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Simplified structural design for reinforced concrete wall buildings

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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 5, *Simplified design standard for concrete structures*.

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

Introduction

This document aims to provide rules for the design and construction of reinforced concrete (RC) wall structures. The design rules are based on the ratio of wall cross-sectional area to the floor area. Therefore, actions (loads) and simplified analysis procedures are included as well as minimum acceptable construction practice guidelines.

Reinforced concrete wall buildings (WRC) consist of bearing walls, wall girders, slabs, footing girders and foundations. These buildings have excellent seismic performance and fire-resistance and are low-priced construction compared to frame structures. This type of structure is one of the most popular buildings for residential apartment houses in the world.

Structural features of WRC buildings can be summarized as follows:

— high seismic performance (according to the damage of the past earthquakes, the damage ratio of WRC structures is much smaller than that of other types of structures);

— fire resistance (the performance is as good as that of RC buildings);

— economical superiority (bearing walls are as thick as wall girders).

Buildings designed according to this document will consequently:

a) for moderate earthquake motions, not produce cracks on bearing walls.

b) for extremely large earthquake motions, prevent from collapse and fall.

The charactersitics of this document to achieve the above performances are as follows:

1) Prevention of shear cracks developing in bearing walls during moderate earthquake motions

The shear stress intensity in bearing walls during moderate earthquake motions on every storey and in every direction should be less than shear cracking stress of concrete being used, in order not to produce cracks in the bearing walls.

Seismic shear force on every storey and in every direction should be set forth corresponding to moderate earthquake motions.

2) Prevention of buildings collapsing during extremely large earthquake motions

The design storey shear force should be set forth corresponding to extremely large earthquake motions. However, this magnitude is reduced, considering the ductility of structures. The reduction value may be about 0,5 for this type of structures. Finally, for example, this magnitude for the first storey almost corresponds to half of the total weight of a building.

In order to secure the structural safety in case of such storey shear, some structural specifications are prescribed in the structural design. The upper limits of average shear stress as well as the maximum storey drift angle are defined in order to control the shearing stress of the wall during the extremely large earthquake motions. That is one of such important specifications. Also, steel bar arrangement specifications and bearing wall arrangement/configuration, etc., are very important specifications to secure structural safety.

This document contains provisions that can be modified by the National Standards Body due to local design and construction requirements and practices. The specifications that can be modified are indicated using [“boxed values”]. The National Standards Body is expected to review the “boxed values” and may substitute alternative definitive values for these elements for use in the national application of this document.

Simplified structural design for reinforced concrete wall buildings

1 Scope

This document applies to reinforced concrete building consisting of load bearing walls of reinforced concrete buildings [such buildings are called reinforced concrete box-shaped wall buildings and (RC wall building)] or to the part of RC wall building which uses both this and other types of structure.

This document applies to RC wall building as follows:

— RC wall building with 5 or fewer aboveground storeys;

— eaves height of 16 m or less;

— storey height on each storey of 3 m or less;

— on the top storey, the storey height can be 3,3 m or less;

— if the roof has a slope, the sum of the storey height of the top storey and the height from the eaves to the ridge of 4 m or less.

Deep foundations, such as piles and caissons, and their pile footings and caps, are beyond the scope of this document, and are not covered by it.

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 2103, *Loads due to use and occupancy in residential and public buildings*

ISO 2633, *Determination of imposed floor loads in production buildings and warehouses*

ISO 4354, *Wind actions on structures*

ISO 4355, *Bases for design of structures — Determination of snow loads on roofs*

ISO 6935-1, *Steel for the reinforcement of concrete — Part 1: Plain bars*

ISO 6935-2, *Steel for the reinforcement of concrete — Part 2: Ribbed bars*

ISO 6935-3, *Steel for the reinforcement of concrete — Part 3: Welded fabric*

ISO 9194, *Bases for design of structures — Actions due to the self-weight of structures, non-structural elements and stored materials — Density*

ISO 15673, *Guidelines for the simplified design of structural reinforced concrete for buildings*

ISO 28842, *Guidelines for simplified design of reinforced concrete bridges*

3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO 28842 and the following 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 https://www.electropedia.org/

3.1
base
level of a structure at which earthquake motions are assumed to be imparted to a building

Note 1 to entry: The base does not necessarily coincide with the ground level.

3.2
load bearing wall
wall proportioned to resist combinations of shear, moments, and axial forces

Note 1 to entry: A "shear wall" is a "structural wall."

3.3
drift
difference between the horizontal displacements of two levels

3.4
factored load
specified nominal load multiplied by the appropriate load factor

3.5
floor system
set of structural elements that comprise the floor of a storey in a building

Note 1 to entry: It includes the beams and girders, the joists (if employed), and the slab that spans between them.

3.6
foundation girder
girder that rests on the foundation soil and spans between footings, used either to support walls or to limit differential settlement of the foundation

3.7
hoop
closed stirrup, tie, or continuously wound spiral

Note 1 to entry: A closed stirrup or tie can be made up of several reinforcement elements, each having seismic hooks at both ends. A continuously wound spiral shall have a seismic hook at both ends.

3.8
non-structural element
set of architectural, mechanical, and electrical components and systems permanently attached to the building

3.9
occupancy
purpose for which a building or other structure, or part thereof, is used or intended to be used

3.10
partition
non-structural wall that is employed to divide spaces

Note 1 to entry: Partitions do not support other parts of the building except themselves. When they are built in the exterior, they are sometimes referred as curtain walls.

3.11
slab on grade
slab set directly on the ground that serves either as an internal traffic surface or as part of the foundation

3.12
storey height
vertical distance between the upper part of the slab of a storey and the upper part of the slab of the floor below

3.13
storey drift angle
angle of the inter-storey drift divided by the storey height

3.14
diaphragm
structural member, such as floor and roof slabs, which transmits inertial induced by earthquake motions

3.15
wall area ratio
ratio of the total wall area in each direction to the floor area

4 Symbols

Symbol	Description	Unit
a	depth of equivalent uniform compressive stress block	mm
a_m	acceleration magnifying factor	—
a_x	acceleration at floor level	—
A_a	effective peak horizontal acceleration coefficient	—
A_b	area of an individual reinforcement bar or wire	mm^2
A_{fi}	area of the *i*-th floor	m^2
A_g	gross area of section of element	mm^2
a_t	area of longitudinal tension reinforcement	mm^2
A_w	area of shear reinforcement within a distance, *s*	mm^2
A_{wi}	sectional area of the structural wall in the *x*- or *y*- direction at the *i* storey	—
b	width of the section of the member	mm
b_f	effective width of the compression flange in a T shaped section	mm
d	effective depth, shall be taken as the distance from extreme compression fibre to centroid of tension reinforcement	mm
d_b	nominal diameter of reinforcing bar	mm
E	load effects of earthquake, or related internal moments and forces	—
E_c	modulus of elasticity of concrete	MPa
f'_c	specified compressive strength of concrete	MPa
$\sqrt{f'_c}$	positive square root of specified compressive strength of concrete	MPa
f_s	shear strength of concrete	—
f_y	specified yield strength of reinforcement, MPa	MPa
$_wf_t$	specified yield strength of transverse or spiral reinforcement	
F	loads due to weight and pressures of fluids with well-defined densities and controllable maximum heights, or related internal moments and forces	—
G_i	shear modulus of concrete at the *i*-th storey	—
h	depth or thickness of structural element or overall thickness of member	mm
h_{bi}	average depth of wall girders in the *x*- or *y*-direction at the *i*-th storey	—
H_i	storey height at the *i*-th storey	—
h_i	average height of structural walls in the *x*- or *y*-direction at the *i*-th storey	—
h_0	clear vertical distance between lateral supports of columns and walls	mm

Symbol	Description	Unit
h_w	height of entire structural concrete wall from base to top	mm
H	loads due to the weight and pressure of soil, water in soil, or other materials, or related internal moments and forces	—
l	span of structural element or length of span measured centre-to-centre of beams or other supports	—
l_d	development length for reinforcing bar	mm
l_i	average length of structural walls in the *x*- or *y*-direction at the *i*-th storey	—
l_w	horizontal length of structural concrete wall	mm
L_i	ratio of the total wall length to the floor area at *i*-th floor	—
L_{0i}	minimum requirement of L_i	—
M	maximum bending moment in the wall girder	—
${}_DM_A$	design moment due to gravity load	—
M_{bE}	moment in of wall girder	—
M_E	moment due to seismic load	—
M_L	moment due to gravity load	—
m_w	mass of the non-structural wall	kg
M_{bn}	nominal flexural moment strength at section at balanced conditions	N·mm
M_{br}	flexural moment strength at section at balanced conditions	N·mm
M_n	nominal flexural moment strength at section	N·mm
M_r	flexural moment strength at section	N·mm
M_u	factored flexural moment at section	N·mm
M_u^-	factored negative flexural moment at section	N·mm
M_u^+	factored positive flexural moment at section	N·mm
n	design shear margin, which shall be greater or equal to 1,5	
P_d	non-factored dead load axial force at section or non-factored concentrated dead load applied directly to the element	N
P_n	nominal axial load strength at section	N
$P_{n(max)}$	maximum compression nominal axial load strength at section	N
P_{0n}	axial compressive strength at section	N
p_w	hoop ratio ($0{,}002 \leq p_w \leq 0{,}012$)	—
P_{wE}	axial force of structural wall	—
ΣP_u	sum of all factored concentrated design loads within the span	N
Q	maximum shear force in the wall girder	—
Q_E	design shear force due to seismic load	—
Q_L	design shear force due to gravity load	—
q_u	factored load per unit area	N/m^2
r_u	factored uniformly distributed reaction from the slab on the supporting girder, beam or structural concrete wall	N/m
R	response modification factor	—
R_1	storey drift angle at the first storey	—
R_i	storey drift angle at the i-th storey	—
R_n	storey drift angle at the top storey	—
s	centre-to-centre spacing of transverse reinforcement measured along the axis of the element or spacing between stirrups or vertical spacing between bars of skin reinforcement or spacing of longitudinal or transverse reinforcement or clear distance between webs	mm

Symbol	Description	Unit
t	thickness of the wall	—
T	cumulative effect of temperature, creep, shrinkage, or differential settlement, or related internal moments and forces	—
U	required factored strength to resist factored loads or related internal moments and forces	—
V_{bE}	shear force of wall girder	—
V_{E}	shear force due to seismic load	—
V_{c}	contribution of the concrete to the nominal shear strength at section, N	N
V_{L}	shear force due to gravity load	—
V_{i}	storey shear in the x- or y- direction at the i-th storey	—
V_{n}	nominal shear strength at section	N
V_{s}	contribution of the horizontal reinforcement to the nominal shear strength at section	N
V_{u}	factored shear force at section	N
W	total weight	—
w_i	i-th floor mean weight	$\mathrm{N/m^2}$
w_{u}	factored uniformly distributed design load per unit element length applied directly to the element	N/m
W_i	weight of i-th sotrey	N
W_{u}	total factored uniformly distributed design load per unit element length	kN/m
α	amplification factor according to the shear span $\alpha = \frac{4}{M/Qd+1}$ and $1 \le \alpha \le 2$	—
α_{b}	fraction of the load that travels in the long direction in two-way slabs-on-girders	—
α_{s}	constant used to compute nominal punching shear strength in slabs	—
β	ratio of clear spans in long to short direction of two-way slabs	—
ϕ	strength reduction factor	—
ν	safety factor, 1/1,5 for gravity load and 1,0 for seismic load	—
ρ	ratio of longitudinal tension reinforcement, $\frac{A_{\mathrm{s}}}{b \cdot d}$	—
ρ_{s}	ratio of spiral reinforcement	—
ρ_{t}	ratio of total longitudinal reinforcement area to gross concrete section area, $\frac{A_{\mathrm{st}}}{b \cdot d}$	—
ρ_{v}	ratio of vertical reinforcement in structural concrete walls	—
g	gravity acceleration	—
$\overline{\tau}_{0\mathrm{i}}$	standard average shear stress	MPa
$\overline{\tau}_{\mathrm{i}}$	average shear stress in the x- or y- direction at the i-th storey $\overline{\tau}_{\mathrm{i}} = \frac{V_{\mathrm{i}}}{\Sigma A_{\mathrm{w,i}}}$	—
$\Sigma A_{\mathrm{w,i}}$	total sectional area of structural walls in the x- or y- direction at the i-th storey	—

5 Materials for reinforced concrete

5.1 General

All materials employed in the construction of the structure designed according to this document shall conform to ISO 15673.

5.2 Cement

Cement shall conform to the project specification.

5.3 Aggregates

Aggregates shall conform to the project specification.

5.4 Water

Water used in mixing concrete shall be potable, clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances deleterious to concrete or reinforcement, and shall conform to the project specification.

5.5 Admixtures

Admixtures shall conform to the project specification.

5.6 Storage of materials

Cement and aggregates shall be stored in such manner as to prevent deterioration and intrusion of foreign matter. Any material that has deteriorated or has been contaminated shall not be used for concrete.

5.7 Steel reinforcement

Steel reinforcement shall be deformed reinforcement, with the exceptions noted in 5.8. Welded-wire fabric shall be considered deformed reinforcement according to this document.

5.8 Deformed reinforcement

The maximum specified yield strength for deformed reinforcement shall be 400 MPa. Deformed reinforcing bars shall conform to ISO 6935-2. ISO 6935-2 covers grades RB 300 and RB 400 (300 MPa and 400 MPa characteristic upper yield stress, respectively) and nominal diameters of 6 mm, 8 mm, 10 mm, 12 mm, 16 mm, 20 mm, 25 mm, 32 mm and 40 mm. However, in this document, the nominal diameter of deformed reinforcement bars is limited to 25 mm (see 15.3).

5.9 Welded-wire fabric

The maximum specified yield strength for wires being part of welded-wire fabric shall be 400 MPa. Welded wire fabric shall conform to ISO 6935-3. In this document, the nominal diameter of wire for welded-wire fabric is limited to 10 mm (see 15.3).

5.10 Plain reinforcement

Plain reinforcement shall be permitted only for stirrups, ties, spirals, and when it is part of a welded-wire fabric. The maximum specified yield strength for plain reinforcement shall be 300 MPa. Plain reinforcing bars shall conform to ISO 6935-1. ISO 6935-1 covers grades PB 240 and PB 300 (240 MPa and 300 MPa characteristic upper yield stress, respectively) and nominal diameters of 6 mm, 8 mm, 10 mm,

12 mm, 16 mm and 20 mm. However, in this document, the nominal diameter of plain reinforcement bars is limited to 16 mm (see 15.3).

5.11 Concrete mixture specification

The procedure for concrete mixture proportioning shall conform to ISO 22965-1 and ISO 22965-2.

The compressive strength of concrete shall not be less than 18 MPa.

6 Design and construction procedure

6.1 Procedure

The design procedure comprises the following steps (see Figure 1):

a) Definition of the layout in plan and height of the structure, following the provisions of Clauses 7 and 8.

b) Calculation of all gravity loads and seismic loads that act on the structure using the provisions of Clause 9.

c) Preliminary location, and trial dimensions for structural concrete walls capable of resisting the lateral loads are established, using the provisions of Clauses 10 and 11 for earthquake forces, the influence of their self-weight is evaluated, and flexure and shear design of the structural concrete walls is performed.

d) Trial dimensions for the wall girders with the provisions of Clause 12. Trial dimensions for the floor slabs with wall girders/structural concrete walls. Calculation of the self-weight of the system, and design of the elements than comprise it, correcting the dimension as required by the strength and serviceability limit states, complying with the provisions of Clause 14 for floor slabs with wall girders/structural concrete walls.

e) Joints between structural concrete wall and wall girders or foundation girders are designed.

f) The loads at the foundation level are determined, and a definition of the foundation system is performed employing the provisions of Clause 16. The structural elements of the foundation are designed.

g) Check the general reinforced concrete requirements using the provisions of Clause 15.

h) Production of the structural drawings.

i) The construction of the structure shall be performed complying with the local construction practice.