INTERNATIONAL STANDARD

ISO 16711

First edition
2015-05-01

Seismic assessment and retrofit of concrete structures

Évaluation sismique et réhabilitation de structures en béton

Reference number
ISO 16711:2015(E)

Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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

The committee responsible for this document is ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 7, *Maintenance and repair of concrete structures*.

Introduction

Earthquakes bringing damage to structures have occurred frequently in many areas of the world. Heavy damage caused by earthquakes are concentrated on vulnerable structures. Due to these damaging earthquakes, human lives are lost and confusion in everyday life and stagnation of economic activities occur.

As the result of the direct action of earthquakes, structures may collapse or overturn in earthquake-prone areas. However, given a main shock occurs, it is expected that through seismic assessment and retrofit of concrete structures, human life losses, economical losses, and structural collapses could be mitigated and/or prevented and quick recovery could be attained.

In some nations, such as Japan and USA, the framework for the identification of vulnerable structures before and after an earthquake, seismic retrofit decision-making and construction exists. In addition, the standards for seismic assessment technology and for seismic retrofit technology are already established in those nations. Furthermore, technical manuals, in order to apply the standards to practical work, are established. Therefore, based on these standards, the social system is built where a country, a district and a local administrative agency (authorities), the owner of the structure, a user, a retrofit designer, a retrofit work supervisor, a retrofit work supplier, and other people concerned on this matter share a purpose of the seismic retrofit and the information about the effect of seismic retrofit, and the owner of the structure can judge the necessity of appropriate retrofit, and a seismic retrofit execution is carried out smoothly.

However, it is not so frequent that a huge earthquake disaster occurs in a specific country or an area. These conditions disturb conducting seismic assessment, seismic retrofit work, and smooth social decision making to conduct seismic retrofit. As a result, it is feared that the earthquake disaster will expand and the recovery from the disaster will be delayed when a large earthquake disaster happens once.

Therefore, it is necessary to establish a principle of seismic assessment, decision making for seismic retrofit, the framework of the procedure for screening the vulnerable structures, and seismic retrofit execution. This International Standard provides comprehensive principle on the evaluation of the seismic damage/expected damage of existing reinforced concrete structures and repair/retrofit. In other words, this International Standard provides the standard work items related to seismic assessment and retrofit, and standard procedures in each stage, and makes contents and the scope of each duty clear.

In this International Standard, the seismic performance of existing reinforced concrete structures is expressed in terms of the intensity of earthquake motions that will lead the structures to the safety limit state[1)] in principle. As the result, whether the existing RC structures fulfill the provisions of the design standard in the specific country or area does not matter. That is the feature of this International Standard.

The retrofit can be also conducted based on seismic performance, not on whether the seismic retrofit meets an existing standard. Because this International Standard set such a rational performance requirement mentioned above, the vulnerable parts which should be reinforced are clearly identified.

1) Ultimate limit state is mainly considered. However, other limit states may be considered such as seismic damage control limit state when time history analysis is used.

Seismic assessment and retrofit of concrete structures

1 Scope

The purpose of this International Standard is to reduce the risk of seismic damage by structural collapse or turnover during a seismic event.

This International Standard provides frameworks and principles of methods of detailed seismic assessment and the judgment, seismic retrofit plan and design, seismic retrofit execution of existing reinforced concrete structures before the occurrence of a severe earthquake and of the structures struck by an earthquake.

This International Standard is applicable to reinforced concrete structures and pre-stressed concrete structures that have been designed on the basis of the structural design criteria set in a specific country or region. It is not applicable to either unreinforced concrete structures or masonry structures.

2 Normative references

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

There are no normative references.

3 Terms and definitions

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

3.1
assessment
set of activities performed in order to verify the reliability of an existing structure for future use

[SOURCE: ISO 13822:2010]

3.2
collapse
loss of the load-carrying capacity of a component or member within a structure or of the structure itself

3.3
damage control limit state
ability of a structure or structural element to be repaired physically and economically when damaged under the effects of considered actions

3.4
design documents
results of structural calculation and design drawings

3.5
design service life
period for which the structure is assumed to be in adequate condition for its intended purpose or function with anticipated maintenance but without requiring substantial repair being necessary

3.6
inspection
conformity evaluation by observation and judgment accompanied as appropriate by measurement, testing or gauging.

[SOURCE: ISO 16311-2:2014]

Note 1 to entry: For structures, this evaluation consists of actions collecting information on the current state of a structure through observation and simplified non-destructive or destructive testing supplemented with materials and structural testing, as required.

3.7
investigation
collection of information through inspection, document search, load testing and other testing

[SOURCE: ISO 16311-1:2014]

3.8
limit of displacement
allowable deformation of the structure in terms of parameters such as inter-story drift and overall horizontal displacement, to control excessive deflection, cracking and vibration

3.9
limit state
critical state specified using a performance index, beyond which the structure no longer satisfies a design performance requirement

[SOURCE: ISO 19338:2014]

3.10
maintenance
set of activities taken to check, evaluate, and preserve/restore structural performance so as to satisfy in service performance requirements

[SOURCE: ISO 16311-1:2014]

3.11
structural repair
restoration of a structure or its components to an acceptable condition by the renewal or replacement of worn, damaged or deteriorated components

[SOURCE: ISO 13823:2008]

Note 1 to entry: Repair is adopted to restore structural performance and to mitigate safety risks up to the initially required design level and to achieve the intended service life.

3.12
restorability (or reparability)
ability of a structure or structural element to be repaired physically and economically when damaged under the effects of considered actions

[SOURCE: ISO 19338:2014]

3.13
life safety performance level
ability of a structure or structural element to ensure no casualty to users of, and people around, the structure, within the limits of acceptable probability

[SOURCE: ISO 19338:2014]

3.14
seismic capacity
force or displacement defined for the limit states

Note 1 to entry: Multiple limit states could be selected besides the life safety limit state, such as acceptable economic loss limit state, reparability limit state, immediate occupancy limit state, or functionality limit state.

3.15
performance objective
required performance level (e.g. life safety) for a given earthquake hazard level (e.g. an earthquake with a 10 % probability of exceedance in 50 years)

3.16
seismic damage
physical evidence of inelastic deformation, cracks or spalling of a structural component caused by an earthquake

3.17
seismic retrofit
restoring or improving the seismic performance of a pre- or post-earthquake existing structure to meet the seismic performance objective, including "structural repair" and "strengthening"

3.18
serviceability
ability of a structure or structural elements to provide appropriate behaviour or functionality in use under the effects of considered actions at serviceability limit state

[SOURCE: ISO 19338:2014]

3.19
service life
actual period during which a structure meets the prescribed performance requirement

[SOURCE: ISO 16311-1:2014]

3.20
strengthening
measures taken to improve structural performance relating to load bearing capacity and deformation of an existing structure and/or its members

[SOURCE: ISO 16311-1:2014]

4 Framework of Assessment and Retrofit

The seismic assessment and retrofit of an existing structure should obey the following procedures after identifying the performance requirements and drafting an overall plan from investigation through detailed seismic assessment, construction and documentation. The schematic of the process is shown in Figure 1. Details of each item are described after Clause 5. All of these items are not necessarily executed; the procedure should be initiated in order from (1), but it may be finished at any stage according to the specific situation under consideration.

(1) Preliminary assessment

The possibility of a structure's collapse or turnover under severe earthquake should be assessed based on the comprehensive information of the structure, such as design documents at the time of design, history of usage and the construction's compliance with the design standard. The inspection of the seismic performance should be carried out in consultation with the client (the owner, the authority, etc.), if the seismic performance is suspected or not clearly adequate.

(2) Detailed seismic assessment

In order to make them clear, those are seismic capacity of an existing RC structure or PSC structure and vulnerable parts in it, detailed seismic assessment should be conducted. And also, the necessity of the seismic retrofit should be determined by comparing the evaluated seismic performance and the seismic performance objectives. The planning of the seismic retrofit should be carried out in consultation with the client (the owner, the authority, etc.), if the deficiency in seismic performance is confirmed.

(3) Planning of seismic retrofit

The plan of the seismic retrofit including outline of the retrofit and construction method should be determined. The validity of the plan should be verified by estimating the seismic performance of the structure after construction. The seismic retrofit execution should be then carried out in consultation with the client (the owner, the authority, etc.), taking into consideration the estimated cost for construction work.

(4) Seismic retrofit execution

The construction method for each structural member should be determined in compliance with the seismic retrofit plan. The construction should be then carried out under the proper supervision and the quality control of the work. The procedure of the work should be documented in a report.

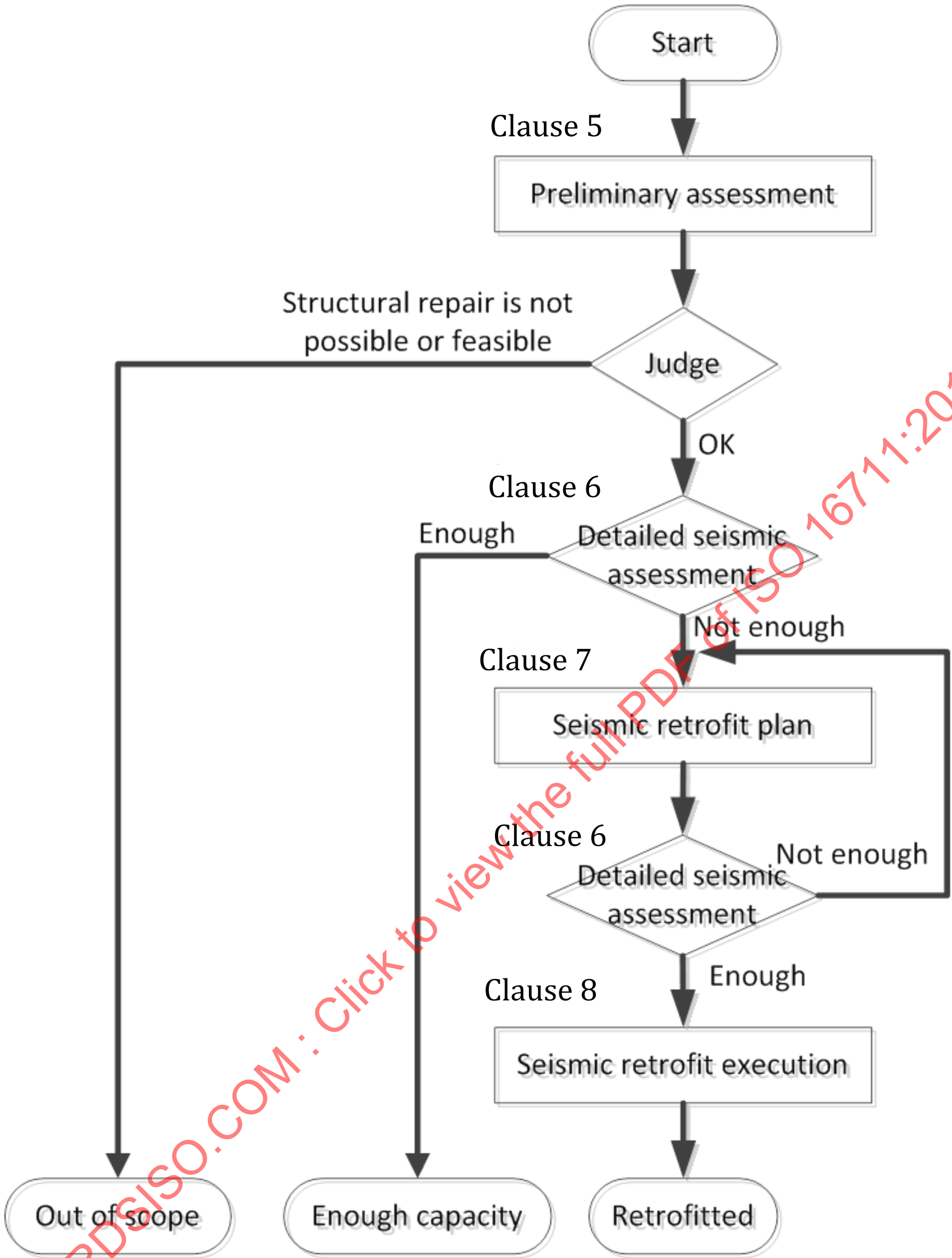

Figure 1 — Procedure of detailed seismic assessment and retrofit

Detailed seismic assessment, retrofit design and execution, construction management and inspection should be conducted by a competent person with the appropriate qualifications, as required by national, regional or local regulations.

5 Preliminary assessment

5.1 General

The preliminary inspection of a structure is conducted to judge the necessity of the detailed seismic assessment and retrofit of the structure in advance. In the preliminary inspection, necessary information to decide the execution of detailed seismic assessment and retrofit is collected by the inspection of the structure regarding the assessment items in 5.2.

5.2 Investigation items

In principle, the following items (1) to (8) should be investigated in the preliminary investigation.

(1) Year of construction

The date and year of design of the structure and the date and year of completion of the structure should be investigated. This will help to know the design standard by which the structure was designed, material properties, arrangement of reinforcement and structural details.

(2) Design standard

Design standard by which the structure was designed should be known. This will reveal the design method by which the structure was designed and the level of seismic performance the structure was designed for.

(3) Existence of design documents

In order to know structural detail and material properties in the objective structure, existence of design documents of the structure, namely architectural drawings, structural drawings, drawings of structural detail, special specification and results of structural calculation, should be confirmed. Where design documents are not available namely architectural drawings, structural drawings, drawing of structural details, efforts should be made to collect as much information as possible so as to recreate these documents.

(4) Predicted intensity of earthquake

In order to examine seismic performance of the structure after retrofitting, the intensity of earthquake that may hit the structure in future should be investigated.

The earthquake hazard level must be established for the site or if the earthquake hazard levels for current new construction should be used.

(5) Record of accident, damage and repair or retrofit

In order to adequately estimate seismic performance of the objective structure, the existence of maintenance record of the structure, which concerns accident, damage and repair or retrofit that the structure, such as fire accident or deterioration due to chemicals, has ever experienced, should be confirmed.

(6) History of change in usage of structure

In order to know the design load of the structure, the history of change in the usage of the structure should be investigated.

(7) Problem in serviceability

In order to consider the influence on seismic performance of the structure, problems in serviceability of the structure, such as deflection of beam and slab, should be investigated.

(8) Detail of the damage caused by the earthquake

In case the structure has just been damaged by an earthquake, the condition of the damage should be investigated in order to adequately estimate seismic performance of the structure.

5.3 Judgment

Based on the information obtained by the preliminary investigation, the necessity of a detailed seismic assessment and retrofit should be judged considering its corresponding costs, the importance of the structure, and the emergency.

6 Detailed seismic assessment

6.1 General

Seismic capacity of structures should be estimated according to the earthquake level when the structure just reaches its safety limit state. Detailed inspection should be conducted to understand the current condition of the structure into account. Seismic performance objective should be estimated according to an expected earthquake level at site for the safety limit state. Detailed seismic assessment should be conducted by comparing the seismic capacity and the seismic performance objective. Detailed seismic assessment results should be stored properly.

6.2 Detailed investigation

Items (1) to (5) should be investigated in a detailed seismic assessment. The detailed investigation results should be taken in context and stored properly.

(1) Design drawings conformance

Dimensions, arrangement of structural members should be confirmed with design drawings. Diameter, number, and strength of steel bars, anchorage shape of steel bar ends, bar arrangements, hoop pitch, lap joint length of main bars, and etc. should be confirmed with nondestructive inspection or partial destructive inspection at site. If no drawings are available, enough number of material samples, more than three samples at each floor of the same term of construction work for example, must be taken and tested to estimate the properties of materials.

(2) Material strengths

In principle, strengths of steel bars, steels, and concrete should be confirmed with samples taken from the structure. If the sample test gives stronger strength than the design value, the test result can be applied for the detailed seismic assessment. If the test gives weaker strength than the design value, the reduced strength from the design value must be applied considering fluctuation of material strength. Other properties such as Young's modulus should be investigated in case of necessity.

(3) Material deterioration

Structural crack pattern and the cause of the crack, structural appearance deterioration, and neutralization depth of concrete sample should be investigated.

(4) Permanent Deformation

Inclination, residual deformation, and uneven settlement of the structure should be investigated.

(5) Seismic damage investigation

If the structure has suffered structural damage from an earthquake, the damage condition such as inclination, residual deformation, crack pattern (seismic damage level) of all structural members should be investigated visually or measured.

6.3 Analysis

In principle, the seismic capacity should be calculated by one of the following four methods. Stiffness, ultimate strength, and ductility of structural members should be considered properly for the calculation. Material deterioration, structural deformation, and the effects of suffered damage history such as fire accidents or earthquakes should be taken into account. The ultimate strength and ductility of structural members of a damaged structure due to an earthquake can be estimated as properly reduced values from the values without seismic damage. The reduced values should be confirmed by experiment and/or appropriate analysis.

(1) Improved strength method

The seismic capacity is calculated in terms of an energy dissipation capacity evaluated based on the ultimate strength and ductility of structural members. Energy dissipation capacity is expressed as the product of strength index and ductility index. Stiffness discontinuity along stories, eccentric distribution of stiffness in the plan, or irregularity and/or complexity of the structural configuration should be considered. Time-dependent deterioration effect should be considered

(2) Load-carrying capacity method based on nonlinear pushover analysis

This method is based on nonlinear pushover analysis of a whole structure including the effect of non-structural elements. Seismic performance objectives (described in the next clause) are defined as the strength at the specified story drift or ductility factor in general. The demand strength associated with the specified story drift or the ductility factor is feasibly defined as the capacity of the energy dissipation of a whole structure to the design earthquake level. The earthquake level may be defined as linear earthquake response spectrum, nonlinear earthquake response spectrum, or earthquake input energy spectrum. The whole structure should be properly modelled, considering nonlinear material characteristics and time-dependent deterioration.

(3) Nonlinear dynamic response analysis method

This method is based on nonlinear time history response analysis with the appropriate ground motion at site. Seismic performance objectives (described in the next clause) are defined as story drift angle or ductility factor in general. The maximum response values should be verified to be smaller than the seismic performance objectives. It is recommended that the seismic capacity is feasibly expressed as the rate of the peak value of the design ground motion corresponding ultimate stage to the design ground motion.

(4) Verification method by the current national seismic code

The verification method specified by the national seismic code may be used based on prudent engineering judgment and site conditions.

6.4 Seismic performance objectives

Seismic performance objectives for each analysis listed in 6.3 should be set as the following:

(1) energy dissipation capacity;

(2) strength at specified drift;

(3) rate of peak ground motion to the design ground motion.

Seismic performance objective should consider the (i) seismic activity in the area, soil amplification, and expected earthquake at site and the (ii) dynamic characteristics of the structure, effect of underground floors, and level of importance of the structure.

6.5 Judgment

Seismic safety of structures should be judged by comparing the seismic capacity and seismic performance objective.

6.6 Documentation

The detailed seismic assessment results from 6.2 to 6.5 should be taken in context and stored properly.

7 Seismic retrofit plan

7.1 General

When an owner or a caretaker of a concrete structure decides that a structure is vulnerable to an expected earthquake and needs seismic retrofit, a seismic retrofit plan should be made in advance to retrofit work. Seismic retrofit plan should consist of the following:

1) selection of a performance objective of the seismic retrofit;

2) selection of basic strategy to reduce vulnerability;

3) planning of modification of members, including type of retrofit construction method, material, location and number of modified members;

4) re-evaluation of seismic vulnerability with the modification;

5) confirmation.

The seismic retrofit plan from 1) to 5) should be documented and provided to the owner or the caretaker of the concrete structure.

7.2 Selection of performance objectives of the seismic retrofit

Performance objectives are selected primarily for life safety performance usually. However, multiple performance objectives could be selected besides the life safety performance, if necessary. Such performance objectives include economic loss based performance, reparability performance, immediate occupancy performance, or loss of function.

Performance objectives of the seismic retrofit should be decided with consideration of the following items:

— remaining life of the structure;

— use of the structure;

— importance of the structure;

— extent of emergency;

— maintenance plan.

7.3 Selection of basic strategy for seismic retrofit

Basic retrofit strategy is chosen such that

1) local weakness of the structural members and connections could be reinforced,

2) lateral capacity and ductility of structural system should increase, or

3) seismic demand to structure should be decreased.

The following factors should be considered in selecting the retrofit strategy.

— change of weight and the distribution of weight;

— change of stiffness and horizontal/vertical distribution of stiffness;

— change of strength and horizontal/vertical distribution of strength;

— change of ductility and horizontal/vertical distribution of ductility;

— change of load path and magnitude of load due to the addition or removal of structural/nonstructural members.

If information available is insufficient to determine the basic retrofit planning, additional investigation/inspection at the site of the structure should be carried out on the following items:

— geometry and dimensions of the existing members, reinforcing bar arrangement, extent of existing damage and deterioration due to fire and severe environment etc.;

— condition of supporting soil.

7.4 Planning of retrofit

The retrofit construction method should be adopted from the methods by which the strength, stiffness and ductility of the retrofitted member and retrofitted structural system can be reasonably predicted. When a retrofit construction method is chosen, the following conditions should be accounted for:

— scope;

— feasibility of construction;

— feasibility of maintenance;

— economical effectiveness;

— environmental impacts;

— durability and fire resistance.

When a new retrofit construction method is adopted and no standard method for prediction of strength, stiffness and ductility exist, the structural performance of a retrofitted member should be verified by an experiment of a sub-assemblage of retrofitted members or any other rational method.

7.5 Seismic re-evaluation

Based on the selected basic strategy of the retrofit and the plan of the modification, the seismic vulnerability should be evaluated using the same method described in 6.3. To evaluate the vulnerability of the retrofitted structure, the appropriate safety margin in evaluating the strength, stiffness and ductility should be reserved.

7.6 Confirmation

Based on the selected seismic performance objectives, the seismic vulnerability of the retrofitted structure should be confirmed using the same method described in 6.5.

7.7 Documentation

The seismic retrofit plan should be documented to record the basis and the process of the retrofit planning and decisions made described in 7.2 to 7.6. As an appendix, the location, number and type of retrofitted construction should be shown on the plan and the elevation of the existing structure, as well as lists of additional members, strengthened members, repaired members and connections.

The documentation should be described in detail such that the planning of construction, as well as estimation of the total cost of the retrofit construction, could be feasible.

