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Seismic design examples based on ISO 23469

Exemples de dimensionnement basés sur l'ISO 23469

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Contents

Page

Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 98, *Bases for design of structures*, sous-comité SC 3, *Loads, forces and other actions*.

Introduction

ISO 23469:2005 provides guidelines to be observed by experienced practicing engineers and code writers when specifying seismic actions in the design of geotechnical works. It might not be so easy for code writers and practitioners to utilize ISO 23469, because that it offers advanced philosophy and general framework of seismic design. The purpose of this Technical Report (TR) is to provide seismic design examples based on ISO 23469 for demonstrating how to utilize ISO 23469 in actual seismic designs to the code writers and the practitioners. The implementation of ISO 23469 will secure the rationality of seismic safety evaluation of the infrastructures in the world, and this TR aims at promoting the implementation.

ISO 23469 is essentially a guideline itself. Therefore, this TR should contain not explicit guidelines but design examples without using the term 'guideline'. Thus, this TR is expected to demonstrate the utilization of ISO 23469 by providing design examples with detailed explanation from the viewpoint of conformity with ISO 23469 for a kind of guidance rather than to provide the detailed recommendation of specific methodologies.

Through the development of this Technical Report, it is concluded that ISO 23469 has been and is going to be an essential and useful guideline of seismic design of geotechnical works for experienced practicing engineers and code writers.

Seismic design examples based on ISO 23469

1 Scope

This Technical Report provides seismic design examples for geotechnical works based on ISO 23469:2005 in order to demonstrate how to use this ISO standard. The design examples are intended to provide guidance to experienced practicing engineers and code writers. Geotechnical works include buried structures (e.g. buried tunnels, box culverts, pipelines, and underground storage facilities), foundations (e.g. shallow and deep foundations, and underground diaphragm walls), retaining walls (e.g. soil retaining and quay walls), pile-supported wharves and piers, earth structures (e.g. earth and rock fill dams and embankments), gravity dams, tanks, landfill and waste sites.

ISO 23469 addresses important issues for seismic actions for designing geotechnical works, including effects of site-specific response, ground displacement, soil-structure interaction and liquefaction, in a systematic manner within a consistent framework. This International Standard presents a full range of methods for the analysis of geotechnical works, ranging from simple to sophisticated, from which experienced practicing engineers can choose the most appropriate option for evaluating their performance. Therefore, this Technical Report includes well-chosen design examples that consider these important issues and covering in a balanced way the wide range of the methods of analysis and the types of model which can be used to evaluate seismic actions of geotechnical works.

2 Purpose and policy of collecting design examples

2.1 Purpose of collecting well-chosen examples

This Technical Report aims at collecting design examples that are basically conformable with ISO 23469. They are expected to be design examples dealing with important things need to be covered in ISO 23469 from the point of view of performance-based design approach. This TR should be well-balanced in included design examples;

- Focusing evaluation of reference earthquake ground motions with detailed description as a common issue.
- Having combination of simplified and detailed analyses.
- Based on simplified equivalent static analysis and detailed analysis for retaining walls, buried structures or earth structures.
- Focusing consideration of soil displacements for pile foundations and buried structures.
- Focusing evaluation of effects of liquefaction for retaining walls, earth structures, pile foundations.
- Focusing consideration of spatial variation in the ground motions for long bridges, buried structures, or dams.
- Based on site specific dynamic response by 1-D analysis.
- Based on detailed dynamic analysis by 2-D or 3-D analysis.

2.2 Concept and policy of choosing and composing

To realize the prescribed purpose of this TR, the basic concept of it is targeting to cover major distinguishing and important issues of IS23469 by all the design examples contained in this TR. Thus, the following points are another requirement for choosing and composing design examples.

— Design examples written with cares for readers in terms of conformity with requirement and recommendation in ISO 23469

— The TR should consist of several well-chosen design examples which cover the key issues of the ISO 23469 with well balance between them.

— The TR is anticipated to be well balanced among Japan, Northern America, and Europe.

— For description of manuscript, each design example is requested to

— Be cared in terms of conformity with requirement and recommendation in ISO 23469

— Have stress on methodology recommended by WG

— Be within 20 pages for a complete example and 8 pages for a sub-example basically

2.3 Development and result

After discussing the policy of collecting and choosing design examples, WG10 also had developed an expected table of contents from arguments through three Working Group meetings held in 2006 and correspondence with consideration of design practice situation in member's countries and regions. After registration of NP12825 in the end of this year, the WG10 repeatedly requested all the WG members and participants of the meetings to provide possible design examples for this Technical Report. The table of contents of the TR of design examples was almost fixed and the drafting persons for the examples were assigned in 2008 through more four WG meetings; eight examples for the first stage of specifying seismic action were expected to be prepared by three persons from Japan and one from Turkey and 28 examples for the second were hopefully to be prepared by 17 persons from Japan, three from USA, one from Greece, and one from Italy.

This NP was officially approved with the submission, in 2008, of the first Working Draft of TR12825 containing six examples, but the NWI was subsequently re-numbered as 12930 from an administrative reason. The third and final Working Draft of TR12930, which was developed through another three meetings in two years for waiting design examples to be offered from countries other than Japan was submitted to TC98/SC3 in the end of 2010 then accepted as a Draft Technical Report with a request of addition of description for a few points. The last two year period was mainly aimed at collecting examples from countries excepting Japan. Notwithstanding the total number of attendees in thirteen WG meetings is 87 and they came from Japan, USA, Greece, France, Poland, Canada, Turkey, Italy, South Africa, Germany, Morocco, Romania, and Russia (in order of total number of attendees), only prescribed persons were merely expected. Probably because that the preparing a manuscript is a tough job with few personal incentive; i.e. a completely volunteer work.

2.4 General conclusion of TR12930 obtained through its development

Eventually seven examples for the first stage and 15 examples for the second stage were successfully collected from thirteen persons consisting of eleven from Japan, one from USA, and one from Greece. The total number of the 22 well-chosen design examples can almost cover major distinguishing and important issues of IS23469 as targeting at the beginning. Through the process of preparing and editing the drafts, it was clarified that IS23469 is useful for evaluation, assessment and review in the seismic design. Furthermore, it was demonstrated that assessment for conformity with IS23469 in can be conducted in terms of provisional sentences according to Clause 3 of this TR. Thus, it is concluded that IS23469 has been and is going to be an essential and useful guideline of seismic design of geotechnical works for experienced practicing engineers and code writers.

2.5 Editors, authors and reviewers

This Technical Report has general remarks and 22 well-chosen design examples written in over 200 pages with 60 thousand words. Reviewing and editing all the manuscripts require tremendously hard works as well as the authors preparing them. Thus, the contributions of editors, authors and reviewers are shown here.

2.5.1 Editors

Prof. Shinichiro Mori, Ehime University, Japan, Convener of ISO/TC98/SC3/WG10

Prof. Kohji Ichii, Hiroshima University, Japan

The editors mainly reviewed and checked the conformity with ISO 23469 in all the manuscripts prepared by authors and added conformity codes corresponding sentences or paragraphs in their ends when necessary. The editors also revised hard-to-understand, confusing or complicated English expressions, written by some Japanese authors, by modifying the expressions and covering logical gaps.

2.5.2 Authors

Authors and Clause(s) or Subclause(s) in their charge are shown as follows:

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Author of Annex A, Member of ISO/TC98/SC3/WG10

2.5.3 Reviewers

The reviewers were basically the members of TC98/SC3/WG10 including 16 members for development of IS23469 from 12 member bodies/countries and additional 24 members from 7 member bodies/countries. They also provided great contributions throughout the development as well. The members of TC98/SC3 were also potentially to be reviewers. The mirror committee of WG10 in Japan with 34 members had been also reviewing as well as preparing the activity prior to each step in this work item.

3 Assessment for conformity with ISO 23469

Assessment of a design with regard to conformity with ISO23489 is made based on the conformity with each provisional sentence in this ISO standard.

In the main text of each sub-sub-clause for a design example, a sentence or a paragraph corresponding to a specific requirement which is provided in a sentence using “shall” in ISO 23469, shall be ended with a corresponding “code” written in parentheses for being checked in terms of conformity with provisional sentences in ISO 23469. A specific recommendation is provided in a sentence using “should” as well. Therefore, this Technical Report adopts a code description in which a code of abbreviation consists of numerals and an alphabet. In the code, consecutive numerals stand for clause, sub-clause, and sub-sub-clause, respectively in principle. An alphabet in capital letter stands for “shall” and that in lower-case letter stands for “should” in appearing order. For examples, the third sentence using “shall” in the sub-sub-clause 6.2.1 in ISO 23469 corresponds to “(621C)” and the first sentence using “should” in sub-sub-clause 8.1.4 corresponds to “(814a).” Exceptionally, zero is placed in the place for sub-clause like “(520A).”

Provisional sentences using “shall” or “should” are extracted from the main body of ISO 23469 with partial reduction if acceptable and shown in appearing order as shown in Annex A.

4 First stage of specifying seismic actions - Determination of site-specific earthquake ground motions demonstrated by design examples

For designing geotechnical works, reference earthquake motions are needed to specify as seismic actions at the first stage. In order to evaluate the reference earthquake ground motions, the motions at the firm ground are evaluated by a seismic hazard analysis based on probabilistic or deterministic approach. As the reference earthquake motions, earthquake motions at the surface of the free field or/and at a certain depth within the subsoil can be evaluated by site response analyses.

The probabilistic approach is more appropriate for the evaluation of seismic actions at scale a nation or region. In general, the probabilistic approach in some case could lead to an underestimation of local seismic action comparing with the deterministic approach.(Grooso S. and Mourgeris M. 2009a and 2009b)

Probabilistic seismic hazard analysis as probabilistic approach shall be used to determine earthquake ground motion for evaluating serviceability. The earthquake ground motion for evaluating safety shall be determined by either probabilistic or deterministic analysis is used to determine. The seismic hazard analysis should capture the characteristics of the ground motion based on the earthquake magnitude, fault type and distance with or without site parameters. More detail seismic hazard analysis should capture the near source effects and directivity effects and should be based on seismic source parameters, including the geometry of seismic faults, propagating of the fault rapture over the seismic fault, attenuation of earthquake motions from the seismic fault, and deep basin effects. The uncertainties in the model parameters of the seismic fault, attenuation relations, and deep basin effects shall be considered appropriately (621A, 621B, 621C 622a, 622b, 622c).

The seismic hazard analysis method includes empirical, semi-empirical, and theoretical method, and a combination of these methods, and shall be chosen, consistent with the degree of refinement required for analysis of the geotechnical works, based on the importance of structures, and the available information on seismic faults and deep basin structures in the vicinity of a site. Results of seismic hazard analysis, ie NEHAP in USA etc. may be available over a country or region from relevant authorities giving the representative values of earthquake ground motion for use in the subsequent analysis. (622A)

Some examples to evaluate seismic hazard analyses in term of probabilistic and deterministic approach are described in Subclause 4.2. Furthermore, some examples for site response analysis are described in Subclause 4.3.

4.1 General

4.1.1 Methodology for empirical method in deterministic approach and examples

The simplest method among empirical methods is to combine an attenuation equation of an intensity of earthquake motions at firm ground with the amplification characteristics of a site of interest. As for the indices of the intensities of the earthquake motions for design, such as maximum acceleration, maximum velocity and amplitudes of response spectra, the attenuation equations of the indices are obtained by regression analyses using earthquake motion records in terms of the magnitude of earthquakes and the hypocentral distance. Using the attenuation equations, a designer can estimate the indices of earthquake ground motions during scenario earthquakes. Recent accumulation of observed earthquake motion records led to upgraded attenuation equations that can consider the regional peculiarity or the mechanism of earthquake source. This methodology has advantages: It is easy to evaluate the characteristics of earthquake ground motion. It has been used for a long time for probabilistic hazard analysis corresponding estimated values to mean values of observed motions. (622a)

An equation developed according to a theoretical formula of earthquake ground motion is adopted as an attenuation equation. A source spectrum, S(T) consists of the terms representing both the effect of fault scale as the magnitude M and the influence of rock stiffness in the source region, where T is the object frequency.

$$S(T) = a(T)M + c(T) \tag{1}$$

The term representing the propagation of earthquake motion waves consists that of the non-elasticity attenuation and that of geometrical damping as the following equation. The hypocentral distance X represents the minimum distance from fault and the object site. Therefore, the accuracy of the focal location and area is required for more accurate estimate in focal region. (622a)

$$P(T) = -\log X - b(T)X \tag{2}$$

Adding the term associated with the relative amplification to the average ground, the final form of the attenuation equation becomes as follows.

$$\log F(T) = S(T) + P(T) + G(T) = a(T)M + c(T) - \log X - b(T)X + d(T) \quad (3)$$

For example, attenuation equations of acceleration response spectra have been developed using earthquake ground motion records of inland earthquakes observed from 1978 to 2003. Estimated acceleration response spectra as per the attenuation equations are shown in Figure 1. The equations can clearly express the difference of amplification characteristics depending on the types of ground.

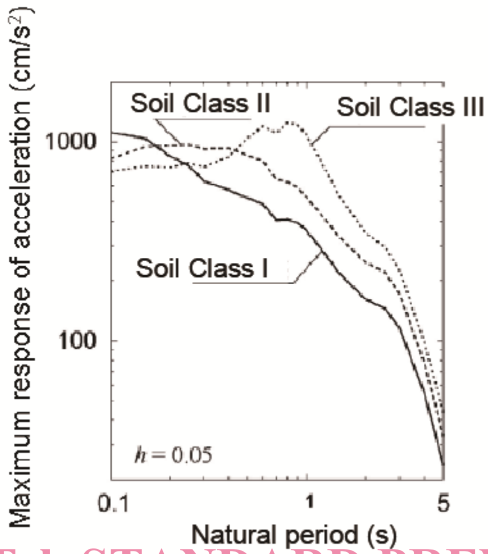

Figure 1 — Acceleration response spectrum obtained by attenuation equation

Further as variables of the fault parameters such as hypocenter depth and the earthquake type, etc. might be added to this equation. The term of the geometrical damping might be assumed 0.5logX instead of logX by considering for propagating the surface wave. The form of the attenuation equation is assumed including coefficients such as a, b, c, and d. The coefficients are evaluated by the regression analysis based on the observed seismic records. The attenuation equation has the characteristics to be applicable to evaluate the motion on the specific ground which is the same ground with that observed seismic records by used of the regression analysis. If the ground is a engineering bedrock, the characteristic value at ground surface is obtained by magnifying the amplification coefficient to the value at the engineering bedrock. (622a)

4.1.2 Examples

First of all, detail of fault plane according to fault zone between Ohoita plane and Yufuin is modeled for two planes with east part and west part based on the evaluation of the Headquarters for Earthquake Research Promotion. The fault length in east part is set to be 27 km, and the length in west part is set to be 14 km as shown in Fig.2. Moreover, this fault zone has been evaluated as the normal fault whose plane inclines the north side. The dip angle around ground surface has been known as 70 degrees based on survey. The dip angle of the fault plane was assumed to be 60 degrees considering tendency to grow the dip angle of the normal fault in the surface ground. Based on the data by the Japan Meteorological Agency, the upper and lower bound depth among fault parameters in the east part were set to 2km, 15km respectively. Those in the west part were set to 3km, 15km respectively. Therefore, the fault width in the east part and the west becomes 15km and 13km respectively. Next, fault area S required for determining the magnitude becomes 5.9×102 km2 by use of the specified fault length and width in the east and west part as the mentioned above. Based on the experimental relationship between the magnitude and the investigated fault plane in the past earthquakes, the magnitude M was set as 6.8. Minimum distance from fault plane to the design object site is set as 2km under the assumption that the value is the same with the upper bound depth of the fault plane. (622a)

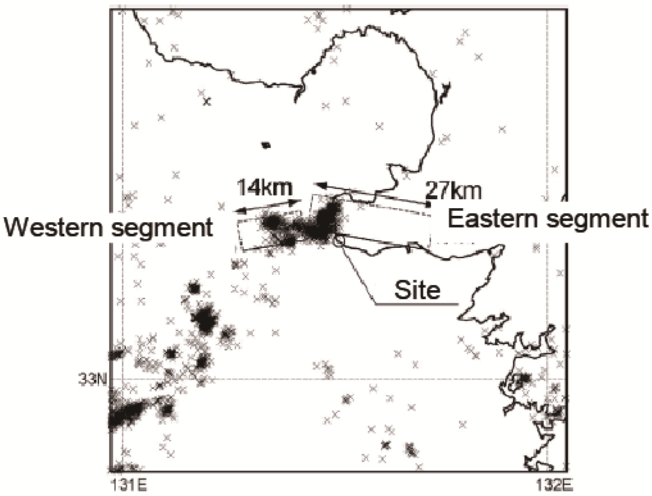

Figure 2 — Fault model at the object site

Acceleration response spectrum among the variable of earthquake ground motion is chosen to determine the seismic action on the geotechnical works. The design acceleration response spectrum at the site whose ground type is characterized as I kind is evaluated by use of the attenuation equation as mentioned above in 4.1.1. The spectrum is shown in Figure 3. As for the applicable lime of the empirical method, it has a difficulty to take into account of the investigated site-specific characteristics in terms of the fault parameters and the ground condition directly. Moreover, it can not apply to evaluate an extremely large-scale earthquake that the strong motion record has not been obtained. (623B)

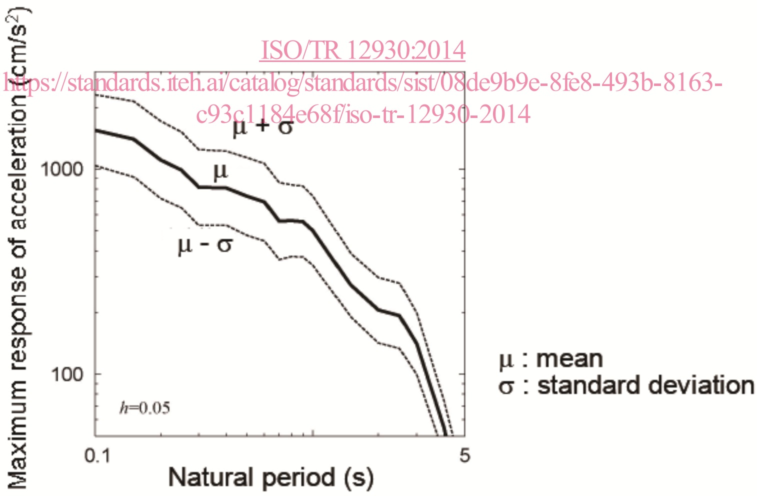

Figure 3 — Estimated acceleration response spectrum for M with 6.8, and X with 2km

4.2 Site-specific seismic hazard analysis evaluation

Site-specific seismic hazard analysis evaluation is conducted either by probabilistic approaches or deterministic ones. In general,