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Bases for design of structures — General principles on seismically isolated structures

Bases du calcul des constructions — Principes généraux des constructions munies d'isolateurs parasismiques

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Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 98, Subcommittee SC 2, *Reliability of structures*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Seismically isolated structures have been constructed since the 1970s. Their reduction of the seismic action has been demonstrated in many earthquakes and the usefulness of seismic isolation has been widely recognized. It is difficult for other seismic mitigation strategies to reduce the acceleration acting on the structure as significantly as seismic isolation. With this feature, the seismic force on the structure as well as foundation is dramatically reduced and the vibration perception of occupants is greatly minimized. Seismic isolation also reduces the vibrations and disruption of building contents, such as furniture and equipment. Since the structure can be restored to the original state without damage, it can remain operational during and immediately after the earthquake without essential interruption in operation. Seismic isolation technique also expands architectural design freedom by reducing seismic force and controlling deformation of superstructure. It also minimizes rate of losses, number of injures and improves of peace of mind of occupants against earthquakes. To mitigate future earthquake disasters, widespread of adoption of seismic isolation is advisable.

The structural design process should ensure that the capacity of structural components exceeds the demands imposed by the design load in order to provide both safety and serviceability. In most cases, the load effect is treated as static. In recent years, however, when a structure with seismic isolation devices is designed for earthquake ground motion, the dynamic performance of the entire structure is evaluated. Therefore, it is desirable to specify the principles of dynamic seismic design of seismically isolated structures. In this document, the items to be considered in the design, and design procedures are described. Then the standard structural calculation procedure is shown, and the methods for construction management and maintenance unique to the seismically isolated structure are also described.

Bases for design of structures — General principles on seismically isolated structures

1 Scope

This document specifies the principles regarding the design of seismically isolated structures under earthquake effects.

This document also describes the principles of construction management and maintenance, since proper construction management and maintenance are important for realizing high quality seismic isolation structures.

This document is not applicable to bridges and LNG tanks, although some of the principles can be referred to for the seismic isolation of those structures.

This document is not applicable to seismic isolation structures that reduce the vertical response to earthquake ground motions, since this document mainly specifies seismic isolation structures that attenuate the horizontal response to horizontal earthquake ground motions.

This document is not a legally binding and enforceable code. It can be viewed as a source document that is utilized in the development of codes of practice by the competent authority responsible for issuing structural design regulations.

NOTE This document has been prepared mainly for the seismically isolated structures which have the seismic isolation interface applied between a superstructure and a substructure to reduce the effect of the earthquake ground motion onto the superstructure. In most cases, the substructure refers to the foundation of the structure. However, the substructure in this document consists of a structural system below the isolation interface that has been designed with sufficient rigidity and strength. Examples include locating the isolation interface in a mid-storey of the building or above the bridge piers (see Annex E).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 3010:2017, *Bases for design of structures — Seismic actions on structures*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms related to structure

3.1.1
superstructure
portion of the structure above the seismic isolation interface

3.1.2
seismic isolation interface
space where seismic isolation devices are installed between superstructure and substructure

3.1.3
substructure
portion of the structure beneath the seismic isolation interface

3.1.4
foundation
lowest part of the substructure such as spread footing, pile foundation, mat foundation, and moat walls

3.2 Terms related to isolation system

3.2.1
seismic isolation system
collection of seismic isolation devices arranged over the seismic isolation interface

3.2.2
isolator
device installed between a substructure and a superstructure that supports the weight of the superstructure, provides lateral mainly and some vertical flexibility, and can have a capacity to dissipate energy and re-centring capability

Note 1 to entry: See Annex A.

3.2.3
hysteretic damper
device having the capacity to dissipate energy by the relationship between resistance force and deformation

Note 1 to entry: See Annex A.

3.2.4
fluid damper
device having the capacity to dissipate energy by the relationship between resistance force of fluid and velocity

Note 1 to entry: See Annex A.

3.2.5
isolation gap
horizontal or vertical space (clearance) between the structure and the moat wall, or the space between adjacent structures in which the structure is free to move sideways without contacting the surrounding structure

3.2.6
scratch plate
metal plate and probe recording the relative movement between a substructure and a superstructure by marking scratches

3.2.7
equipment in isolation interface
equipment connecting the superstructure and the substructure, such as piping and wiring

3.3 Terms related to structural design

3.3.1
design response spectrum
spectrum used for the design of seismically isolated structure as a function of the fundamental period of the structure

3.3.2
design earthquake ground motion
earthquake ground motion used for the design of seismically isolated structure in response history analysis

3.3.3
effective stiffness
secant stiffness obtained by dividing the peak force of isolation system or an isolation device by the corresponding displacement

3.3.4
effective damping
equivalent viscous damping corresponding to the energy dissipation of the isolation system or an isolation device

3.3.5
equivalent linear system
system to evaluate the maximum response of a seismically isolated structure based on the response spectrum using effective stiffness and effective damping of the isolation system

3.3.6
response spectrum analysis
calculation method to evaluate the maximum response of a seismically isolated structure under earthquake ground motions based on the response spectrum

3.3.7
response history analysis
calculation method to evaluate the time history response of a seismically isolated structure under earthquake ground motions

3.4 Terms related to maintenance and construction

3.4.1
warning signage
signboard to give notice the danger of the movement of the seismically isolated structure during an earthquake

3.4.2
type test
test to validate material properties and performance of isolation products

Note 1 to entry: See ISO 22762-1 for elastomeric bearings.

3.4.3
routine test
test for quality control of isolation products

Note 1 to entry: See ISO 22762-1 for elastomeric bearings.

3.4.4
base plate
steel plate which connects an isolator to the superstructure and the substructure with bolts

3.4.5
construction clearance
isolation gap considering the construction error which is generally wider than the design clearance

3.4.6
creep
permanent deformation induced by long-term compressive load on isolators, especially rubber bearings

3.4.7
design clearance
isolation gap decided by the SE in the design stage, where horizontal clearance is decided based on the maximum response displacement at an isolation interface and vertical clearance is decided considering creep deformation and short-term compressive deformation of isolators

3.4.8
inspection at completion
inspection conducted when the building construction is completed

3.4.9
inspection under construction
inspection conducted immediately after the isolation interface is constructed

4 Symbols and abbreviations

C_e effective damping coefficient of the isolation system

D_M design maximum displacement

F_i lateral force at *i*-th level of structure

h_d effective damping of the hysteretic dampers

h_v effective damping of the fluid dampers

K_e effective stiffness of the isolation system

M mass of the superstructure

Q_s seismic design base shear of superstructure

S_a design acceleration response spectrum

T_e effective period of the structure or isolation system

V_e effective velocity at the design maximum displacement, D_M

ΔW total energy dissipated in the hysteretic dampers during a full cycle of response at the design maximum displacement, D_M

W total potential energy in the isolation system at the design maximum displacement, D_M

β_d modification factor of the effective damping of the hysteretic dampers

β_v modification factor of the effective damping of the fluid dampers

β_s modification factor of the seismic design base shear of superstructure

$k_{F,i}$ seismic force distribution factor over the height of the superstructure

CM construction manager in charge of the construction of isolation interface

CS construction supervisor responsible for the total quality of the whole building

GM general manager at a construction site

MFR manufacturer of the SI devices, base plates, flexible pipe joints etc.

IE inspection engineer

SE structural engineer

SI seismic isolation or seismically isolated structural system

5 Basic principles of structural planning

5.1 General

The seismically isolated structure shall be designed to have an isolation interface between a superstructure and a substructure.

The reduction of seismic response of superstructure is obtained by increasing the fundamental natural period of the structure and increasing the effective damping using isolators or dampers installed in the isolation interface.

The seismically isolated structure shall be designed considering earthquake ground motions with the effects of multi-directional input.

Seismic isolators are designed to support the weight of structure in a stable manner under the design seismic forces.

Dampers are designed to have damping effect by absorbing vibration energy to reduce the response of the structure.

The foundation of the seismically isolated structure shall be constructed so as not to cause settlement.

The ground condition of the site and its effect to the response of seismically isolated structure shall be investigated.

5.2 Isolation interface

The centre of resistance of the isolation interface shall be as close as possible to the vertical projection of the centre of masses of the superstructure on the isolation interface to minimize torsional movement.

Isolators shall have appropriate compressive strength to resist vertical loads from the superstructure. The vertical loads shall also include vertical loads generated due to earthquakes.

Isolators shall be designed to increase the fundamental period of the structure to reduce the inertia force induced by the earthquake vibration.

Dampers shall be designed to have damping effect by absorbing vibration energy to reduce the response of the structure.

The isolation system shall have appropriate restoring force to re-centre the structure.

The isolation system shall have appropriate horizontal deformation capacity under seismic forces.

The isolation interface shall have enough space to allow inspection, maintenance and replacement of the devices.

5.3 Superstructure and substructure

Isolation system shall be designed such that most of the lateral deformation of isolated structure is concentrated at the isolation interface.

The substructure shall have sufficient stiffness and strength against the lateral and vertical force, bending moment, shear force transmitted by the superstructure.

5.4 Foundation

The foundation of the seismically isolated structure shall have sufficient rigidity and strength to support the structure in a stable manner and not to cause settlement.

5.5 Connections of isolation devices

Connections between the isolation devices and structures shall have sufficient stiffness and strength against shear, tension, compression forces, and bending moments generated by the deformation of the isolation devices.

5.6 Isolation gap

The isolation gap shall be sufficiently wide to accommodate the displacement of isolation system in both horizontal and vertical directions, so that the structure does not collide with the moat wall during an earthquake under the ultimate limit state (ULS).

Gap covers should be kept in place to prevent passers-by from falling into the moat.

5.7 Non-structural components and equipment in isolation interface

Non-structural components and equipment crossing the isolation interface, such as piping and wiring, shall be designed to accommodate the displacement of the isolation system under the ULS.

6 Target performance of the seismically isolated structure

6.1 General

The seismically isolated structure shall remain operational without any damage to structures by earthquakes which may be expected to occur at the site during the service life of the structure. This limit state is referred to as the serviceability limit state (SLS).

The seismically isolated structure shall withstand with limited and reparable damage to structures by severe earthquakes that could occur at the site, such that the building can remain operational even right after the earthquakes. This limit state is referred to as the ultimate limit state.

The seismically isolated structure shall protect occupants against extraordinary and possibly unforeseen events like natural hazards, accidents, or human errors by providing sufficient robustness.

The seismically isolated structure shall be safe and operational under wind loads (see Annex D).

6.2 Superstructure

In the SLS, the superstructure shall remain undamaged.

In the ULS, the superstructure shall withstand with limited and reparable damage such that the building can remain operational.

6.3 Substructure

In the SLS, the substructure shall remain undamaged.

In the ULS, the substructure shall withstand with limited and reparable damage.

6.4 Isolation system

a) The isolation system shall support the loads during deformation in a stable manner.

b) The sustained compressive stress of the isolator shall be less than the design capacity.

c) The maximum lateral deformation of the isolator under design seismic forces shall be less than the design capacity.

d) The tension force and deformation of the isolator under design seismic forces induced by the vertical component of the earthquake ground motion and/or the superstructure's overturning moment shall be less than the design capacity.

e) The isolation system shall resist wind loads and other design loads. The fatigue characteristics of the seismic isolation devices should be considered when evaluating response due to earthquake or wind load (see Annex D).

f) The effect of aging, creep, temperature, moisture, and other environmental conditions to the characteristics of isolation devices shall be considered appropriately.

g) The isolator shall have adequate fire protection if necessary.

7 Design seismic force

7.1 General

The seismically isolated structures shall be designed using appropriate design earthquake ground motions or design response spectra established considering the seismicity and site conditions as described in ISO 3010:2017.

7.2 Design response spectrum

A design response spectrum shall be defined as the input to perform a response spectrum analysis for equivalent linear system. This spectrum may either be a code specified response spectrum for the site or a site-specific design response spectrum developed for the proper damping ratio.

7.3 Design earthquake ground motion

A set of earthquake ground motions is required as the input to perform a response history analysis with two horizontal and one vertical components. These motions may either be recorded or simulated earthquake ground motions that are selected and scaled to generally match the design response spectrum for the site. For both types of ground motions, the stochastic nature of earthquake ground motions should be considered.

The earthquake ground motions shall be determined for each limit state, considering the seismicity, local soil conditions, return period of past earthquakes, distance to active faults, source characteristics of possible earthquakes, uncertainty in the prediction, design service life of the structure, and occupancy category of the structure.

8 Structural analysis

8.1 General

The following analysis methods are considered appropriate for the structural analysis of seismically isolated structures depending on the determined conditions:

a) Response spectrum analysis method for equivalent linear system;

b) Response history analysis method.

8.2 Modelling of isolation system

The isolation system shall be modelled based on the characteristics of isolation devices.

The model of each isolation device should be verified by natural scale testing results.

Upper and lower bounds of restoring force characteristics of isolation devices shall be evaluated considering the influence of production variability, environmental condition, heating by cyclic dynamic deformation, and time deterioration.

8.3 Modelling of superstructure and substructure

For a structure with irregular configuration, a three-dimensional structural model should be used to evaluate the torsional response.

8.4 Response spectrum analysis method for equivalent linear system

8.4.1 General

Response spectrum analysis method for equivalent linear system is a practical calculation method evaluating the maximum response of a seismically isolated structure based on the design response spectrum using linearized effective stiffness and effective damping of the isolation system.

8.4.2 Basic requirements

a) Response spectrum analysis for equivalent linear system shall be used for the design of a seismically isolated structure that consists of an isolation interface at the base of the structure.

b) The horizontal elastic stiffness of the superstructure shall be sufficiently larger than the effective stiffness of the isolation system so that the superstructure behaves as an almost rigid body and the structure can be modelled as a single degree of freedom system.

c) The height of the superstructure shall be limited so that the higher mode effect of vibration can be ignored.

d) The superstructure shall have regular forms in both plan and elevation to minimize torsional movement.

e) The nonlinear restoring force characteristic of the seismic isolation system shall be replaced with an equivalent linear restoring force having effective stiffness and effective damping.

f) The design response spectrum shall be defined as the acceleration response spectrum of input earthquake ground motion as a function of the fundamental natural period and a damping ratio.

g) The maximum response of the isolation system shall be evaluated by the iterative manner until convergence from the reduced response spectrum for the effective stiffness and the effective damping ratio.

h) Response spectrum analysis for equivalent linear system shall be performed separately for upper bound and lower bound of the restoring force characteristics of the isolation system to determine the maximum shear force and the maximum displacement of the isolation system.

i) The superstructure shall be designed using the maximum shear force. This shear force shall be distributed as the lateral static force over the height of the superstructure.

j) The seismic devices shall be designed against the maximum displacement considering the appropriate safety factor.

k) At the maximum response, no tension is allowed in isolators.

8.4.3 Effective stiffness

The effective stiffness, K_e, of the isolation system shall be calculated as the secant stiffness obtained by dividing the peak force by the design maximum displacement, D_M, in the force-deflection behaviour of the isolation system.

8.4.4 Effective period

The effective period of the isolation system at the design maximum displacement, D_M, shall be calculated from Formula (1):

$$T_e = 2\pi\sqrt{\frac{M}{K_e}} \tag{1}$$

where

T_e is the effective period of the isolation system,

M is the mass of the superstructure,

K_e is the effective stiffness of the isolation system.

8.4.5 Effective damping

8.4.5.1 Effective damping of hysteretic dampers

The effective damping ratio of the isolation system should be calculated from Formula (2):

$$h_d = \frac{1}{4\pi}\beta_d\frac{\Delta W}{W} \tag{2}$$

where

h_d is the effective damping ratio of the hysteretic dampers,

β_d is the modification factor of the effective damping of the hysteretic dampers that takes into account the non-stationarity of the seismic response, usually less than 1.0,

ΔW is the total energy dissipated in the hysteretic dampers during a full cycle of response at the design maximum displacement D_M,

W is the total potential energy in the isolation system at the design maximum displacement, D_M, as calculated from Formula (3):