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

FDIS stage

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Contents

Foreword

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

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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 losses rate, number of injures and improves of peace of mind of occupants against earthquakes. To mitigate future earthquake disasters, wide spread 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 standard, 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 principles regarding the design of seismically isolated structures under earthquake effects.

This document also describes 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 1 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, *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.

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
the 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 may have 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 crossing the isolation interface, such as piping and wiring

3.3 Terms related to structural design

3.3.1
design response spectrum
response spectrum used for the design of seismically isolated structure in response spectrum analysis for equivalent linear system

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.

4 Notations

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

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.

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 ultimate limit state.

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 (ULS).

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 requirement

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 by

$$T_e = 2\pi\sqrt{\frac{M}{K_e}} \quad (1)$$

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 by

$$h_d = \frac{1}{4\pi}\beta_d\frac{\Delta W}{W} \quad (2)$$

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 by

$$W = \frac{1}{2}K_e D_M^2 \quad (3)$$

8.4.5.2 Effective damping of fluid dampers

The effective damping ratio of the isolation system with fluid dampers should be calculated by

$$h_v = \frac{1}{4\pi}\beta_v\frac{T_e C_e}{M} \quad (4)$$

where

h_v is the effective damping ratio of fluid dampers,

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

C_e is the effective damping coefficient of the fluid dampers obtained by dividing the damping force of the fluid dampers F_D by the equivalent velocity $V_e = 2\pi D_M/T_e$ at the design maximum displacement D_M as

$$C_e = F_D/V_e \quad (5)$$

8.4.6 Maximum displacement of isolation system

8.4.6.1 Response spectrum

The seismic input is defined as a design acceleration response spectrum, $S_a(T, h)$, as a function of the fundamental natural period, T, and a damping ratio, h, of the structure.

8.4.6.2 Maximum displacement including torsion

The maximum displacement, D_M, of the isolation interface at the centre of mass shall be calculated by the following equation by the iterative manner.

$$D_M = \frac{M S_a(T_e, h_D)}{K_e} \tag{6}$$

where

h_D is the effective damping ratio considering the combined effect of hysteretic damping and viscous damping.

The maximum displacement at the individual element of isolation interface should include additional displacement caused by the torsional movement of isolation interface by an appropriate manner.

8.4.7 Seismic design forces

8.4.7.1 Seismic design base shear of the superstructure

The superstructure shall be designed based on the seismic design base shear, Q_s, calculated by

$$Q_s = \beta_S K_e D_M \tag{7}$$

where

Q_s is the seismic design base shear of superstructure,

β_s is the modification factor of the seismic design base shear of superstructure.

8.4.7.2 Seismic design forces of the foundation

The foundation shall be designed to against the lateral and vertical force, bending moment, shear force transmitted by the superstructure.

8.4.7.3 Vertical distribution of lateral forces

The lateral forces applied at each level of the superstructure shall be calculated by

$$F_i = k_{F,i} Q_s \tag{8}$$

where

F_i is the lateral force at i-th level of the superstructure,

$k_{F,i}$ is the force distribution factor to distribute the seismic design base shear, Q_s, to the i-th level of the superstructure, which characterizes the distribution of seismic forces in elevation.

where $\sum k_{F,i} = 1$

8.4.7.4 Drift limit of the superstructure

The maximum storey drift of the superstructure corresponding to the design lateral force shall be less than the design limit.

8.5 Response history analysis method

8.5.1 General

The response history analysis is a calculation method evaluating the time history response of a seismically isolated structure under earthquake ground motions.

8.5.2 Basic requirements

a) The nonlinear restoring force characteristics of the seismic isolation interface shall be explicitly modelled based on the constitutive law of each isolation device.

b) The nonlinear restoring force characteristics of the seismic isolation interface shall be explicitly modelled based on the constitutive law of each isolation device.

c) The nonlinear restoring force characteristics of the seismic isolation interface shall be explicitly modelled based on the constitutive law of each isolation device.

8.5.3 Number of earthquake ground motions

Because of the large uncertainties in the characteristics of seismic motions, a sufficient number of earthquake ground motions with different time-frequency characteristics shall be used to evaluate the response of seismically isolated structures as described in ISO 3010.

8.5.4 Upper bound and lower bound of stiffness and force

Response history analysis shall be performed separately for upper bound and lower bound of the stiffness and the force of the hysteresis model of the isolation system considering the influence of production variability, environmental condition, and time deterioration to determine the maximum shear force and the maximum displacement.

8.5.5 Maximum displacement of isolation system

The maximum displacement of the isolation system shall be calculated from the vector sum of the two horizontal and vertical orthogonal displacements at each time step.

8.5.6 Maximum storey drift and shear force of superstructure

The maximum storey drift and shear force of the superstructure obtained by response history analysis shall be less than the design limit.

9 Construction management specified in design documents

9.1 Construction planning

Construction plan shall be prepared including manufacturing of the isolation devices, installation procedures of the isolation devices, piping and electrical wiring and expansion joints, temporary works, detailed construction procedures considering the possibility of earthquakes and strong winds in the construction period, and inspection details (see Annex B).

9.2 Quality control of isolation device manufacturing

The delivered isolation devices and non-structural components crossing isolation interface shall be confirmed to meet the requirements specified in the design documents (see Annex B).

9.3 Temporary work planning

The delivered isolation devices and non-structural components crossing isolation interface shall be confirmed to meet the requirements specified in the design documents (see Annex B).

9.4 Construction procedures of isolation interface

In the construction period, the isolation devices should be covered to keep away from any damages caused by impact, heat, chemicals, oil, and rainwater etc (see Annex B).

If the isolation interface is dedicated to some building usage such as office room, machine room and parking lot, permanent fire protection for isolators shall be utilized (see Annex B).

Inspection of the isolation interface such as the precision of the position and slope for the isolation devices, the clearance between the flexible pipe joints and the superstructure and the isolation gap shall be conducted during and after the construction period (see Annex B).

10 Maintenance specified in design documents

10.1 Maintenance of seismic isolation system

The isolation system maintenance plan shall be submitted to the building owner so that the isolation system can be kept in good condition and periodically checked and maintained (see Annex C).

10.2 Monitoring of system performance

Earthquake response recording instruments should be installed for confirming the performance of seismically isolated structures. The scratch plate should be installed as the minimum (see Annex C).

10.3 Warning signage

Warning signage should be posted to keep occupants away from the isolation interface during an earthquake as it moves and to avoid placing obstacles in the isolation gap (see Annex C).

11 Performance requirement of isolation devices

11.1 Performance information of isolation devices

Performance of the isolation devices shall be confirmed based on the document provided from the manufacturer describing the characteristics of isolator devices including the influence of production variability, environmental condition, and time deterioration, etc.

11.2 Test of isolation devices

When a new isolation device is used, the nominal values of properties and performances from type test shall be provided prior to the application. In case of elastomeric bearings, refer to ISO 22762-1.

For the construction project, a routine test shall be conducted at a specific number of production units to validate design properties. In case of elastomeric bearings, refer to ISO 22762-1.

Annex A
(informative)

Classification and performance characteristics of isolation devices

A.1 General

A.1.1 Objectives

Isolation devices are provided for seismically isolated structures to reduce their response under earthquake. In this Annex, classification and performance characteristics of typical isolation devices are specified.

When a new isolation device is used, type test should be conducted prior to the application.

The following types of devices and combinations are covered:

- Seismic isolators including Elastomeric Isolators, Curved Surface Sliders and Sliding seismic-protection isolators,
- Dampers including Viscous Dampers (Velocity Dependent Devices) and Steel Hysteretic Dampers.

A.1.2 Normative references

EN 15129: *Anti-seismic devices* (2009)

ISO 22762: *Elastomeric seismic-protection isolators*

ISO 22762-1 Part1: *Test methods*

ISO 22762-2 Part2: *Applications for bridges – Specifications*

ISO 22762-3 Part3: *Applications for buildings – Specifications*

ISO 22762-4 Part4: *Guidance on the application of ISO 22762-3*

ISO 22762-5 Part5: *Sliding seismic-protection isolators for buildings*

A.1.3 General design rules

A.1.3.1 Performance requirements and compliance criteria

As stated on main part of ISO23618, isolation devices are required to improve structural performance under earthquake and to provide assured system to carry loads under non-seismic situations.

A.1.3.2 Functional requirements

Devices and their connections to the structure should be designed and constructed in such a way as to function according to the design requirements and tolerances throughout their projected service life, given the mechanical, physical, chemical, biological, and environmental conditions expected.

Devices and their connections to the structure should be designed, constructed, and installed in such a way that their routine inspection and replacement are possible during the service life of the construction.

For the enforcement of this requirement, it is necessary that the design of the structure takes account of accessibility for both equipment and personnel. For further specifications see Annex B: Construction management of seismically isolated structures.

A.1.3.3 Structural and mechanical requirements

A.1.3.3.1 General

Devices and their connections to the structure should be designed and constructed in such a way that their performance conform to the design requirements.

The verification of the devices at the design limit states; the serviceability limit state (SLS) and the ultimate limit state (ULS), is associated with the design seismic situation, with due consideration of the reliability of the structural system.

The devices and their connections to the structure should be verified, with an adequate degree of reliability, to have an appropriate strength and ductility to withstand under seismic design situation.

A.1.3.3.2 Requirements at the SLS

Under the SLS, the devices and their connections to the structure should remain in a serviceable state, and undergo only very minor or superficial damage which should not induce interruption of use, nor require immediate repair.

A.1.3.3.3 Requirements at the ULS

Under the ULS, the devices and their connections to the structure may suffer damage, but should not reach failure. They should retain residual capacities at least equivalent to the permanent actions under combination of actions that correspond to the possible post-earthquake design situation, including the seismic situation, defined by the structural design.

Replacement of the devices after damage has occurred should be possible without resorting to extensive intervention.

A.1.3.4 Compliance criteria

Performance requirements concerning the devices and their connections to the structure should comply with the procedures setting forth in the corresponding clauses of this guideline or relevant standard, according to the type of devices used.

The verification of compliance criteria may be obtained by appropriate modelling or testing according to the corresponding clauses of this guideline or relevant standard.

A.2 Seismic isolators

A.2.1 General

Seismic isolators should:

- support the gravity load of a structure without excessive creep and resist non-seismic actions such as wind loadings and thermally induced displacements,
- provide low horizontal stiffness and achieve desired low horizontal natural frequency for the isolated structure,
- be able to accommodate the large horizontal displacements produced by seismic actions whilst still safely supporting the gravity load of the structure and resisting the vertical forces produced by the seismic actions,
- provide sufficient damping to control the horizontal displacements produced by the seismic actions unless supplementary devices are used to provide the damping.

The types of isolators covered by this clause are:

a) Elastomeric isolators, including those with a plug of lead or high damping polymeric material to enhance the damping,
b) Sliders with curved surfaces,
c) Sliding seismic-protection isolators,
d) Linear re-circulating guides.

Isolators should be designed and manufactured to accommodate the translation and rotation movements imposed by seismic and other actions whilst supporting the vertical load imposed by gravity, seismic actions, and other live loads. They should work correctly if subjected to the environmental conditions during their design service life. When isolators are likely to be subjected to exceptional environmental and application conditions, such as immersion in water, exposure to oils or chemicals, or installation in an area constituting a significant fire risk, additional precautions should be taken.

The isolators considered in this ISO standard provide isolation against only horizontal seismic actions. They can be designed additionally to provide isolation against vertical vibrations. When devices are expected to function for vertical vibration, additional vertical stiffness tests would be required.

A.2.2 Elastomeric isolators

The following ISO Standards should be followed:

ISO 22762: *Elastomeric seismic-protection isolators*

ISO 22762-1 Part1: *Test methods*

ISO 22762-2 Part2: *Applications for bridges – Specifications*

ISO 22762-3 Part3: *Applications for buildings – Specifications*

ISO 22762-4 Part4: *Guidance on the application of ISO 22762-3*

ISO 22762-5 Part5: *Sliding seismic-protection isolators for buildings*

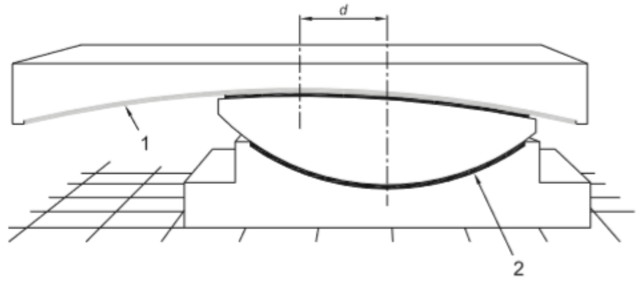
A.2.3 Curved surface sliders

A.2.3.1 Description and operating principle

The Curved Surface Sliders are seismic isolators that provide the four main functions (ability to support gravity load of superstructure, ability to accommodate lateral displacements, energy dissipation and re-centering capability) through an appropriate arrangement of curved sliding surfaces and use the characteristics of a pendulum to lengthen the natural period of the isolated structure.

In a structure that is isolated by means of the Curved Surface Sliders, the period of oscillation mainly depends on the radius of curvature of the curved sliding surface, i.e., it is almost independent of the mass of the structure.

The curved main sliding surface of the Curved Surfaces Sliders provides a restoring force at the displacement, d. Energy is dissipated by friction due to movement in the main sliding surface. Rotations are accommodated by the secondary sliding surface (Figure A.1).



Key

1 main sliding surface

2 secondary sliding surface

Figure A.1 — Functional principle and main elements of Curved Surface Sliders

The Curved Surface Sliders are characterised by:

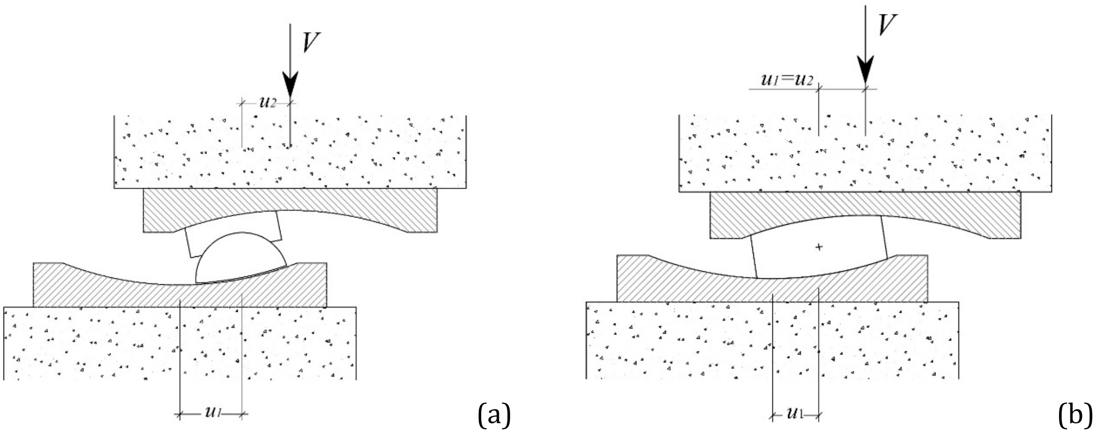
- a concave slider (top element) whose radius of curvature imposes the period of oscillation and that accommodates for the horizontal displacement,
- a base element with a secondary concave sliding surface that permits the rotation,
- a steel intermediate element with two convex surfaces suitably shaped to be coupled with the other two elements.

This subclause also applies to the Double Concave Curved Surface Sliders that comprises two facing primary sliding surfaces with the same radius of curvature, both contributing to the accommodation of horizontal displacement (Figure A.2).

The Double Concave Curved Surface Sliders are characterised by two primary concave sliding surfaces with the same radius of curvature; both surfaces accommodate for horizontal displacement and rotation. In this case each single sliding surface is designed to accommodate only half of the total horizontal displacement, so that the dimensions in plan of the devices may be significantly smaller in comparison with the Curved Surfaces Sliders.

The Curved Surface Slider is characterised by a marked nonlinear behaviour; thus it induces significant nonlinearity and energy dissipation into the dynamic characteristics of a structural system, features which should be appropriately taken into account in the modelling of the structure.

The Triple Curved Surface Sliders are also available.



Key

u_1 horizontal displacement at the bottom of the slider

u_2 horizontal displacement at the top of the slider

Figure A.2 — Functional principle and main elements of Double Curved Surface Sliders: (a) with the articulated element and (b) non articulated element

A.2.3.2 Performance requirements

A.2.3.2.1 General

The performance requirements define quantifiable characteristics that should be determined for the Curved Surface Sliders by type tests.

A.2.3.2.2 Load bearing capacity

The Curved Surface Sliders with no lateral displacement should be capable of supporting a vertical load equal to the vertical load in non-seismic conditions.

The device should not show any damage and the sliding material of both primary and secondary sliding surface should not show any sign of progressive flow or deterioration due to inadequate mechanical resistance, bonding and/or confinement in tests.

The load bearing capacity of the Curved Surface Slider should remain unaltered after the tests.

The sliding material of the primary sliding surface acts as a conventional bearing material under service conditions and thus it is essential to verify the stability of its mechanical properties after an earthquake.

A.2.3.2.3 Horizontal displacement capacity

The Curved Surface Sliders should be capable of accommodating the horizontal design displacement.

A.2.3.2.4 Rotation capacity

In the Curved Surface Slider, translation movements induce rotational movements in the slider, which are accommodated by the secondary sliding surface.

The secondary sliding surface should be designed to accommodate the rotation of the slider consequent to the horizontal design displacement.

A.2.3.2.5 Maximum frictional resistance to service movements

In the Curved Surface Slider, the static friction resistance is the maximum force to produce macroscopic motion occurring during the first movement and it should be considered in the design of the isolator, its anchoring system, and the adjacent structural members.

The value of the frictional resistance force should be checked by tests.

A sliding material specimen should be subjected to a long-term friction test. The maximum coefficient of the friction for each temperature and the contact pressure determined from the long-term friction tests should be reported, and used to define the design values of the maximum frictional resistance force.

A.2.3.2.6 Isolation characteristics

Under all loading conditions, the movement in the sliding surfaces should be smooth and without producing any type of vibrations such as those by the stick-slip phenomenon.

The friction coefficient and all the related performance parameters should fall within the prescribed limits under the testing conditions.

The temperature, ageing and service life dependent upper and lower bound design values should be based on the results of the long-term friction tests. The influence of ageing on the coefficient of friction should be taken from the ageing test.

The change in long-term friction behaviour due to the accumulated sliding under service conditions should be monitored.

A.2.3.2.7 Wear resistance

The sliding elements are the critical components of the Curved Surface Sliders and should maintain functionality without immediate maintenance interventions and/or a rehabilitation intervention after a major earthquake.

The creep deformation is significant and its effect is subtracted from the observed thickness reduction in order to evaluate the extent of the wear correctly.

The wear resistance of the sliding surfaces during their service life and at the occurrence of a design level earthquake should be properly defined.

A.2.3.3 Characteristics for the structural design

The restoring force characteristics of the Curved Surface Slider is idealized by the bilinear hysteresis with the first branch stiffness K_1 , the friction force F_y, and the second branch stiffness K_2 shown in Figure A.3.

Since the natural period of motion is controlled by the radius of curvature of the sliding surface, the lateral stiffness is determined according to the design natural period.

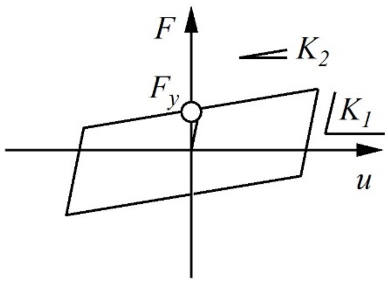


Figure A.3 — Characteristics of a Curved Surface Slider

A.2.4 Sliding seismic-protection isolators

The following ISO Standards should be followed:

ISO 22762: *Elastomeric seismic-protection isolators*

ISO 22762-5 Part5: *Sliding seismic-protection isolators for buildings*

A.3 Dampers

A.3.1 General

Dampers can be classified in

- Viscous Dampers means Fluid Viscous Damper (FVD)
- Steel Hysteretic Dampers (SHD)

The Viscous Dampers are velocity dependent devices. The Steel Hysteretic Dampers are displacement dependent devices.

A.3.2 Viscous dampers

A.3.2.1 Description and operating principle

The Fluid Viscous Dampers are cylinder/piston assemblies in which the lamination of a silicone or other viscous fluid through an appropriate hydraulic circuit permits the dissipation of energy.

A.3.2.2 Performance requirements

Within the tolerances specified by the structural engineer, the Viscous Damper should provide an output force in either tension or compression that complies with the constitutive law declared by the manufacturer.

The Fluid Viscous Damper output force should depend on velocity only and should not change with damper stroke position.

The damper design stroke should be decided taking into account the displacement due to long-term effects, thermally induced effects, and seismic effects.

The damper should be equipped with self-lubricating spherical hinges at each end in order to maintain the transmitted load aligned along its major axis and avoid undesired bending effects that may be detrimental to the sealing system.

The rotation capacity of the spherical hinges should be determined giving consideration to live load effects, earthquake movements, installation misalignments, etc.

The clevis plates or other components should not physically impede the design rotation.

A.3.2.3 Characteristics for the structural design

The typical force-speed constitutive law is $F = CV^{\alpha}$ shown in Figure A.4, where F is force, C is the damping constant, V is speed and α is a coefficient provided by manufacturer.

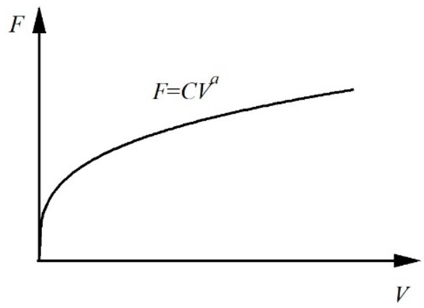


Figure A.4 — Characteristics of a Fluid Viscous Damper

A.3.3 Steel Hysteretic Dampers

A.3.3.1 Description and operating principle

The Steel Hysteretic Dampers exploit the plasticization of appropriately-shaped steel elements, designed to ensure a stable cyclic behaviour. They are also classified as nonlinear Displacement Dependent Devices (DDD).

The crescent-shaped and peg-shaped elements are the most used for bridges, while buckling-restrained axial dampers are the most used as bracing in buildings.

For bridges, steel hysteretic dampers can be combined with shock transmitters.

A.3.3.2 Performance requirements

The DDD, in general, should be able to sustain the design displacement and action effects other than seismic, which can affect the initial configuration of the device.

In order to use the theoretical bilinear cycle to model the device’s behaviour in nonlinear analyses of structural systems, the unloading branch of the theoretical cycle should well approximate the real behaviour of the device.

The experimental parameters of device properties can differ from the design values because design parameters are typically simplified and/or enveloped values of multiple tests. These variations should be evaluated experimentally, in order to establish the upper and lower bound values to be considered in design.

The maximum differences of the experimental values of the behavioural parameters, obtained during initial type tests, with respect to the design values or to the normal condition values, should be within the tolerance limits. These limits are relevant to the variations within the supplied statistical variations, as well as the variations due to ageing, temperature, and displacement rate.

A.3.3.3 Characteristics for the structural design

The restoring force characteristics of the nonlinear DDD is identified by the bilinear hysteresis with the first branch stiffness K_1, the yielding force F_y, and the second branch stiffness K_2 shown in Figure A.5.

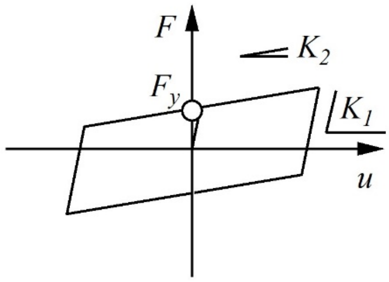


Figure A.5 — Characteristics of a Steel Damper

Annex B
(informative)

Construction management of seismically isolated structures

B.1 General

B.1.1 Objectives

This annex is applicable to the construction of seismic isolation interface, setting of isolation devices and related parts. The following structures are within the scope of this annex.

a) Newly constructed buildings with base isolation or mid-storey isolation

b) Retrofitted buildings with base isolation or mid-storey isolation

B.1.2 Terms and definitions

B.1.2.1
CM
construction manager in charge of the construction of isolation interface

B.1.2.2
CS
construction supervisor responsible for the total quality of the whole building

B.1.2.3
GM
general manager at a construction site

B.1.2.4
MFR
manufacturer of the SI devices, base plates, flexible pipe joints etc.

B.1.2.5
SE
structural engineer

B.1.2.6
SI
seismic isolation or seismically isolated structural system

B.1.2.7
base plate
steel plate which connects an isolator to the superstructure and the substructure with bolts

B.1.2.8
construction clearance
isolation gap considering the construction error which is generally wider than the design clearance

B.1.2.9
creep
permanent deformation induced by long-term compressive load on isolators, especially rubber bearings, which is generally defined as a few percent of the total rubber thickness

B.1.2.10
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

B.1.2.11
inspection at completion
inspection conducted when the building construction is completed

B.1.2.12
inspection under construction
inspection conducted immediately after the isolation interface is constructed

B.2 Construction planning

B.2.1 Quality control planning

The CM should make a construction plan for the isolation interface and related parts including the inspection details, to follow the design requirements. The construction plan should be approved by the CS before the construction begins. Mutual exchange of knowledge and information among the CS, GM, CM, and SE is highly important to complete the building construction with the expected quality.

B.2.2 Documents for the construction plan

B.2.2.1 General

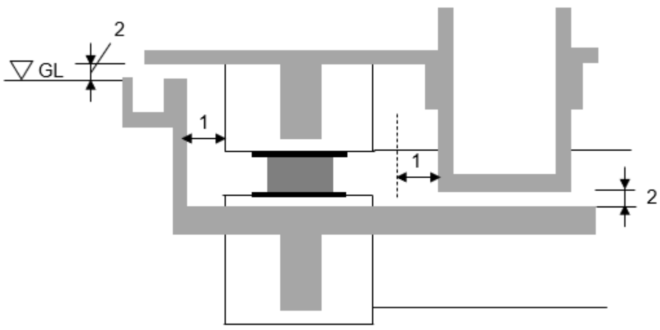
Documents for the construction plan should include manufacturing and setting procedures of the SI devices, piping and electrical wiring and expansion joints, temporary works, detailed construction procedures considering the possibility of earthquakes and strong winds in the construction period, and inspection details.

B.2.2.2 SI device manufacturing

Types, quantities, mechanical properties, and routine test details should be specified in the documents to confirm that the manufactured SI devices meet the design requirements.

B.2.2.3 Clearance (isolation gap)

Horizontal and vertical design clearances, horizontal and vertical construction clearances, and inspection items under construction and at completion should be specified in the documents to confirm that the isolation interface meet the design requirements.



Key

1	Horizontal Clearance	2	Vertical Clearance

NOTE

Both horizontal and vertical clearance are summarized as isolation gap

Figure B.1 — Definition of horizontal and vertical clearance (isolation gap)

B.2.2.4 Piping and electrical wiring

Types and quantities, allowable deformations and setting plan considering the possible movable area should be specified in the documents to confirm that piping and electrical wiring across the isolation interface meet the design requirements.

B.2.2.5 Expansion joints

Types and quantities, allowable deformations and setting plan considering the possible movable area should be specified in the documents to confirm that the expansion joints across the isolation interface meet the design requirements.

B.2.2.6 Temporary work plan

Scaffolding, cranes, construction lifts, bridges for construction vehicles and horizontal restraints (if needed) should be carefully planned and specified in the documents considering that the relative deformation may occur at the isolation interface due to the earthquakes and strong winds in the construction period.

B.2.2.7 Basements for SI devices

Construction details of the basements for the SI devices, such as rebar configuration, position and slope of the base plates and concrete filling method under the base plates, should be specified in the documents so that the quality of the isolation interface meets the design requirements.

B.2.2.8 Inspection under construction or at completion

Inspection under construction should be conducted immediately after the construction of isolation interface is completed. Generally, the dimensions of the horizontal and vertical clearances (isolation gaps) are measured to confirm that those values meet the design specification.

Inspection at completion should be conducted when the building construction is completed. The inspection contains the measurement for the exterior dimensions of the SI devices, horizontal and vertical clearances (isolation gaps). Those will be the initial values compared with the values in the future measurements. The CM should report the inspection results to the building owner.

Details regarding the inspections under construction and at completion should be specified in the documents so that the constructed SI building realizes the required anti-seismic performance.

B.2.2.9 Other important points

Measures to concrete shrinkage due to drying, measures to rainwater into the isolation interface, ventilation of the isolation interface and protection of the SI devices from welding sparks may be specified in the documents so that the quality of the isolation interface meets the design requirements.

B.3 Quality control of SI device manufacturing

B.3.1 General

The CM should confirm that the delivered SI devices, base plates, and flexible pipe joints meet the requirements specified in the design documents.

B.3.2 SI devices

MFR should make documents that specify the manufacturing and the routine test procedures. The CM should confirm that all the items specified in the documents meet the design requirements and approve them before the manufacturing begins.

The CM is responsible for the quality of the manufactured SI devices. Thus, the CM should confirm that all the inspections in the manufacturing and the routine test were appropriately carried out by the MFR.

B.3.3 Base plates

As the base plates need to transfer the weight of the superstructure to the substructure and the foundation, following matters are highly important.

The MFR should make documents that specify the detailed manufacturing procedure. The CM should confirm that all the items specified in the documents meet the design requirements and approve them before the manufacturing begins.

The CM is responsible for the quality of the manufactured base plates. The CM should confirm that all the inspections in the manufacturing were appropriately carried out by the MFR.

B.3.4 Flexible pipe joints

Pipes for water, sewage, gas etc. installed in the isolation interface should follow the horizontal and vertical deformation in earthquakes. Generally flexible pipe joints are utilized.

Flexible pipe joints should have sufficient deformability, anti-fatigue property, leakage proof, and restoring property. It is also important to be able to replace them when damaged or deteriorated.

The MFR should make documents that specify the detailed manufacturing procedure. The CM should confirm that all the items specified in the documents meet the design requirements and approve them before the manufacturing begins.

The CM is responsible for the quality of the manufactured flexible pipe joints. The CM should confirm that all the inspections in the manufacturing were appropriately carried out by the MFR.

B.3.5 Expansion joints

The MFR should make documents that specify the detailed manufacturing procedure. The CM should confirm that all the items specified in the documents meet the design requirements and approve them before the manufacturing begins.

The CM is responsible for the quality of the manufactured expansion joints. The CM should confirm that all the inspections in the manufacturing were appropriately carried out by the MFR.

B.4 Temporary work planning

B.4.1 General

Even in the construction period, significant relative deformation may occur at the isolation interface due to earthquakes and strong winds. The CM should deal with the possible relative deformation to avoid the interference or collision of the temporary works with the superstructure.

B.4.2 Temporary works

a) Scaffolding should be set on the basement of the superstructure to keep away from the interference or collision with the superstructure. In case the scaffolding needs to be set on the substructure or the ground, sufficient horizontal clearance to the superstructure should be needed.

b) In case the cranes are set on the substructure or the ground, sufficient horizontal clearance to the superstructure should be needed to avoid the interference or collision with them.

c) Construction lifts should be set on the superstructure to keep away from the interference or collision due to the relative deformation at the isolation interface in earthquakes and strong winds. In case the construction lifts are set on the substructure or the ground, sufficient horizontal clearance to the superstructure should be needed to avoid the interference or collision with them.

d) Bridges for construction vehicles over the clearance (isolation gap) should follow the relative deformation at the isolation interface in earthquakes and strong winds.

e) Temporary horizontal restraints may be utilized to prevent the horizontal deformation at isolation interface when subjected to earthquakes and strong winds in the construction period. The CM should discuss the necessity and details of restraints with the CS.

f) Temporary horizontal restraints are generally set between the upper and lower flange plates of each isolator or over the isolation gap at the circumference of the superstructure.

B.5 Construction procedures of isolation interface

B.5.1 Product acceptance

The CM should confirm that the delivered SI devices, base plates, and flexible pipe joints conform to the items specified in the documents for the construction plan. Visual inspection should also be conducted by the CM to check if there is no damage that may occur due to the transportation. All the inspection results should be approved by the CS.

B.5.2 Construction of isolation interface

The CM should conduct the construction of the isolation interface according to the construction plan specified in B.2.2. Especially, the basements for the isolators should be constructed with the utmost care and attention, as those are one of the most important parts for the anti-seismic performance of the SI building. The area directly under the base plates should be sufficiently solid so that the seismic loads of the SI devices are inevitably transferred between the superstructure and the substructure.

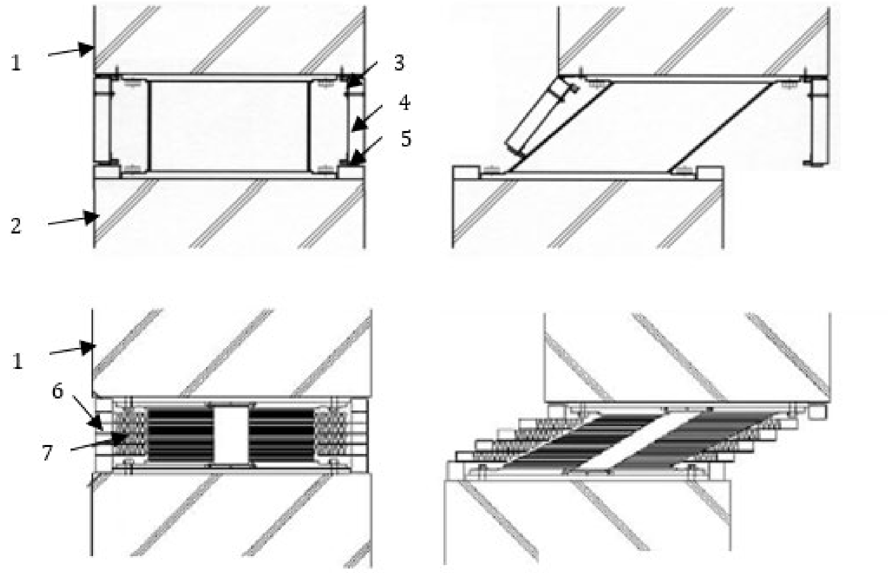
B.5.3 Protection of SI devices

In the construction period, the SI devices should be covered to keep away from any damages caused by impact, heat (sparks, flames etc.), chemicals, oil, and rainwater etc. It is noted that in general welding work should be prohibited in the vicinity of the SI devices as the sparks may significantly damage them. If the welding work is unavoidable near the SI devices, temporary fire protection should be applied.

B.5.4 Fireproofing

Isolators should be covered with fire protection material for mid-storey isolation, to keep supporting the weight of the superstructure during and after the fire. Fireproofing should follow the horizontal and vertical deformation of the isolators in earthquakes as shown in Figure B.2.

If the isolation interface of a mid-storey isolation building is dedicated to some building usage such as office room, machine room and parking lot, permanent fire protection for isolators should be utilized. Fireproofing should be set surrounding the isolators but not to prevent the horizontal and vertical deformation during earthquakes and strong winds.



(a) (b)

Key

1	Upper Column	2	Lower Column
3	Hing	4	Fire Proofing Panel
5	Rubber (Fire Proofing Sealant)	6	Calcium Silicate Plate
7	Glass Wool		

NOTE Index (a) and (b) state below

(a) Deformation under usual time

(b) Deformation under earthquake

Figure B.2— Example for fireproofing system under usual time and earthquake

B.5.5 Safety management

As the CM should be responsible for the construction safety of the isolation interface, the following matters are highly important.

a) Safety education on construction for new entry workers should be provided on site.

b) A qualified person should direct the construction work on behalf of the CM. Construction plan, roles and responsibilities of each worker and important points should be clearly announced before the daily work begins.

c) Construction machines and tools should be checked by the workers themselves. The check results should be reported to the CM.

d) Safety lanes should be provided for both the workers and the construction vehicles.

e) No outsiders are allowed to enter the isolation interface.

f) No one should go under the SI devices hung from the cranes.

g) Construction vehicles should be guided by a qualified conductor not to endanger the workers in the vicinity.

h) Construction tools should be returned to the original position.

i) The work area should be cleaned up for the work of the next day.

B.5.6 Inspection under construction

Inspection of the SI devices and the clearance (isolation gap) should be frequently undertaken in the construction period, as the earlier the errors are found, the easier the correction work becomes. Especially, position and slope or alignment of each isolator should be inspected directly after the basement is constructed or the device has been set on the basement. Furthermore, the clearance (isolation gap) should be measured right after the construction of the isolation interface is finished. The CM should be responsible for conducting the inspection.

B.5.7 Inspection at completion

The CM should conduct the inspection of the isolation interface such as the measurement of the position and slope for all the SI devices, the clearance between the flexible pipe joints and the superstructure and the clearance (isolation gap), right after the building construction is completed. The record of the measured values is highly important as those are the initial values to the future inspection results to maintain anti-seismic performance of the SI building. The inspection result should be approved by the CS. Moreover, the inspection report should be submitted to the building owner or the building manager.

Annex C
(informative)

Maintenance of seismically isolated structures

C.1 General

C.1.1 Objectives

Maintenance methods unique to SI buildings are necessary because SI buildings behave differently during earthquakes than the conventional buildings due to the application of SI devices. Even though this annex is a guideline for maintenance of SI buildings, building owner and SE should basically determine control values by themselves and implement the maintenance.

This annex shows basic matters for maintenance of SI buildings, maintenance items, decision methods for control values, and standard concepts for judgement. In addition, it is to provide a guideline for maintenance of seismically isolated buildings that should be implemented by building owners, building managers, construction managers and inspection engineers.

Inspection engineers should make plans for maintenance of SI devices and the related parts because the safety of SI buildings is greatly affected by the performance of SI system and the related parts. Basic methods of maintenance in other structures, including SI bridges and SI liquified nitrogen gas (LNG) storage tanks, are similar to this guideline and should be referenced.

Since the quality of individual products depends on the quality control standards of the respective manufacturers, this standard is not applicable to it.

C.1.2 Technical terms

C.1.2.1
SI
seismic isolation, seismically isolated

C.1.2.2
IE
inspection engineer

C.1.2.3
SE
structural engineer

C.1.2.4
CM
construction manager

C.1.2.5
Exp.J.
expansion joint

C.2 Basic matters of maintenance

C.2.1 Maintenance scheme

Every person involved has the following responsibilities: (See Figure C.1 and Table C.1)

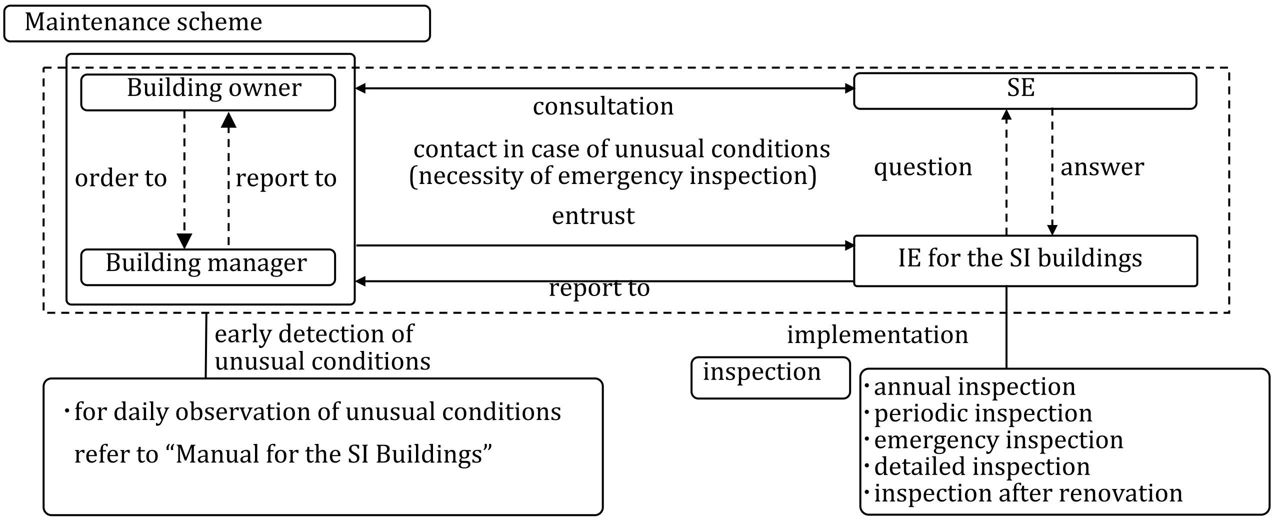


Figure C.1 — Maintenance scheme for the SI buildings

Table C.1 — Roles for maintenance

Category	Roles (Responsibility)
Building owner	・ To take all responsibility for maintenance of the building ・ To implement inspections for maintenance of the building ・ To consult the SE when it is difficult for her/him to understand the report and to implement proper solution based on the decision of the SE
Building manager	・ To order the IE to implement inspections ・ To check daily if there is any malfunction of the seismic isolation layer and the related parts ・ To check report of the inspection and to report it to the building owner ・ To contact the IE if emergency inspection is necessary and to confide to the IE the emergency inspection
SE (designer)	・ To make plans for maintenance ・ To decide maintenance standard value or control value and to specify them in the design documents ・ To reply to the questions of the IE ・ To propose appropriate solution when unexpected malfunctions that are not in the design documents are found ・ To propose appropriate solution if there are malfunctions to judge after inspections
IE	・ To implement inspection (for maintenance of the SI buildings) using appropriate measures and tools ・ To confirm secure situation at site ・ To make inspection reports ・ To indicate problems from the results of the inspections

CM	・ To implement inspection upon completion ・ To get approval for the report of the inspection of the construction of the SI part and to submit it to the supervisor and the building owner ・ To discuss measuring methods with the supervisor and the building owner to make values of inspection upon completion as the initial values for inspection for maintenance

C.2.2 Classification of inspection

Inspection upon completion and five other inspections are classified below, according to purpose. The IE conducts these at the required time (see Table C.2). If any countermeasures are necessary, the interested parties (the building owner, the building manager, the SE (designer)) discuss them.

C.2.3 Items of inspection

Items of inspection are shown in Table C.3 related to the performance of the SI system.

Table C.2 — Classification of inspection

Classification	When	Responsibility	Method	Items	Control value: decided by	Contents
Upon completion	At the time of building completion	CM	Visual and measurements	All	SE	・SI devices ・Piping for equipment ・Electrical equipment ・SI layer ・Building periphery ・Clearance ・Fireproofing ・Exp.J. ・Marking (Marks) for maintenance ・Others (・Structures in which the SI devices are installed ・Signboard for the SI building, ・Tracer for displacement ・Test isolator for other malfunctions)
Annual	Every year except when periodic inspection is scheduled	Building owner	Visual	All	SE	Visual inspection of contents on inspection list upon completion
Periodic	5 years and 10 years after completion of building, and every 10 years after that		Visual and measurements	Visual: all Measurements: Sampling[1)]		The number of items is fewer than items on inspection upon completion. (It is based on the premise that inspection upon completion was carried out by the IE)
Emergency	After a major earthquake,		Visual	All		・The purposes of this

	strong wind, flood, fire, or similar extreme loading event					inspection are to identify damaged parts and to quickly notify the building manager and the designer. ・Contents are the same as those of annual inspection.
Detailed	When unusual conditions are recognized during other inspections		Visual and measurements	To be designated by the SE		The worst damaged parts should be inspected.
After renovation	After construction relating to the SI systems		Visual and measurements	All constructions related to any part of building		Areas of renovation and areas affected by the said renovation

1) In the sampling test, for example, more than three devices of each type of devices should be inspected. For visual inspection, all the devices should be inspected.

Table C.3 — Items of inspection

Position	Devices	Details	Items for inspection
SI devices	Isolator	・Laminated rubber bearing ・Slider ・Rolling bearing	・Appearance ・Conditions of steel parts ・Connection parts ・Vertical and horizontal displacements ・Covers for dust
	Damper	Hysteretic damper	・Appearance ・Conditions of steel parts ・Connection parts ・Size of main parts ・Displacement ・Range of movement
		Fluid damper	・Appearance ・Conditions of steel parts ・Connection parts ・Displacement ・Viscous material and oil
Fireproofing	Fireproofing for the SI device		・Appearance ・Conditions of installation ・Clearance of between fireproofing ・Condition of movement
SI layer	Clearance between building and retaining walls	Specific position for measuring	・Horizontal clearance ・Vertical clearance ・Marks
	Condition of the SI layer		・Obstacles or inflammable objects ・Drainage conditions
	Position of building	Plumb bob	・Position of installation ・Movement
Piping for equipment and	Flexible pipe-joints	・Waterworks ・Sewerage ・Gas ・Other pipes	・Position of installation ・Condition of fixed frame for flexible pipe- joints

electrical equipment		・Piping and cable rack ・Structure ・Periphery of building	Clearance
	Electrical equipment	・Power supply ・Cable for correspondence ・Lightning protection and the earth	・Position of installation ・Following ability for displacement
Periphery of Building	Periphery	・Superstructure ・Berm ・Equipment of periphery of building	・Clearance ・Obstacle
		・Space between berm and retaining wall	Horizontal opening
	Exp.J.		・Position of Exp.J. ・Condition of movement and function ・Condition of connecting parts
Others	Signboard for the SI building		Position for setting
	Tracer for displacement		・Position of installation ・Amount of movement
	Separately placed test isolator		・Condition of installation, ・Steel parts (installation part)
	Malfunctions		Serious malfunctions

C.3 Replacement of SI devices

C.3.1 General

Architectural and structural plans should be designed so that SI devices can be replaced.

Temporary plans should be designed to stabilize the building against vertical loads when replacing the SI devices. If it takes a long time to replace the SI devices, temporary plans should be designed to stabilize the building against horizontal loads as well.

C.3.2 Design of SI layer and SI device mounting section

An architectural plan should be designed so that SI devices can be removed from the SI layer and taken out. In order to replace the isolators that support vertical loads, it is necessary to install hydraulic jacks around isolators and jack up the isolator locations. The structural members around the isolator should be designed to withstand the forces exerted during jacking up. If it takes a long time to replace the components of the SI layer, it is necessary to replace the SI devices so that the seismic performance is not lost during replacement work. The attachment part of the SI device should be designed to be removable so that it can be replaced.

C.3.3 Replacement of an isolator supporting a vertical load

Before jacking up, structural calculation and analysis should be carried out to confirm that the parts to be replaced and the surrounding structural members can withstand the jacking. In consideration of the stability of the building, isolators should be replaced one by one.

The jack is installed on the foundation of the isolator or the peripheral beam to jack up the part where the isolator is to be replaced. At that time and after replacing, the vertical displacement should be measured by a monitoring system installed at the periphery of the isolator. It should be confirmed in advance by structural calculation and analysis that the structural members of the replacement part and its periphery are within the allowable deformation range during replacement work.

If there is a gap between the replaced isolator and the building, the gap should be filled with grout or mortar. If a flat jack is used, the flat jack should also be filled with epoxy resin or grout so that the vertical load acting on the building is smoothly transferred to the isolator.

C.3.4 Replacement of a damper not supporting a vertical load

When a damper is replaced, structural calculation and analysis are carried out in advance to confirm that the parts to be replaced and the structural members around the parts can withstand the loads during the replacement work. In consideration of the stability of the building, the SI devices should be replaced one by one. The joint of the damper should be fixed to the building so that there is no gap between the replaced damper and the building frame.

Annex D
(informative)

Wind-resistant design of seismically base isolated buildings

D.1 General

D.1.1 Objectives

This Annex evaluates the performance of the seismic isolation system of seismically base-isolated buildings against the wind actions based on Japan Society of Seismic Isolation:2018, Guidelines for Wind-resistant Design of Base-isolated Buildings. This Annex is not intended to be used for mid-storey isolated buildings or base-isolated detached houses.

D.1.2 Wind loads

a) The wind loads on a base-isolated building should be calculated in accordance with ISO 4354:2009.

b) In the serviceability limit state (SLS), the wind loads have a return period of approximately 50 years.

c) In the ultimate limit state (ULS), the wind loads have a return period of approximately 500 years.

d) For time history analysis and frequency domain response analysis, the wind loads should be determined appropriately.

e) Cumulative wind load time duration should be carefully estimated, taking into account the meteorological conditions at the building location, the condition of the isolation devices and other related conditions.

D.2 Target performance of the seismic isolation system

a) The design objective of This Annex is to ensure that the seismic isolation system of seismically base-isolated buildings has an appropriate level of safety in both SLS and ULS wind loads.

b) In the SLS, the seismic isolation system should remain elastic. Tension load in the isolators should not be allowed.

c) In the ULS, the seismic isolation system should not have dangerous deformation, tension in the isolators during the wind actions and do not have too large residual deformation after the wind actions.

d) To the wind loads, not only the maximum response but also the accumulated damage of isolation devices over long-duration, cyclic loading should be evaluated.

e) The response of the isolation system to the wind loads is calculated first. The safety evaluation of the isolation devices should be conducted then.

D.3 Evaluation of seismic isolation system in ULS

D.3.1 General

a) In the ULS, responses of the seismic isolation system should be evaluated.

b) Allowable Stress Design method should be used to calculate the wind response.

c) This Annex shows methods to evaluate the characteristics of the wind responses which are different from the characteristics of seismic responses. The evaluation method should consider the rate of loading, amplitude dependencies and temperature dependencies of isolation devices. The static “creep” response of isolation systems subjected to static mean components of the wind loads should also be considered.

D.3.2 Design concepts

a) The estimation of the wind loads for seismically base-isolated buildings should be carefully undertaken. The across-wind and torsional responses of a seismically base-isolated building are likely to be greater for a similar sized conventional building. For seismically isolated buildings with an aspect ratio ($H/\sqrt{BD}$, where H: building height, B: building width, D: building depth) more than three, the combination of the wind loads (along-wind force, across-wind force and torsional moment) should be considered.

b) Safety evaluation of the isolation devices should be based on appropriate cyclic loading tests.

c) Isolation devices which support the vertical loads of buildings should not experience changes in properties due to the wind loads. Therefore, isolation devices such as laminated rubber bearings and sliding bearings, should be designed to ensure that any changes or deterioration in their performance due to the ULS wind loads are negligible.

d) In using wind-restraint devices to limit the deformation or damages of the isolation system under the wind loads, those devices should be confirmed to have expected performance. In addition, the design should ensure the safety of the seismically base-isolated building under a strong wind when the wind-restraint devices malfunction or fail to operate as intended.

e) Other items: since the wind response of a seismically base-isolated building usually will be greater than that of a similar-sized conventional building, the following items should be considered.

   1) habitability

   2) aerodynamic instable vibration

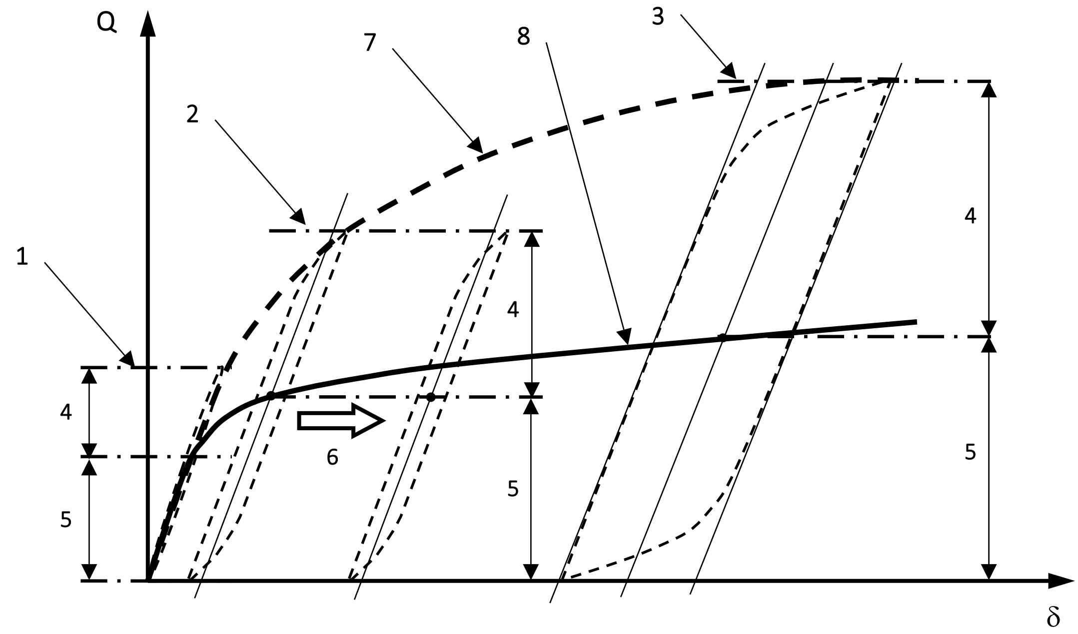
D.3.3 Verification procedures

a) This Annex classifies seismically base-isolated buildings into three categories: Rank A, B and C, shown in the Table D.1 and Figure D.1, depending on the response displacement of the isolation system calculated statically. Based on the Rank, different requirements and evaluation methods apply.

b) In the ULS, the safety of the seismic isolation system should be verified according to the classification as follows.

Table D.1 — Classification by Rank of seismically base-isolated buildings in terms of wind response of the isolation system

Rank A	The response of the isolation system is in the elastic range
Rank B	The maximum response of the isolation system exceeds the elastic range, but the response to the fluctuating component of the wind load is in the elastic range
Rank C	Both the maximum response and the response to the fluctuating component of the wind load exceed the elastic limit of the isolation system



Key

Q shear force of the seismic isolation system

δ horizontal deformation of the seismic isolation system

1 Rank A

2 Rank B

3 Rank C

4 fluctuating wind load

5 mean wind load

6 creep deformation

7 skeleton curve of the seismic isolation system (for seismic design)

8 balance point curve of the seismic isolation system with mean wind load (without creep deformation)

Figure D.1 — Idealized force-deformation curve of seismic isolation level showing categories

1) Rank A:

Cases fall in this category where the response of an isolation system to the wind action remains in its elastic range. There are two cases: (a) No isolation devices exceed their elastic limits, (b) if devices having static "creep" characteristics or sliding bearings comprise parts of the isolation system, the restoring force of the isolation system, excluding those devices, remains in elastic range or the friction force of the sliding bearings only can sustain the wind action.

- Since the responses of all isolation devices remain in its elastic range, no special assessments are required.
- In case (b), those devices having static "creep" characteristics or sliding bearings should accommodate the response of the isolation system and keep their functions.

2) Rank B:

Cases fall in this category where the response of an isolation system to the wind action exceeds its elastic range, while the response to the fluctuating component remains in the elastic range.

- The response to the mean and fluctuating components may be calculated separately by a static procedure. To calculate the response to the mean component, those devices having static “creep” characteristics or sliding bearings should be excluded in the hysteresis model of the isolation system. To calculate the response to the fluctuating component, the seismic response analysis hysteresis model may be used.
- The responses of the major isolation devices should remain in the elastic range. The yielded isolation devices should be confirmed to accommodate the response and have enough safety.
- Taking into account that the wind action may last for long time, the safety of the isolation devices used in the isolation system should be verified for the wind action that lasts for 2-3 hours.
- The response displacement to the mean component should be treated as a residual deformation. The isolators should have enough safety to support the building. The function of the building should be maintained. Otherwise, the devices should be pushed back to the original positions.

3) Rank C:

Cases fall in this category where the response of an isolation system to the wind action exceeds its elastic range. The response to the fluctuating component of the wind action also exceeds its elastic range.

- In principle, verification by time history analysis is required. Structural safety should be verified based on the maximum deformation and fatigue damages of the isolation devices.
- The assessments of the fatigue damages and the energy dissipation of the isolation devices are necessary. Thus, detailed modelling of the wind loads including their time duration is required.
- In case residual deformation occur, the isolators should have enough safety to support the building. The function of the building should be maintained. Otherwise, the devices should be pushed back to the original positions.
- Safety should be confirmed in the entire period of the service life of the building. For this purpose, fatigue damages accumulated during the service life should be assessed in addition to the safety assessment for the ULS wind loads.

D.4 Design of seismic isolation devices

D.4.1 Items of evaluation

a) The design of seismic isolation devices should ensure that their function is maintained during and after both SLS and ULS. Therefore, a wind safety evaluation should be conducted.

b) In the wind safety evaluation, the characteristics of the wind should be appropriately considered. These include the potential for a long duration of fluctuating component of loading which may result in fatigue damage, a reduction in stiffness resulting from an increase in temperature, possible strength degradation and creep deformation resulting from the mean component of the wind load.

c) The change in mechanical characteristics of the isolation devices resulting from temperature rise or cycled deformations should not exceed the allowable limit values set for the device. If a change in the mechanical characteristics results from the wind loads, and this change is anticipated to affect the overall building response, the change in the mechanical characteristics should be considered in the response analysis.

d) For seismic isolation devices that may accumulate damage in frequent earthquakes or winds over the service period of the building (for example the fatigue of metal devices), the devices should be carefully evaluated considering these effects.

e) The wind safety evaluation should include the estimation of horizontal residual deformation after the wind actions.

D.4.2 Evaluation of wind resistant performance

a) Safety of seismic isolation devices to the wind loads should be evaluated based on experimental test results or accepted evaluation methods and established safety limits.

b) Safety of seismic isolation devices to the wind loads should be evaluated depending on a comparison of the expected stress level in the device to the yield stress, and classified into 3 Ranks 'i', 'ii' and 'iii' as described below.

1) Rank i:

This rank is for the case when the stress in the isolation devices resulting from the wind loads does not exceed the yield stress. In this case, the safety evaluation method may be simplified. For devices which show elasto-plastic behaviour in the small amplitude range, it is recommended that they be considered as Rank ii, even if the stresses are lower than the yield stress levels of the restoring force models for earthquake response analyses.

2) Rank ii:

This rank is for the case when the stresses in the isolation devices exceed the yield stress, however, the stresses due to the fluctuating components of the wind loads do not. In this case, the safety should be evaluated, and the fluctuating components of the wind loads may be modelled as equivalent sinusoidal waves of constant amplitude corresponding to the maximum wind amplitude.

3) Rank iii

This rank is for the case when the stresses in the isolation devices resulting from the fluctuating load exceed the yield stress. In the case that the response level of isolation system is Rank C, a detailed evaluation of the safety should be made, and the evaluation should be conducted considering the detailed representation of the wind loads. If the characteristics of the isolation devices vary due to repeated deformation, it should be judged whether the assumed variances in the mechanical properties defined for the wind response analyses are adequate.

For the fluid dampers, such as oil dampers, the rank should be set equal to the rank of the major hysteretic isolation devices installed in the building. If there are no other hysteretic isolation devices, the rank should be set as Rank ii or Rank iii.

c) When simplifying the wind loads on the isolation devices to be equivalent sinusoidal waves of constant amplitude, the duration and the amplitude should be adequately determined. The equivalent applied duration should be defined based on an examination of the meteorological conditions, including the velocity histories, at the construction site. The amplitude of the equivalent sinusoidal wave representing the fluctuating component of the wind should be defined as the maximum wind load multiplied by a reduction factor, which is defined so that the cumulative fatigue damage, energy dissipation, and cumulative deformation are equivalent to the original values.

d) For cases where deterioration of the isolation devices (such as cracks or large residual deformation) is expected, or if wind trigger which restrains the deformation in small loading level or stoppers are necessary to be pushed back to their original state, the method should be specified in the maintenance plan developed for the building.

Annex E
(informative)

Mid-storey seismically isolated buildings

E.1 General

E.1.1 Application

This Annex is applicable to the isolation design of new mid-storey seismically isolated buildings. The mid-storey isolation retrofit for existing buildings can be carried out in accordance with this guideline.

E.2 Technical terms

E.2.1
mid-storey isolation
seismic isolation configuration with an isolation interface at a mid-storey above the bottom of the building, usually at the lower part of the building.

E.3 Notations and definitions

The mid-storey seismically isolated building can be modelled as a lumped mass-spring-damper storey-system shown in Figure E.1. M_{un}, K_{un} and C_{un} denote the lumped mass, the lateral stiffness, and the damping coefficient of the n-th storey in the superstructure, respectively. M_{sm}, K_{sm} and C_{sm} are the lumped mass, the lateral stiffness, and the damping coefficient of the m-th storey in the substructure. M_b, K_b and C_b represent the lumped mass, the lateral stiffness, and the damping coefficient of the seismic isolation interface, respectively.

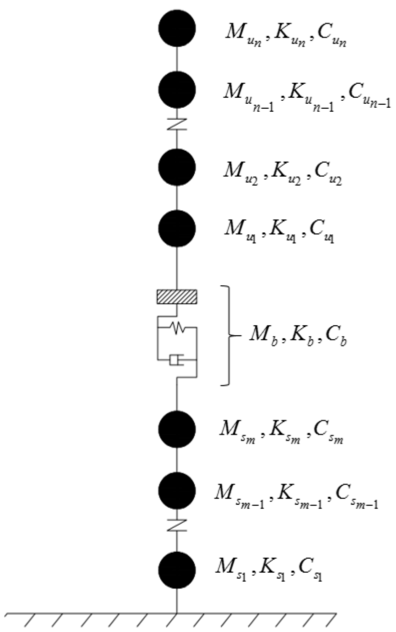


Figure E.1 — Diagrammatic sketch of mid-storey seismically isolated building

E.4 Basic requirements

E.4.1 General

a) The isolation interface of the mid-storey seismically isolated building should be located at the middle or lower parts of the building, or the location where the structural type or feature changes.

b) The calculation of the vertical seismic action for the mid-storey seismically isolated building should be carried out.

E.4.2 Seismic isolation interface

a) The seismic isolation interface of the mid-storey seismically isolated building should possess sufficient safe margin not only for earthquakes but also for wind loads and other non-seismic actions. Vertical creep should be kept small enough for each isolator. The horizontal residual deformation should be small enough after the horizontal action by seismic load or wind load.

b) The seismic isolation interface should provide necessary load bearing capacity, lateral stiffness and damping. The pipelines, circuits of equipment and stairs crossing the seismic isolation interface should adopt flexible connection and other effective measures to withstand the horizontal displacement under ultimate limit state of seismic action.

c) Measures should be taken to protect the mid-storey isolation interface under excessive displacement.

d) Fire protection measures should be taken for the seismic isolation interface.

E.4.3 Superstructure

a) The superstructure should be designed considering the additional stresses caused by wind load and other loads during construction stage. When calculating the vertical load action, the additional internal force of the structure caused by the vertical deformation of isolators should be considered.

b) The maximum drift of superstructures under earthquakes should meet the limit requirement of the mid-storey seismically isolated building.

E.4.4 Substructure

a) The substructure should stably support the loads transferred from the superstructure.

b) The connections of the isolators with the superstructure and the substructure should be able to transfer the ultimate horizontal shear force of the isolator unit under earthquake.

c) The elasto-plastic storey drift of substructure should be strictly controlled to ensure that the isolation interface can work reliably under earthquakes of ultimate limit state.

E.5 Design of mid-storey seismically isolated buildings

E.5.1 General

The design of mid-storey seismically isolated building includes calculation of the representative load of the superstructure, layout and design of the isolation devices, dynamic analysis and calculation of the mid-storey isolated building, comparison, and analysis of the results, etc. Response history analysis method should be adopted in the response analysis.

E.5.2 Structural modelling

The analysis model of the mid-storey seismically isolated building should comply with the following provisions:

a) The selected analytical model should be able to reasonably reflect the actual stress conditions of the structural members.

b) The superstructure and the substructure can be calculated by the lumped-mass-spring system, or three-dimensional structural model.

c) The calculation model of the isolators and dampers should be selected according to its mechanical performance.

E.5.3 Seismic action

The design seismic action for the mid-storey seismically isolated building on rock soils can be referred to that adopted for the base isolated building. The design seismic action for the mid-storey seismically isolated building on soft soils should be corrected taking into account substructure-soil interaction.

E.5.4 Design of isolation interface

E.5.4.1 Plane layout of isolators

The layout of the isolation interface should comply with the following provisions:

a) The plane layout of isolators of the mid-storey seismically isolated building should correspond to the position of the vertical members in both superstructure and substructure. Otherwise, reliable structural transformation measures should be adopted.

b) The size, quantity and configuration of the isolators should be determined by calculation according to the requirements of vertical bearing capacity, lateral stiffness, and damping. Further, measures for the convenience of check and replacement should also be considered.

c) If there are external walls, elevator shafts and elevator systems or some isolation devices of the isolation interface are at different elevations, effective measures should be taken to ensure that the isolation devices work collaboratively.

d) When multiple seismic isolators are used at the same support, the gap between the isolators should not be less than the space required for installation and replacement.

e) If needed, the damping device, wind-resistant device or anti-tension device of the isolation interface should be reasonably arranged in the building.

E.5.5 Design of superstructure

The design of superstructure of the mid-storey isolated building should follow the design of the seismically base isolated building.

E.5.6 Design of substructure and foundation

a) The bearing capacity of the substructure should be checked under combination of axial force, bending moment, horizontal shear force transmitted by the superstructure. The additional bending moment caused by the vertical load under the shear deformation of the isolators should also be considered.

b) The bearing capacity of pillars and connected components at the isolation interface should be checked under vertical force, horizontal force and bending moment under ultimate limit state of seismic action.

c) The design of foundation and base of the mid-storey isolated building can be referred to the design of the seismically base isolated building.

E.6 Seismic isolation detailing

E.6.1 General

a) The mid-storey seismically isolated buildings should be designed avoiding collisions and obstruction under deformation of the isolation interface under seismic action.

b) The in-plane stiffness of the floor or beam systems on the top and the bottom of the seismic-isolation interface, should be sufficient to ensure the seismic isolation motion in synchronous manner.

c) Fire protection measures according to the architectural function should be considered for each isolator and its connection.

E.6.2 Connection between isolator and structure

a) The ultimate capacity of the connection between the isolator and the structure should be reliable, to ensure its undamaged state even when isolator reaches its ultimate failure state. Exposed embedded parts should have reliable anti-rust treatment. The exposed surface of the metal parts of the isolator should be treated with anticorrosion measures.

b) Local compression damage of the structural pillar bearing the isolator should be avoided.

E.6.3 Isolation gap

a) The horizontal isolation gap should be set between the superstructure and the surrounding fixtures to avoid possible obstruction or collision under ultimate limit state of seismic action.

b) The vertical isolation gap should be set between the superstructure and the substructure to comply with the creep and the vertical deformation of isolators.

c) The elevator shaft crossing the isolation interface may be directly suspended. The width of the isolation gap between the elevator shaft and the substructure should be large enough.

d) Generally, sliding cover plates should be set between the entrance of the suspended elevator shaft and the substructure. Sufficient sliding capacity of the sliding cover plates should be considered under ultimate limit state of seismic action.

E.6.4 Facilities and pipelines crossing the seismic isolation interface

a) The staircase, the handrails, the elevators, the ramps, and other facilities crossing the seismic-isolation interface, should avoid possible obstruction and collision under seismic action, and should adopt disconnection or deformable structural measures at appropriate locations.

b) Flexible measures should be adopted for the pipeline crossing the seismic-isolation layer and the reserved horizontal deformation should not be less than the width of the isolation gap.

c) When using steel bars as lightning rods, flexible conductors should be used to connect the steel bars of the superstructures and substructures of the seismic-isolation interface.

E.7 Construction and maintenance of mid-storey seismically isolated buildings

E.7.1 Construction of mid-storey seismically isolated buildings

Construction of the mid-storey seismically isolated buildings follows the guideline described in the Annex B: Construction management of seismically isolated structures.

E.7.2 Maintenance of mid-storey seismically isolated buildings

Maintenance of the mid-storey seismically isolated buildings follows the guideline described in the Annex C: Management of seismically isolated structures.

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