielding.

iii) Connections for structural members shall be able to smoothly transfer the stresses and have sufficient deformation performance.

iv) Members composing the floor and their connections shall have the sufficient strength and rigidity against the forces which occur within the floor during earthquake.

v) Column base shall be designed in such a manner that supporting conditions assumed for structural calculations will be satisfied and, in addition, strength and deformation of anchor bolts, base plates and concrete foundation shall be examined.

7.3.3 Yield strength and deformation performance

i) Yield strength of beams shall be principally calculated from the load at the time when local buckling or lateral buckling occurs at the section.

ii) Yield strength of column member shall be calculated from either one of the following loads, whichever is smallest:

a) Load when local buckling, flexural buckling or flexural twisted buckling occurs at the section.

b) Load when load-deformation curve reaches ultimate value due to the additional flexural effect brought by lateral deflection and axial compressive force of column.

iii) Deformation performance of structural members and their connections of steel buildings shall be properly evaluated depending upon their materials and geometrical dimensions.

8. Earthquake-Resistant Performance of Other Structural Members

8.1 General

Principles of the earthquake-resistant performance of various structural members not described in Chapters 6 and 7 will be described in this chapter.

8.2 Earthquake-resistant performance of structural wood members of traditional wood frame buildings

8.2.1 General

Structural wood members and their connections in traditional wood frame buildings shall have the necessary strength and functions against constantly applied load and also have the necessary strength and deformation performance against seismic load.

8.2.2 Basic precautions to be considered for designing

When designing structural wood members of traditional wood frame buildings, the following precautions shall be taken into consideration:

- i) Double plates on foundation, columns, beams, wall braces, knee braces, pilasters, floor framing members and roof framing members shall be safe and able to effectively resist stresses in each member.
- ii) Each connection of structural wood members shall have sufficient strength and required rigidity and ductility.

8.2.3 Yield strength and deformation performance

When designing structural wood members of traditional wood frame buildings, it is required to maintain the ductility in order to prevent sudden failure until the inherent yield strength will be fully utilized when checking the safety of members against the seismic load shown in Paragraph 4.3 and when determining the specifications of members and details of connections.

8.3 Earthquake-resistant performance of non-structural members of buildings

8.3.1 General

Non-structural members of buildings shall have their fundamental functions required and be designed in such a manner that minimum functions required during earthquake can be secured out of various functions to be retained for buildings.

8.3.2 Basic precautions to be considered for designing

When designing the non-structural members, the following items shall be taken into consideration:

- i) Prevention of sudden mechanical failure.
- ii) To determine seismic coefficient and displacement between layers based upon the dynamic behavior of the main structure.
- iii) To select an appropriate structural system.

8.3.3 Yield strength and deformation performance

Yield strength and deformation performance of non-structural members of buildings shall be determined by structural calculations and conform to the structural requirements provided for the purpose of securing the ductility.

8.4 Earthquake-resistant performance of buried pipes

Yield strength and deformation performance of buried pipes shall principally, conform to the relevant standards and be tested if necessary for confirmation.

PART II. EARTHQUAKE-RESISTANT DESIGN FOR CIVIL ENGINEERING STRUCTURES

1. Outline

1.1 General

Present earthquake-resistant provisions being used for various civil engineering structures have been gradually altered and developed utilizing the knowledge obtained through the experience of damages to structures caused by past earthquakes and the results of research and development on earthquake-resistant design. The method of earthquake-resistant design for civil engineering structures was compiled in conformity with the fundamental requirements for the earthquake-resistant design described in Part I, while respecting the current earthquake-resistant provisions for each civil engineering structure. However, this design method permits one to use the method selectively depending on the particular characteristics of structure concerned.

1.2 Uses and kinds of structures in earthquake-resistant design

In making earthquake-resistant designs for civil engineering structures, uses and kinds of structures shall be taken into consideration, and required design considerations corresponding to them shall be taken.

1.3 Various coefficients for earthquake-resistant design

1.3.1 General

Various coefficients required for determining the seismic loads shown in Paragraph 4.3 of Part I shall be not lower than the values described herein.

1.3.2 Coefficients for the seismic coefficient method

i) Standard horizontal seismic coefficient for design (K_0) shall be 0.2.

ii) Seismic zones coefficient (Δ_1) shall conform to the values shown in Table 1.3.1 for seismic zones shown in Fig. 1.3.1.

Table 1.3.1 Seismic Zones Coefficient (Δ_1)

Seismic Zone	Coefficient Δ_1
A	1.0
B	0.85
C	0.7

iii) Ground condition coefficient (Δ_2) shall be the value as indicated in Table 1.3.2.

Table 1.3.2 Ground Condition Coefficient (Δ_2)

Group	Definitions ¹⁾	Value of v_2
1	(1) Ground of the Tertiary era or older (defined as bedrock hereafter) (2) Diluvial layer ²⁾ with depth less than 10 meters above bedrock	0.9
2	(1) Diluvial layer ²⁾ with depth greater than 10 meters above bedrock (2) Alluvial layer ³⁾ with depth less than 10 meters above bedrock	1.0
3	Alluvial layer ³⁾ with depth less than 25 meters, which has soft layer ⁴⁾ with depth less than 5 meters	1.1
4	Other than the above	1.2

- (Notes) 1) Since these definitions are not very comprehensive, the classification of ground conditions shall be made with adequate consideration of the bridge site. Depth of layer indicated here shall be measured from the actual ground surface.
- 2) Diluvial layer implies a dense alluvial layer such as a dense sandy layer, gravel layer, or cobble layer.
- 3) Alluvial layer implies a new sedimentary layer made by a landslide.

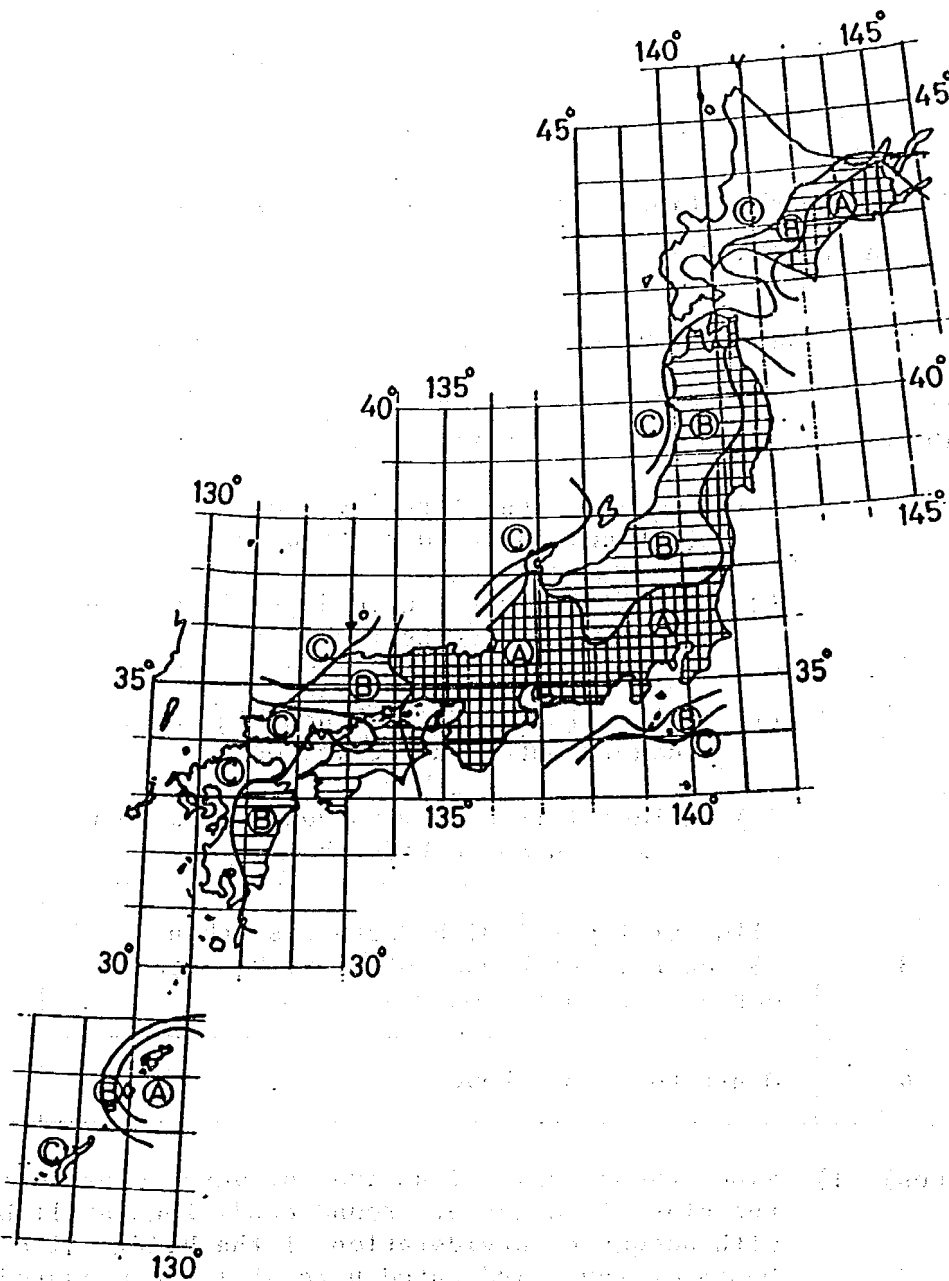


Fig. 1-3-1 Seismic Zones

iv) Other coefficients (Δ_3) shall be determined by considering uses and kinds of structures. Coefficients for the kinds of structures shall be the values shown in Table 1.3.3.

Table 1.3.3 Coefficients for Kinds of Structures

Definition	Coefficient
Steel structures	1.0
Concrete structures	
Reinforced concrete and steel structures	
Huge structures of rigid-body type	0.5
Earth structures	

1.3.3 Coefficients for modified seismic coefficient method

i) Standard horizontal seismic coefficients for design (K_0), seismic zones coefficient (Δ_1), and ground condition coefficients (Δ_2) shall conform to Paragraph 1.3.2.

ii) Coefficients (Δ_4) dependent on the response characteristics of structures that are determined for each ground condition shall conform to Fig. 1.3.2. However, Δ_4 shall be 1.0 when natural period T is less than 0.5 second.

iii) Coefficient (Δ_5) for structural characteristic shall be 1.0 when in the allowable stress method and shall be determined depending on the amount of ductility expected when calculating the retained yield strength by assumption.

iv) Other coefficients (Δ_6) shall be determined by considering the uses and kinds of structures. Coefficient Δ_6 shall be 1.0 if special consideration is not required.

1.3.4 Amplitude and other factors for the seismic deformation method

Displacement amplitude of ground in the seismic deformation method can be determined by the method shown below.

i) Displacement amplitude in horizontal direction at depth x from the ground surface shall be determined by the following equation:

$$U_h(x) = \frac{2}{\pi^2} S_v \cdot T \cdot K_H' \cdot \cos \frac{\pi x}{2H} \quad (1.3.1)$$

where

$U_h(x)$: Displacement amplitude (cm) in the horizontal direction at depth x (cm) from ground surface.

S_v : Response velocity (cm/sec) per unit seismic coefficient.

T : Fundamental natural period (sec) of subsurface deposit.

K_H' : Design horizontal seismic coefficient to be applied to subsurface deposit.

H : Thickness (cm) of subsurface deposit.

ii) Response velocity (S_v) per unit seismic coefficient shall be determined by using Fig. 1.3.3 depending upon the fundamental natural period of the subsurface deposit.

iii) Fundamental natural period (T) of the subsurface deposit shall be principally calculated using measured shear wave velocity at the construction site considering of shear strain level developed during earthquake.

iv) Horizontal seismic coefficient (K_H') for design to be applied to the subsurface deposit shall be determined by the following equation:

$$K_H' = \frac{1}{B_G} \cdot \frac{K_H}{\Delta_2} \quad (1.3.2)$$

where: K_H and Δ_2 shall conform to Paragraph 4.3.2 of Part I.

B_G : Amplification coefficient of the subsurface deposit, generally between 4/3 to 2.

v) Thickness (H) of the subsurface deposit shall be the distance from the ground surface to bedrock assumed for designing.

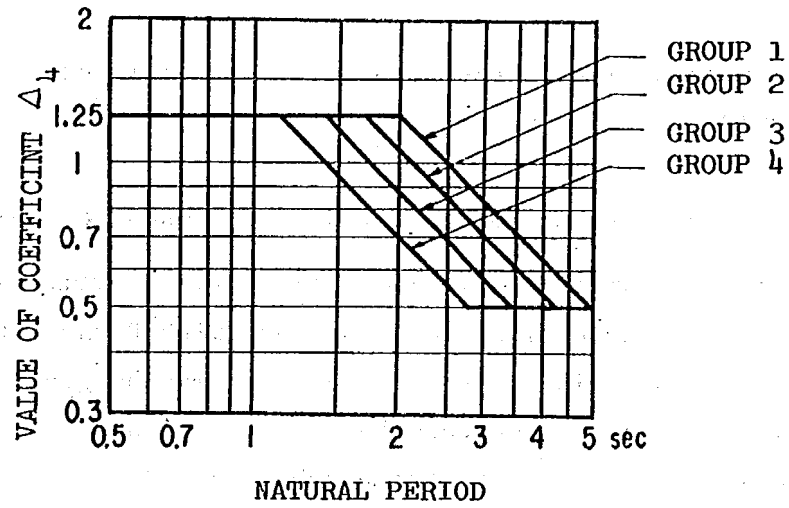


Fig. 1-3-2 Coefficient Δ_4

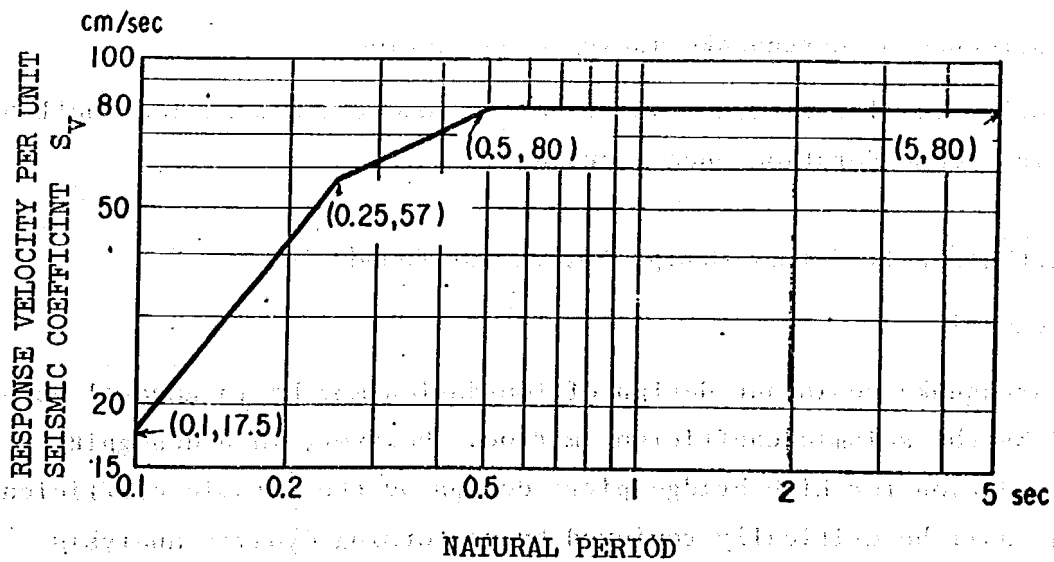


Fig. 1-3-3 RESPONSE VELOCITY PER UNIT SEISMIC COEFFICIENT

vi) It is desirable to determine the wave-length required for design calculations based on the characteristics of construction site.

vii) When considering vertical displacement amplitude U_v , U_v shall be equal to $U_h/2$.

1.3.5 Earthquake ground motion for dynamic response analysis

i) Earthquake ground motion to be used for the dynamic response analysis shall be determined in accordance with Paragraph 4.2 of Part I, but K_H^I shown in Paragraph 1.3.4 iv) may be generally used for the intensity of the earthquake ground motion for analysis purposes by considering the influence of the subsurface deposit.

ii) Response spectrum curve to be used for the response spectrum method shall conform to Paragraph 4.2.1 of Part I.

iii) Earthquake ground motion to be used for the time-history response analysis method shall be selected in accordance with Paragraph 4.2.1 of Part I, and at least 3 kinds of acceleration records shall be used.

1.4 Influence of earthquake during construction

Influence of earthquake on structures under construction shall be taken into consideration when necessary.

2. Earthquake-Resistant Design Method for Foundation

2.1 General

Earthquake-resistant design of foundation may be in general performed by the seismic coefficient method. However, when designing the foundation for high bridge piers design by the seismic coefficient method shall be critically reviewed by performing dynamic analysis for the whole structural system.

2.2 Influence of earthquake

The following earthquake forces shall be in general, considered as influence of earthquake:

- i) Inertia force due to dead weight of structure
- ii) Inertia force due to superimposed load
- iii) Hydrodynamic pressure during earthquake
- iv) Earth pressure during earthquake

2.3 Bearing stratum and allowable bearing capacity

Bearing stratum for foundation shall have sufficient bearing capacity not only during normal time but also during earthquake and shall be stable soil that will not be affected by meteorological and hydrological conditions.

Allowable bearing capacity of foundation shall be either the value determined by the strength of the ground, or value restricted by allowable displacement developed in the structure, whichever the most critical value.

2.4 Calculation method for stresses, displacements and stability

2.4.1 General

When calculating stresses, displacements and stability of foundation, the kinds of foundation shall be classified depending on the flexural rigidity of the structure and elastic properties of the ground.

2.4.2 Spread foundation

Stability calculations for bearing capacity, overturning and sliding, and calculations of displacement of the spread foundation shall be performed by treating such foundation as a rigid body.

2.4.3 Caisson foundation

Calculations for stresses, displacements and stability of caisson foundation shall be made by assuming caisson to be a rigid body and external force acting on the caisson be balanced with the vertical reaction at the bottom, shearing resistance and horizontal reaction at the front.

2.4.4 Pile foundation

Calculations for stresses, displacements and stability of pile foundation shall be performed by assuming that the external force acting on the pile foundation be supported by the horizontal, vertical and rotational springs at the head of pile.

2.4.5 Sheet pile foundation

i) Basic design conditions

a) Checking of sheet pile foundation shall be made by comparing the maximum reaction of the ground at the bottom of well to the allowable bearing capacity of ground at that location.

b) Checking of sheet pile foundation shall be made by comparing the shearing force at the bottom of the well of sheet pile foundation to the allowable shearing resistant force.

c) Checking of sheet pile foundation shall be made by comparing the maximum reaction of ground at the front of the well to the allowable bearing capacity of the ground at that location.

d) Displacement of sheet pile foundation shall be examined by considering the allowable displacement that will be determined by the design of superstructure.

e) Checking shall be made by comparing the stress of the sheet pile foundation to the allowable stress for each portion.

f) Horizontal resistance shall be calculated for sheet pile foundation as a beam on an elastic foundation for which shearing deformation between each sheet pile is taken into consideration. In this case, checking shall be made by comparing the shearing stress of the joint section to the allowable shearing stress.

ii) Conditions for calculations

a) Resistance of the soil within the well shall be considered depending upon the size of sheet pile foundation.

b) Shearing resistance between joints of sheet piles shall be considered.

c) Inertia force acting on the ground within the well during earthquake shall be considered if necessary.

d) Deformation of wall sections of the well shall be considered depending upon the size of the sheet pile foundation.

e) When installing partition wall within the well, its horizontal resistance shall be considered and sectional deformation of the well wall shall be generally neglected.

f) When using the sheet pile foundation also as temporary cofferdam, residual deformation and residual stress of the sheet pile which generally occur during construction work shall be taken into consideration.

iii) Design of deck slab

Connecting portion between sheet piles and deck slab shall be designed to provide rigid connection for such portion.

2.4.6 Multi-pile foundation

i) Basic design conditions

In general, multi-pile foundation shall be designed in conformity with design methods for pile foundation.

ii) Method of calculations

a) Distribution of seismic force acting on the multi-pile foundation shall be determined by considering its dynamic characteristics.

b) Loads to be considered for designing generally shall conform to those of pile foundation.

c) A particular method of earthquake-resistant design shall be selected by considering the size, structural characteristics and so forth of the multi-pile foundation.

iii) Basic design conditions of deck slab

Deck slab shall be principally designed as a rigid body.

3. Method of Earthquake-Resistant Design of Concrete Structures and Steel Structures

3.1 General

Earthquake-resistant design of concrete structures and steel structures shall be conducted in accordance with the method shown from Paragraphs 3.3.1 to 3.3.5 depending on the kinds of structures.

3.2 Influence of earthquakes

For earthquake influence, the following earthquake forces shall be taken into consideration:

- i) Inertia force due to the dead weight of the structure.
- ii) Inertia force due to superimposed load.
- iii) Earth pressure during earthquake.
- iv) Hydrodynamic pressure during earthquake.

3.3 Calculating method for stresses and displacements

3.3.1 Bridges (reinforced concrete bridge piers and abutments)

i) General

Seismic design calculations for reinforced concrete bridge piers and abutments shall be made by examination of ductility in addition to either one of the examination methods for yield strength, which is the most appropriate, shown in Paragraph a) below depending upon their structure and size.

a) Methods of examination for yield strength

(1) Seismic coefficient method.

(2) Modified seismic coefficient method.

(3) Dynamic response analysis.

b) Examination of ductility

ii) Seismic coefficient method

Each section of members shall be determined in such a manner that the stress of a member on which earthquake forces prescribed in Paragraph 3.2 are being applied will not exceed the relevant allowable stress. The design seismic coefficient to be used for the seismic coefficient method shall conform to Paragraph 1.3.2.

iii) Modified seismic coefficient method

Each section of members shall be determined in such a manner that the stress of member on which earthquake forces prescribed in Paragraph 3.2 are being applied will not exceed the relevant allowable stress. The design seismic coefficient to be used for the seismic coefficient method shall conform to Paragraph 1.3.3.

iv) Dynamic response analysis

Dynamic response analysis shall be carried out upon establishing an appropriate mathematical model for the structure concerned. Earthquake ground motions to be used for dynamic response analysis shall conform to Paragraph 4.3.5 of Part I and Paragraph 1.3.5 of Part II. Sections shall be determined in such a manner that the stress of member obtained from the dynamic response analysis will not exceed the allowable stress.

v) Safety examination considering the ductility

If stress is examined by either seismic coefficient method, the modified seismic coefficient method or dynamic response analysis, the safety shall be examined by considering the ductility, as a rule.

3.3.2 Bridges (steel bridge piers)

i) General

Earthquake-resistant designs for steel bridge pier shall be made, depending upon the structural characteristics of the pier, by any one or combination of the following methods.

- 1) Seismic coefficient method
- 2) Modified seismic coefficient method
- 3) Dynamic response analysis

ii) Method of earthquake-resistant calculations.

Method of earthquake-resistant calculations for steel bridge pier by means of seismic coefficient method, modified seismic coefficient method or dynamic response analysis shall conform to Paragraph 3.3.1 ii), iii) or iv). As a rule, ultimate conditions shall conform to Paragraph 7.2.3 of Part I.

3.3.3 Concrete dams (concrete gravity dams, hollow gravity dams and arch dams)

i) General

Earthquake-resistant designs for concrete dams shall be principally made by the seismic coefficient method.

ii) Seismic coefficient method

a) Basic design conditions

Basic conditions for seismic design calculations shall be principally determined by using the results of investigations and tests and by considering the results of previous research.

b) Earthquake-resistant design

Earthquake-resistant design for dams shall be made by considering the influence of earthquake to assure the safety for dams. Seismic loads for the seismic coefficient method shall include (1) inertia force during earthquake, (2) hydrodynamic during earthquake, and (3) influence of surface water waves during earthquake, depending upon the actual conditions of dams and dam sites. Dynamic mud pressure is generally not taken into consideration.

iii) Dynamic response analysis

When performing dynamic response analysis by considering the local effect, the basic design conditions shall conform to Paragraph 3.3.3 ii) and the earthquake ground motion shall conform to Paragraph 4.3.5 of Part I.

3.3.4 Tanks

i) General

Earthquake-resistant design for tanks shall be made for both the states when sloshing of the liquid in the tank occurs and the state when sloshing does not occur to check its safety.

ii) Calculating method for stresses and displacements

In the case when the liquid contained in the tank does not develop sloshing earthquake-resistant calculations for tanks shall be made by the seismic coefficient method in consideration of inertia force, earth pressure during earthquake and hydrodynamic pressure during earthquake acting to the structure.

iii) Influence of sloshing of liquid

Tank structure and its strength shall be determined to provide the safety against increased pressure and impact pressure acting to the structure as a result of sloshing of the liquid, and the safety of structure shall be checked against sliding, overturning, bearing capacity of ground and so forth.

3.3.5 Others

i) Retaining walls

Examination of earthquake resistance of retaining walls shall be made in accordance with Paragraph 3.3.1.

ii) Gates

Examination of earthquake resistance of supports for gates shall be made in accordance with Paragraph 3.3.1.

4. Method of Earthquake-Resistant Design for Earth Structures

4.1 Influence of earthquake

As influence of earthquake upon the earth structures, the inertia force due to dead weight of earth structure and the influence of pore water pressure shall be considered.

4.2 Method of stability calculations

4.2.1 General

Safety of earth structure during earthquake shall be confirmed by stability calculations considering the influence of pore water pressure. However, items for which the safety was empirically confirmed by conventional structural requirements may be neglected.

4.2.2 Fill-type structures

i) General

Earthquake-resistant design calculations for fill-type structures shall be principally made by the seismic coefficient method.

ii) Seismic coefficient method

In the safety examination for a fill-type structure, sections shall be determined in such a manner that the stability of both embankment and foundation can be assured by means of stability calculations considering the influence of earthquake.

The design seismic coefficient shall be determined in conformity with Paragraph 4.3.2 of Part I in response to actual conditions of earth structure and construction site.

iii) Dynamic response analysis

For large-scale fill dams and for earth structures for which local effects are to be taken into consideration, it is desired to determine the earthquake ground motion in accordance with Paragraph 4.3.5 of Part I and to perform dynamic response analysis considering the characteristics of the materials.

4.2.3 Artificial island

When designing an artificial island mainly using earth material in water, stability calculations using the seismic coefficient method considering the earthquake force shall be performed.

4.2.4 Artificially developed ground

Artificially developed ground shall be, if necessary, examined for the following items to improve earthquake-resisting ability:

- i) Stability of filled slope
- ii) Stability of cut surface
- iii) Stability of artificially developed ground
- iv) Others

4.2.5 Cut slope

The stability of cut slope during earthquake shall be reviewed and, if necessary, its earthquake-resisting ability shall be improved.

4.3 Ground improvement

If an increase in earthquake-resistance of ground is necessary, the required strength shall be secured by using earthquake improvement method.

4.4 Degree of safety

The degree of safety of earth structures during earthquake shall be judged from a comprehensive viewpoint by considering the design calculation method, design seismic coefficient and various design constants employed.

5. Method of Earthquake-Resistant Design for Underground Structures

5.1 Influence of earthquake

As influence of earthquake, the following earthquake forces shall be considered:

- i) Displacement or deformation of ground during earthquake
- ii) Inertia force due to dead weight of structure
- iii) Earth pressure during earthquake
- iv) Hydrodynamic pressure during earthquake

5.2 Stability of adjacent ground

In the earthquake-resistant design for underground structures, the stability of ground adjacent to the structures during earthquake shall be examined.

5.3 Calculating method for stresses and displacement

5.3.1 General

Earthquake-resistant calculations for underground structures shall be made by the seismic deformation method and the seismic coefficient method in conformity to the shape, size, weight and items of examination of the relevant structures.

5.3.2 Underground buried pipes

Earthquake-resistant calculations for underground pipes shall be made by the seismic deformation method.

5.3.3 Underwater tunnels and underground conduits

Earthquake-resistant calculations for underwater tunnels and underground conduits shall be made by using the seismic deformation method, but design for cross sections of structures and examination for stability of structure against sliding may be performed by using the seismic coefficient method.

5.3.4 Underground structures

Earthquake-resistant calculations for underground structures shall be performed as a rule by using the seismic coefficient method, but the seismic deformation method shall be used if virtual unit weight of the structure is smaller than the unit weight of adjacent earth.

5.4 Degree of safety

The degree of safety of earthquake resistance of underground structures shall be judged by considering all stresses and conditions of deformation, stability of ground adjacent to structure during earthquake, dynamic characteristics of structure, and earthquake-resistant calculation methods.

6. Evaluation of Safety of Earthquake Resistance of Existing Structure

6.1 Earthquake resistance evaluation system

Earthquake resistance of existing structures shall be evaluated in view of the engineering properties of structures and from a socio-economic viewpoint.

6.2 System for retrofitting

Structures requiring retrofitting shall be reinforced in conformity with earthquake-resistant design methods, as a rule.

7. Structural Details

7.1 Foundation

The structural details of the foundation shall be safe against stresses that occur during earthquakes and assure good workability during construction.

7.2 Substructure and measures for preventing bridge collapse

7.2.1 Reinforced concrete bridge piers and abutments

i) Anchoring of reinforcing bars

a) When anchoring longitudinal reinforcing bars of substructure into footing, special consideration shall be taken for providing sufficient anchoring effects of reinforcing bars and also for assuring connecting functions between substructure and footing.

b) Longitudinal reinforcing bars for the intermediate portion of the substructure shall be anchored by extending such bars up to the

portion where the stresses are small and, if necessary, it shall be reinforced by the transverse reinforcing bars.

ii) Splices of reinforcing bars

Lap joints of longitudinal reinforcing bars shall have prescribed length of lapping, and transverse reinforcing bars shall be placed to such lap joints to provide ductility against repetitive loading during earthquake.

iii) Reinforcement for independent column type bridge pier

a) Longitudinal reinforcing bars shall be so arranged that resisting force as uniform as possible can be obtained against bending moment during earthquake throughout the whole extent of the substructure.

b) Longitudinal reinforcing bars shall be reinforced with transverse bars (hoops and ties). Particularly for pier section near the connection to the footing where flexural yielding tends to occur first, such transverse bars shall be placed with a small spacing between them to provide the ductility required.

iv) Reinforcement for a rigid-framed bridge pier

a) Longitudinal reinforcing bars in the column section shall be tied with transverse reinforcing bars required for preventing the occurrence of shearing brittle failure prior to the flexural failure of the member. Particularly for the section near the end of the member, the transverse reinforcing bars shall be placed with a small spacing between them to provide the required ductility.

b) The steel ratio for tensile reinforcing bars for beam portion shall be so determined that the required flexural ductility will be given to such member. Longitudinal reinforcing bars (main bars) shall be tied with sufficient stirrups to prevent the precedence shear failure of the member. Particularly, the section near the end of member shall have stirrups with a small spacing between them to provide the required ductility.

c) The connecting portion for both the column and beam shall be so reinforced with bars that the resisting bending moment of column will become greater than that of beam, and also shall be reinforced with transverse bars.

v) Crest of bridge pier

a) The portion of the pier crest near the bridge seat shall be reinforced with reinforcing bars so that necessary shearing resistance will be provided against horizontal force during earthquake.

b) Movable supports shall have a stopper, and proper measures for preventing bridge collapse shall be provided by employing a connecting device between adjacent girders or by providing a prescribed distance between the end of the support to the edge of substructure.

7.2.2 Devices for preventing superstructure from falling

Movable supports shall have stoppers to prevent the superstructures from falling from the substructure, caused by the dislocation of the upper shoes of the supports from the lower shoes during strong earthquakes.

For the girder ends one of the following methods shall be employed. As well as the above mentioned consideration.

i) A method extending the length between the end of the support and the edge of the substructure in order to prevent the superstructures from falling from the substructure.

ii) A method connecting adjacent girders on the substructure to prevent the superstructures from falling from the substructure even if they become dislodged from the substructure.

7.3 Earth structures

The following considerations shall be taken into account for the earth structures:

i) Slope tamping

ii) Slope protection

iii) Drainage

iv) Filling near the structure

7.4 Underground structure

7.4.1 General

When making detail design for underground structures, the influence of structural details upon the whole structural system shall be examined, and the earthquake-resisting ability shall be taken into consideration not only for the parts but also for the whole structure. Particularly, for section where topography, geology or structure suddenly varies, the detail design shall be cautiously made since large displacement or structural deformation is expected during an earthquake.

7.4.2 Construction of joints

When providing joints for underground structure, the type and interval of such joints shall be examined and some precautions shall be taken to prevent their possible behavior as structural weak points during earthquake.

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要 旨

本資料は建設省の新耐震設計法(案)(昭和52年3月)のうちの、第1編(基本事項関係)および第2編(土木構造物関係)の本文を土木研究所資料第1185号にもとづき、漸定的に英語翻訳したものである。

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建設省土木研究所

地震防災部振動研究室 御中

茨城県筑波郡豊里町大字旭一番地

No.89

No. 89

配布先氏名

配布先住所

土木研究所資料第 1535 号 部

上記のとおり受領しました。

所 属 (住所)

氏 名

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