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Bases for design of structures — Seismic actions for designing geotechnical works

Bases du calcul des constructions — Actions sismiques pour le calcul des ouvrages géotechniques

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 23469 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions* in collaboration with ISSMGE/TC4 and CEN/TC205/SC8.

Introduction

This International Standard provides guidelines to be observed by experienced practising engineers and code writers when specifying seismic actions in the design of geotechnical works. Geotechnical works are those comprised of soil or rock, including 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 rockfill dams and embankments), gravity dams, landfill and waste sites. The seismic actions described are compatible with ISO 2394.

The seismic performance of geotechnical works is significantly affected by ground displacement. In particular, soil-structure interaction and effects of liquefaction play major roles and pose difficult problems for engineers. This International Standard addresses these issues in a systematic manner within a consistent framework.

The seismic performance criteria for geotechnical works cover a wide range. If the consequences of failure are minor and the geotechnical works are easily repairable, their failure or collapse may be acceptable and explicit seismic design may not be required. However, geotechnical works that are an essential part of a facility handling hazardous materials or a post-earthquake emergency facility shall maintain full operational capacity during and after an earthquake. This International Standard presents a full range of methods for the analysis of geotechnical works, ranging from simple to sophisticated, from which experienced practising engineers can choose the most appropriate one for evaluating the performance of a geotechnical work.

Bases for design of structures — Seismic actions for designing geotechnical works

1 Scope

This International Standard provides guidelines for specifying seismic actions for designing geotechnical works, including 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 rockfill dams and embankments), gravity dams, landfill and waste sites.

NOTE The guidelines provided in this International Standard are general enough to be applicable for both new and existing geotechnical works. However, for use in practice, procedures more specific to existing geotechnical works can be needed, such as those described for existing structures in ISO 13822.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2394:1998, *General principles on reliability for structures*

ISO 3010:2001, *Bases for design of structures — Seismic actions on structures*

ISO 13822:2001, *Bases for design of structures — Assessment of existing structures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2394, ISO 3010 and ISO 13822 and the following apply.

3.1
array observation
simultaneous recording of earthquake ground motions and/or microtremors by an array of seismometers

3.2
basin effects
effects on earthquake ground motions caused by the presence of a basin-like geometrical boundary beneath the site

NOTE Deep basin effects are defined as effects due to the geometry of the interface between the upper crustal rock and the overlying firm ground or soil deposits. Shallow basin effects are defined as effects due to the geometry of the interface between the firm ground (or shallow upper crustal rock) and the local soil deposits and may be treated as part of the local site response.

3.3
coherency function
function describing a degree of correlation between two time histories

3.4
crest
top of a geotechnical structure, typically defined for embankments and dams

3.5
culvert
tunnel-like structure constructed typically in embankments or ground forming a passage or allowing drainage under a road or railroad

3.6
damping
mechanism that dissipates energy of motion

3.7
deep foundation
foundation having a large depth to width ratio, which transfers applied loads to deep soil deposits

EXAMPLES Pile foundation, sheet pile foundation, cofferdam foundation, caisson foundation.

3.8
design working life
duration of the period for which a structure or a structural element is designed to perform as intended with expected maintenance, but without major repair being necessary

3.9
deterministic seismic hazard analysis
seismic hazard analysis based on the selection of individual earthquake scenarios

3.10
dynamic analysis
analysis for computing the dynamic response of a system based on the equations of motion

3.11
earth pressure
pressure from soil on a wall or an embedded portion of a structure

3.12
earth structure
geotechnical work consisting primarily of soil or rock

EXAMPLES Earth and rockfill dams, and embankments.

3.13
earthquake ground motions
transient motions of the ground caused by earthquakes, including those at the ground surface, within the local soil deposit, and at the interface between the firm ground and the local soil deposit

3.14
effective stress analysis
analysis with consideration of pore pressure changes

3.15
equivalent linear model
linear model incorporating elastic shear moduli and damping factors that are compatible, at various strain amplitudes, with the non-linear stress-strain relationship under cyclic loading

3.16
equivalent static analysis
static analysis that approximates the dynamic response of the system

3.17
excess pore water pressure
change of water pressure in the soil pores with respect to those at a reference state

3.18
failure mode
pattern of failure defined by distinctive features of the deformed shape after failure

3.19
fault displacement
permanent tectonic ground displacement associated with fault dislocation

3.20
firm ground
soft rock or stiff soil layer

3.21
free field
ground not subject to the effect of geotechnical works or structures

3.22
geotechnical characterization
specification of material and geometrical parameters of soil or rock

3.23
geotechnical hazard
hazard associated with geotechnical phenomena, including ground failure and subsidence

3.24
geotechnical work
work that includes soil or rock as primary components with or without structural parts made of concrete, steel, or other materials

EXAMPLES 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 rockfill dams and embankments) gravity dams, landfill and waste sites.

3.25
ground failure
mass movement of soil including liquefaction-induced ground deformations (settlement, lateral spreading, flow failure) and non-liquefaction-induced ground deformations (seismic compaction, permanent deformations and landslides)

3.26
horizontal wave propagation effect
effect causing spatial variation of ground motion in the horizontal direction due to the finite speed of wave propagation

3.27
hydro-dynamic pressure
transient pressure exerted by a fluid on a structure in a system subject to dynamic motion

3.28
importance of a structure or facility
degree of possible consequences of failure of a structure or facility caused by a reference earthquake motion

3.29
inertial interaction
part of soil-structure interaction arising from the inertia forces acting on the structure

3.30
kinematic interaction
part of soil-structure interaction arising from the deformation of the soil relative to that of the structure

3.31
liquefaction
large drop in soil shear strength and/or stiffness caused by an increase in pore water pressure that may cause significant reduction in the shear resistance of geotechnical works and ground or may induce large ground displacement

3.32
liquefaction potential
susceptibility of the soil to the onset of liquefaction under a reference earthquake motion

3.33
local site effect
effect of the local geological configuration on earthquake ground motions

3.34
lumped mass
mass assigned at discrete points of a model representing a continuum

3.35
microtremors
small amplitude vibration of the ground generated by either human activities or natural phenomena

3.36
overstrength
strength of a structure or structural element, typically specified by the ratio of actual strength to nominal design strength

3.37
performance criteria
set of conditions for specifying the response of a geotechnical work to meet the expected state defined by engineering parameters, such as acceptable displacements, strains or stresses, that characterize the performance objectives of design

3.38
performance objective
expression of the expected performance of a facility in order to fulfil its purposes and functions

3.39
phase velocity
velocity at which a monochromatic seismic wave travels along a surface

3.40
pipeline
long tube or a network of tubing used for the transportation of fluid, gas, or solid mixed with fluid or gas

3.41
probabilistic seismic hazard analysis
seismic hazard analysis considering the probability of occurrence of different levels of ground shaking at a site during the reference period

3.42
reference earthquake motions
earthquake motions specified for evaluating seismic performance of a geotechnical work (seismic actions are specified, in a subsequent stage, based on the reference earthquake motions)

3.43
residual displacement
displacement present after the earthquake, typically due to non-reversible deformation or sliding

3.44
residual response
response of a system remaining after the earthquake

3.45
residual strength
shear strength of the soil after failure including liquefaction

3.46
retaining wall
wall supporting backfill soil, embankment soil or a cut slope

3.47
scenario earthquake
earthquake that is specified for determining earthquake ground motions typically by deterministic seismic hazard analysis

3.48
seismic actions
loads, deformations, or other actions imposed upon models of structures and geotechnical works during and after an earthquake

3.49
seismic coefficient
coefficient that represents the dynamic forces on the structure by static forces as a fraction of the weight of the structure

3.50
seismic coefficient approach
static approach in which the dynamic response of soil-structure system is evaluated by an inertia force distributed over the system

3.51
seismic hazard analysis
analysis for determining earthquake ground motions on the basis of the regional seismic activity and characteristics of source and wave propagation

3.52
seismic performance
response of a structure or geotechnical work during and after an earthquake compared to specified performance criteria

3.53
shallow foundation
foundation having a small depth to width ratio, which is supported directly by soil at or near the ground surface without using piles or other structural elements

EXAMPLES Spread foundation, footing foundation.

3.54
site amplification factor
factor describing the increase in amplitude of earthquake motions in local soil deposit, defined as the ratio of the peak ground surface motion to the peak earthquake motion input to the local soil deposit

3.55
site classification
differentiation of sites based on soil profile and other parameters

3.56
site response analysis
analysis of the response of a site to earthquake ground motion taking into account the local soil deposits

3.57
site-specific
characterization of conditions specific to a site

3.58
sliding soil mass
portion of a geotechnical work, typically defined as that part of the soil or rock expected to slide along a failure surface

3.59
soil-structure interaction
effect by which soil and adjacent structures mutually affect their overall response

3.60
spatial variation of ground motion
lateral variations of ground motion over a given area

3.61
stress resultants
bending moments, shear forces and axial forces in a structure

3.62
subgrade reaction
resulting stresses on a surface in the ground (typically a surface of a foundation or retaining wall) due to external loading

3.63
superstructure
that part of a structure constructed above the ground surface

NOTE This definition is adopted for the purpose of this International Standard (for further discussion, see H.2).

3.64
surface wave
seismic wave that travels along the ground surface and whose amplitude decreases exponentially in the half space with depth

3.65
threshold limit
limit beyond which a structure exhibits an irreversible response

EXAMPLES Sliding limit, elastic limit.

3.66
total stress analysis
analysis without explicit consideration of pore pressure changes

EXAMPLES Linear analysis, equivalent linear analysis, non-linear total stress analysis.

4 Symbols and abbreviated terms

CPT cone penetration test

FE finite element

LDPT large diameter penetration test; detailed specifications are available for Becker penetration test

PSHA probabilistic seismic hazard analysis

SPT standard penetration test

1-D one-dimensional

2-D two-dimensional

3-D three-dimensional

5 Principles and procedure

5.1 Principles

5.1.1 Purposes and functions

In designing geotechnical works, the purposes and functions shall be defined in accordance with broad categories of use such as commercial, public and emergency use.

5.1.2 Performance objectives for seismic design

Performance objectives for seismic design of geotechnical works should generally be specified on the following basis, depending on the expected functions during and after an earthquake:

— serviceability during and after an earthquake: minor impact to social and industrial activities, the geotechnical works may experience acceptable residual displacement, with function unimpaired and operations maintained or economically recoverable after temporary disruption;

— safety during and after an earthquake: human casualties and damage to property shall be minimized, geotechnical works that are an essential part of a facility handling hazardous materials or a post-earthquake emergency facility shall maintain full operational capacity, and geotechnical works shall not collapse.

The performance objectives should also reflect the possible consequences of failure.

Seismic actions on geotechnical works shall be specified, which are compatible with the performance objectives.

NOTE The collapse of a certain type of geotechnical works such as pipelines might not necessarily cause human casualties if fail-safe measures such as shutdown valves are provided. In this design situation, the collapse can be allowed.

5.1.3 Reference earthquake motions

For each performance objective described in 5.1.2, reference earthquake motions shall be specified for evaluating seismic performance of the geotechnical works as follows:

- for serviceability during or after an earthquake: earthquake ground motions that have a reasonable probability of occurrence during the design working life;
- for safety during or after an earthquake: earthquake ground motions associated with rare events that may involve very strong ground shaking at the site.

NOTE Annex D describes in more detail the concepts of reference earthquake motions and their applicability in different circumstances.

5.1.4 Performance criteria and limit states

Performance criteria shall generally be specified by engineering parameters that characterize the response of geotechnical works to the reference earthquake motions. These engineering parameters shall be specified considering the design working life.

The engineering parameters depend on the process for verifying that the performance criteria have been met. The importance of the facility differentiates the level of performance objectives. These issues shall be taken into account in the formulation of the performance criteria.

The seismic performance of geotechnical works can be described with reference to a specified set of limit states. These limit states are

- serviceability limit state during or after an earthquake: a limit state for satisfying serviceability during and after an earthquake, and defined by an acceptable state of displacement, deformation, or stress, and

- ultimate limit state during or after an earthquake: a limit state for satisfying safety requirements during and after an earthquake, and defined by a state with appropriate margin against collapse.

More than one serviceability limit state may be introduced. For example, if one serviceability limit state is defined as the state with no residual displacements, another serviceability limit state may be defined as the state with an acceptable residual displacement and operation of the facility recoverable after minimum disruption with reasonable cost for repair.

One may evaluate only one limit state, provided that the seismic performance objectives specified by other limit states can be satisfied through the evaluation of the one limit state.

NOTE 1 In conventional seismic design of geotechnical works based on the equivalent static method, a seismic coefficient has been used to achieve both serviceability and safety during and after an earthquake. However, as a result of case histories of seismic damage during the 1990s, limitations of conventional seismic design have been recognized widely. The approach described in this International Standard can be used to overcome these limitations.

NOTE 2 The conventional approach in which margin to a specified limit state is specified in terms of the load factor is described in ISO 3010.

5.1.5 Specific issues related to geotechnical works

Seismic actions on geotechnical works shall be specified taking the following factors into account:

- seismic response that involves non-linear behaviour of soil and structural materials;
- appropriate mode of and path to failure so that damage can be readily repaired and local failure of a geotechnical work does not immediately lead to global failure;
- performance criteria in terms of residual displacements, deformations, strains and stability;

— soil-structure interaction, including fluid-structure interaction, that is often simplified as actions on a local system within a global system.

These factors can be sensitive to the details of earthquake ground motions. Improved knowledge shall be used through the procedures described in Clause 6 for evaluating earthquake ground motions in designing geotechnical works.

5.2 Procedure for determining seismic actions

Seismic actions on geotechnical works shall be determined as follows:

1st stage: characterize

— the firm ground (or bedrock) motion at the site through seismic hazard analysis;

— the fault displacements if applicable;

— the free field earthquake motions by site response analysis; and

— the potential for earthquake-induced phenomena such as ground failure and other geotechnical hazards, including liquefaction;

2nd stage: specify, based on the results of the 1st stage, the seismic actions due to

— the earthquake ground motions;

— the ground displacements due to fault movement; and

— ground failure and other geotechnical hazards, taking due account of the methods of analysis to be used for modelling the geotechnical works.

Clauses 7 to 9 describe seismic actions on various models of analysis.

NOTE Annex A presents the primary issues for specifying seismic actions. Seismic actions depend on the model of analysis.

6 Evaluation of earthquake ground motions, ground failure, and fault displacements

6.1 General

6.1.1 Earthquake ground motions and fault displacements

In the 1st stage described in 5.2, earthquake ground motions defined in 5.1.3 and fault displacements shall be evaluated for use as basic variables in subsequent analyses (i.e. in the 2nd stage described in 5.2) for specifying seismic actions on geotechnical works.

6.1.2 Ground failure and other geotechnical hazards

Liquefaction potential shall also be evaluated in the 1st stage described in 5.2 (see Annex G). If liquefaction is judged to occur, the effects of liquefaction shall be incorporated in the 2nd stage described in 5.2 either as seismic actions or effects on the model of the soil-structure system, depending on the models and methods of analysis used. Ground displacements due to liquefaction, including induced ground displacement, shall be evaluated in the 1st stage described in 5.2 as basic variables to be used in the subsequent analysis for specifying seismic actions.