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Requirements for seismic assessment and retrofit of concrete structures

Exigences relatives à l'évaluation sismique et à la réhabilitation des structures en béton

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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 of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 7, *Maintenance and repair of concrete structures*.

This second edition cancels and replaces the first edition (ISO 16711:2015), which has been technically revised.

The main change compared to the previous edition is the addition of a new paragraph in 5.3.

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

Introduction

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 likely to be lost. Confusion in everyday life and stagnation of economic activities also occur.

As the result of the direct action of earthquakes, structures can 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 can be mitigated and/or prevented and quick recovery can be attained.

In some countries, such as Japan and the 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 have already been established in these countries. Furthermore, technical manuals have been established in order to apply the standards to practical work. 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 by this matter share a purpose of the seismic retrofit and the information about the effect of seismic retrofit. Also, 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 expands and the recovery from the disaster is delayed when a large earthquake disaster happens once.

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

In this document, the seismic performance of an existing reinforced concrete structure is expressed in terms of the intensity of earthquake motions that lead the structures to the safety limit state[1)] in principle. As the result, whether the existing reinforced concrete (referred to as RC, hereafter) structures fulfil the provisions of the design standard in the specific country or area does not matter. That is the feature of this document.

The retrofit can be also conducted based on seismic performance, not on whether the seismic retrofit meets an existing standard. Because this document sets such rational performance requirements, the vulnerable parts which should be reinforced are clearly identified.

National and regional standards are generally more prescriptive in nature than International Standards and vary somewhat from region to region.

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

Requirements for seismic assessment and retrofit of concrete structures

1 Scope

This document provides requirements for seismic assessment and retrofit of concrete structures.

It can be used to reduce the risk of seismic damage by structural collapse or turnover during a seismic event.

This document provides the framework 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.

It is an umbrella-type document with general provisions intended to provide wide latitude of choice in terms of comprehensive principle on the evaluation of the seismic damage/expected damage of existing reinforced concrete structures and repair/retrofit. Therefore, it is intended to be used in conjunction with sound engineering judgment.

This document 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 unreinforced concrete and masonry structures.

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 1920-4:2020, *Testing of concrete — Part 4: Strength of hardened concrete*

ISO 15630-1:2019, *Steel for the reinforcement and prestressing of concrete — Test methods — Part 1: Reinforcing bars, rods and wire*

3 Terms and definitions

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

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

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

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

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

[SOURCE: ISO 13822:2010, 3.1]

3.2
design document
document resulting from structural calculation and design drawings

3.3
inspection
conformity evaluation by observation and judgment accompanied as appropriate by measurement, testing or gauging.

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.

[SOURCE: ISO 16311-2:2014, 3.15]

3.4
investigation
collection of information through *inspection* (3.3), document search, load testing and other testing

[SOURCE: ISO 16311-1:2014, 3.7]

3.5
limit state
critical state specified using a performance index, beyond which the structure no longer satisfies a design performance requirement

[SOURCE: ISO 19338:2014, 3.9]

3.6
maintenance
set of activities taken to check, evaluate the performance of a structure, and preserve/restore it so as to satisfy performance requirements in service

[SOURCE: ISO 16311-1:2014, 3.8]

3.7
seismic capacity
force or displacement defined for the *limit states* (3.5)

Note 1 to entry: Multiple limit states can 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.

3.8
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)

3.9
seismic damage
physical evidence of inelastic deformation, cracks or spalling of a structural component caused by an earthquake

3.10
seismic retrofit
restoring or improving the seismic performance of a pre- or post-earthquake existing structure to meet the seismic *performance objective* (3.8), including “structural repair” and “strengthening”

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.

Note 2 to entry: Strengthening relates to the measures taken to improve structural performance relating to load bearing capacity and deformation of an existing structure and/or its members.

4 Framework of assessment and retrofit

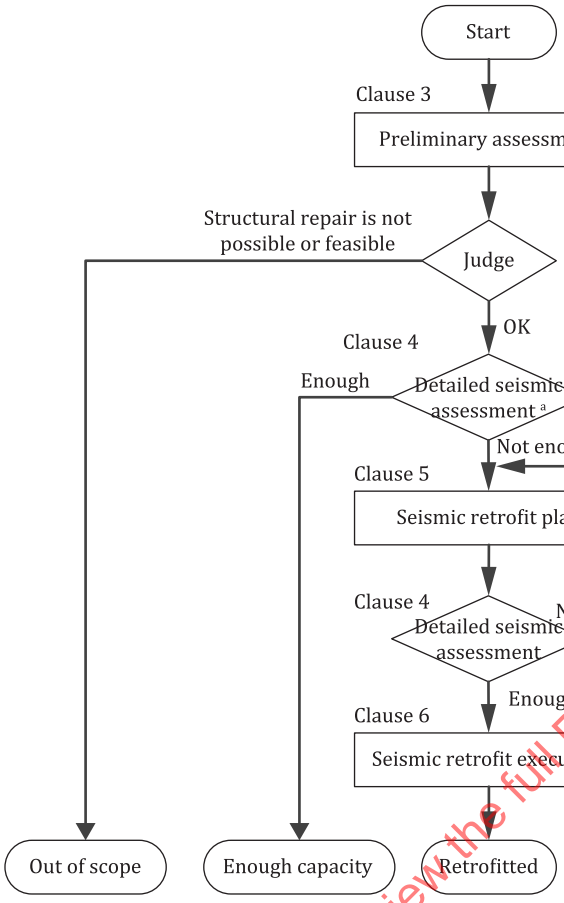
The seismic assessment and retrofit of an existing structure shall obey the following procedures after identifying the performance requirements and drafting an overall plan from investigation through detailed seismic assessment, construction and documentation. The schematic of the process is shown in Figure 1. Details of each item are described in Clause 5. All 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 earthquakes shall 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 shall 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 clarify the seismic performance of an existing RC or PSC structure and the vulnerable part of the structure, detailed seismic assessment shall be conducted. Necessity of the seismic retrofit shall be determined by comparing the evaluated seismic performance and the seismic performance objectives. The planning of the seismic retrofit shall 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 the outline of the retrofit and construction method shall be determined. The validity of the plan shall be verified by estimating the seismic performance of the structure after construction. Then, the seismic retrofit execution shall be 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 shall be determined in compliance with the seismic retrofit plan. The construction shall be then carried out under the proper supervision and the quality control of the work. The procedure of the work shall be documented in a report.



Key

a Detailed seismic assessment can have several levels.

Figure 1 — Procedure of detailed seismic assessment and retrofit

Detailed seismic assessment, retrofit design and execution, construction management and inspection shall be conducted by a competent person with the appropriate qualifications.

5 Preliminary assessment

5.1 General

The preliminary inspection of a structure shall be 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 shall be collected by the inspection of the structure regarding the assessment items in 5.2.

5.2 Investigation items

In principle, the following items shall 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 shall be investigated.

   NOTE 1 The year of construction helps to know the design standard by which the structure was designed, material properties, arrangement of reinforcement and structural details.

2) Design standard: The design standard by which the structure was designed shall be known.

NOTE 2 The design standard adopted reveals 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 details 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, shall be confirmed. Where design documents are not available namely architectural drawings, structural drawings, drawing of structural details, efforts shall 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 can hit the structure in future shall be investigated.

   The earthquake hazard level shall be established for the site or the earthquake hazard levels for current new construction shall 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 a maintenance record of the structure, which concerns accident, damage and repair or retrofit that the structure has ever experienced (such as fire accident or deterioration due to chemicals) shall 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 shall 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, shall be investigated. Where, serviceability is the 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

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 shall be investigated in order to adequately estimate seismic performance of the structure.

5.3 Judgment

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

2) Structural types designated as having sufficient seismic performance are excluded from detailed seismic evaluation and retrofit.

6 Detailed seismic assessment

6.1 General

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

6.2 Detailed investigation

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

1) Design drawings conformance: Dimensions and arrangement of structural members shall be confirmed with design drawings. The diameter, number, and strength of steel bars, anchorage shape of steel bar ends, bar arrangements, hoop pitch, lap joint length of main bars, etc., shall be confirmed with non-destructive 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, shall be taken and tested to estimate the properties of materials.

2) Material strengths: In principle, strengths of steel bars, steels, and concrete shall 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 shall be applied considering fluctuation of material strength. Other properties such as Young's modulus shall be investigated in case of necessity.

   The sample tests shall be conducted in accordance with ISO 15630-1:2019 and ISO 1920-4:2020.

3) Material deterioration: Structural crack pattern and the cause of the crack, structural appearance deterioration and carbonation depth of concrete sample shall be investigated.

4) Permanent deformation: Inclination, residual deformation and uneven settlement of the structure shall 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 shall be investigated visually or measured.

6.3 Analysis

In principle, the seismic capacity shall be calculated by one of the following four methods. Stiffness, ultimate strength and ductility of structural members shall be considered properly for the calculation. Material deterioration, structural deformation and the effects of suffered damage history, such as fire accidents or earthquakes, shall 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 shall be confirmed by experiment and/or appropriate analysis.

1) Improved strength method: The seismic capacity shall be calculated in terms of an energy dissipation capacity evaluated based on the ultimate strength and ductility of structural members. Stiffness discontinuity along stories, eccentric distribution of stiffness in the plan, or irregularity and/or complexity of the structural configuration, shall be considered. Time-dependent deterioration effect shall be considered.

   NOTE 1 Energy dissipation capacity is expressed as the product of strength index and ductility index.

2) Load-carrying capacity method based on nonlinear pushover analysis: Seismic performance objectives (described in 6.4) shall be defined as the strength at the specified story drift or ductility factor in general. The whole structure shall be properly modelled, considering nonlinear material characteristics and time-dependent deterioration.

   NOTE 2 This method is based on nonlinear pushover analysis of a whole structure including the effect of non-structural elements.

NOTE 3 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 can be defined as linear earthquake response spectrum, nonlinear earthquake response spectrum or earthquake input energy spectrum.

3) Nonlinear dynamic response analysis method: Seismic performance objectives (described in 6.4) are defined as story drift angle or ductility factor in general. The maximum response values shall 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.

NOTE 4 This method is based on nonlinear time history response analysis with the appropriate ground motion at site.

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 shall be set based on one of 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 shall be considered with 1) the seismic activity in the area, soil amplification and expected earthquake at site, and 2) the dynamic characteristics of the structure, effect of underground floors and the level of importance of the structure.

6.5 Judgment

Seismic safety of structures shall 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 shall 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 shall be made in advance to retrofit work. Seismic retrofit plan shall 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) shall 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 of the seismic retrofit shall 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.

NOTE Usually, performance objectives are selected primarily for life safety performance. However, multiple performance objectives can be selected besides the life safety performance, if necessary. Such performance objectives include economic loss based on performance, reparability performance, immediate occupancy performance or loss of function. Where, reparability is the ability of a structure or structural element to be repaired physically and economically when damaged under the effects of considered actions

7.3 Selection of basic strategy for seismic retrofit

Basic retrofit strategy shall be chosen such that:

1) local weakness of the structural members and connections can be reinforced;

2) lateral capacity and ductility of structural system can increase; or

3) seismic demand to structure can be decreased.

The following factors shall 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/non-structural members.

If available information is insufficient to determine the basic retrofit planning, additional investigation/inspection at the site of the structure shall 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 shall 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 shall be accounted for:

— scope;

— feasibility of construction;

