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Simplified design of connections of concrete claddings to concrete structures

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Foreword

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This document was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and prestressed concrete*, Subcommittee SC 5, *Simplified design standard for concrete structures.*

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Introduction

The current design practice of reinforced concrete buildings, most commonly precast, is based on a frame model, where the peripheral cladding panels enter only as masses without any stiffness. The panels are then connected to the structure with fastenings dimensioned with a local calculation based on their mass for anchorage forces orthogonal to the plane of the panels.

Furthermore, the seismic force reduction in the type of reinforced concrete structures of concern relies on energy dissipation in plastic hinges formed in the columns. Very large drifts of the columns are needed to activate this energy dissipation foreseen in design. However, typically, the capacity of the connections between cladding and structure is exhausted well before such large drifts can develop. Therefore, the design of these connections cannot rely on the seismic reduction factor typically used for design of the bare structure.

This document contains a set of practical provisions for the design of mechanical connections of concrete claddings to concrete structures under seismic actions as well as suggestions for structural analysis for the specified systems.

Simplified design of connections of concrete claddings to concrete structures

1 Scope

The present document refers to the panel-to-structure and panel-to panel connections used for the cladding systems of reinforced concrete frame structures of single-storey buildings, typically precast. They can be used also for multi-storey buildings with proper modifications.

The fastening devices considered in the present document consist mainly of steel elements or sliding connectors. Dissipative devices with friction or plastic behaviour are also considered. Other types of common supports and bond connections are treated where needed.

The use of any other existing fastening types or the connections with different characteristics than those described in the following clauses is not allowed unless comparable experimental and analytical studies do provide the necessary data and verify the design methodology for the particular type.

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 20987, *Simplified design for mechanical connections between precast concrete structural elements in buildings*

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
behaviour factor *q*
q factor by which the elastic design spectrum in linear analysis is reduced

Note 1 to entry: Directly or indirectly linked to the ductility and deformation demands on members and connections.

4 Generalities

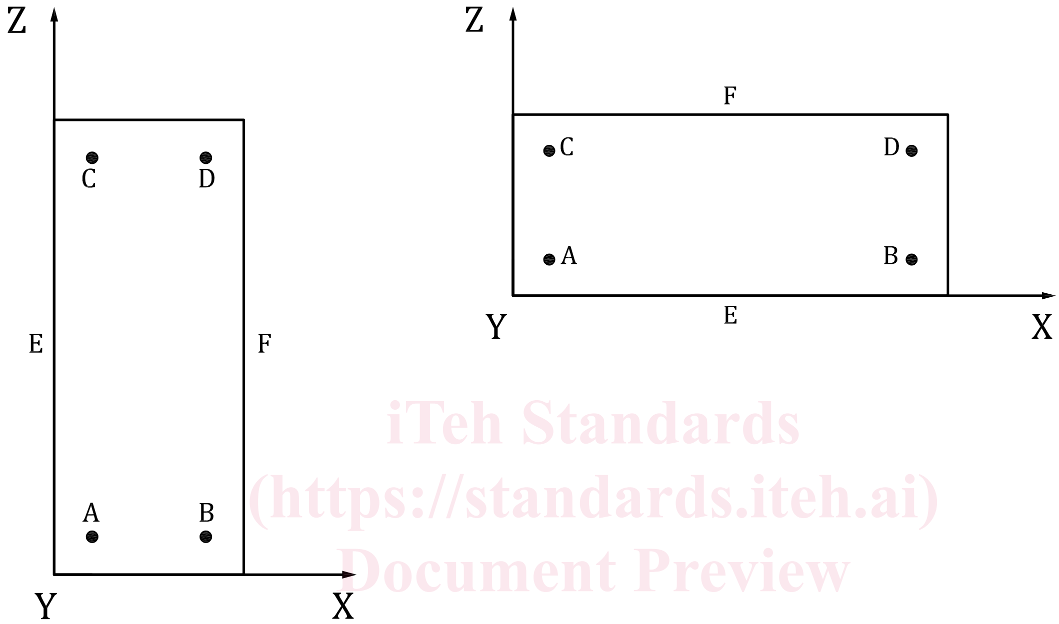
4.1 Cladding panel orientations

Figure 1 a) shows a vertical panel orientation referred to a system of orthogonal axes, where x is oriented horizontally in the panel plane, y is oriented orthogonally to that plane and z is oriented vertically parallel to the gravity loads. The origin is placed in a corner at the base side of the panel.

Four connections are foreseen at the corners of the panel, indicated respectively by A, B, C and D. Any one of these connections is intended to give only translational restraints without any rotational restraint. E and F indicate the possible joint connections with the adjacent panels. Usually, the connections A and B are attached to the foundation beam, the connections C and D are attached to the top beam.

The couple of bottom and top connections may be replaced by single connections placed in the middle of the bottom and top sides for a pendulum arrangement of the panel. In this case, the connections are respectively named A and C, and the symbols B and D are omitted.

In Figure 1 b), the same reference system is associated with a horizontal panel for which the connections A, B, C and D are usually attached to the columns, and E and F refer to the possible joint connections with the adjacent panels, foundation or top beam where the uncertain friction effect can act due to the superimposed panels.



a) **Vertical** b) **Horizontal**

Figure 1 — Cladding panel orientations

Table 1 — Symbols and graphic schemes for supports

Symbol	Description	Graphic scheme
f	fixed (bilateral)	▼ ▶◀,▲
f+	fixed (unilateral in + direction)	▲, ▶
f-	fixed (unilateral in - direction)	▼, ◀
s	sliding (bilateral)	↔, ↕
d	dissipative	ΛΛΛ
/	omitted	[empty]

Table 1 gives a general description of the symbols and graphic schemes regarding the effect of the supports along the three directions x, y and z. As an example, Table 2 gives the arrangement matrix indicating the effect of the supports for a vertical panel.

Table 2 — Arrangement matrix – example

Direction	A	B	C	D	E	F
x	f	/	s	/	f	f
y	f	/	f	/	/	/
z	f	/	/	/	d	d

The term “fixed” is used with reference to the restrained linear displacement while the rotational restraints are not provided.

4.2 Design criteria to connect frame and panels

4.2.1 Isostatic approach

An isostatic arrangement of panel connections is able to allow without reactions the large displacements expected for the frame structure under earthquake conditions. Very large displacement capacities are required for connectors with this choice.

The frame deformation demand is allowed by a relative clearance that uncouples the motion of frame and panels. The two systems are kinematically uncoupled, except for the out-of-plane displacements [see Figure 2 a)].

4.2.2 Integrated approach

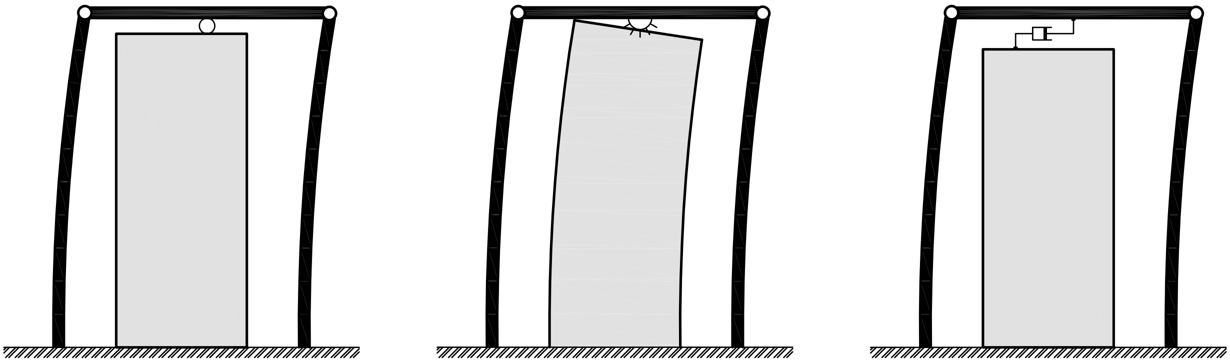
An integrated arrangement relies on fixed connections that integrate the panels in the resistant structural assembly with a dual wall-frame system behaviour. High forces may arise in the connections with this choice.

Panels and frame have a coupled motion: the system is kinematically paired [see Figure 2 b)]. Panels become part of the seismic resisting system and they act as the main restraints in the horizontal direction thanks to their higher stiffness. As a consequence, the connections shall be over-proportioned to carry the higher loads transferred by the frame, according to capacity design rules.

4.2.3 Dissipative approach

An arrangement of dissipative connections between the panels is added to an isostatic system of fastenings to the structure, able to maintain displacements and forces within lower predetermined limits.

Specific devices can balance the overall building response, reducing the displacement and keeping the load below an imposed threshold, determined by the connections themselves [see Figure 2 c)]. Like in the isostatic configuration, the systems are kinematically uncoupled but they are also constrained by inelastic links, like friction or yielding devices. The joints between structure and panels – or among the panels – shall be designed to dissipate energy during the seismic action.



a) b) c)

Figure 2 — Design criteria to connect frame and panels

4.3 Strategies to implement isostatic and dissipative design criteria

4.3.1 Sliding-frame (SF)

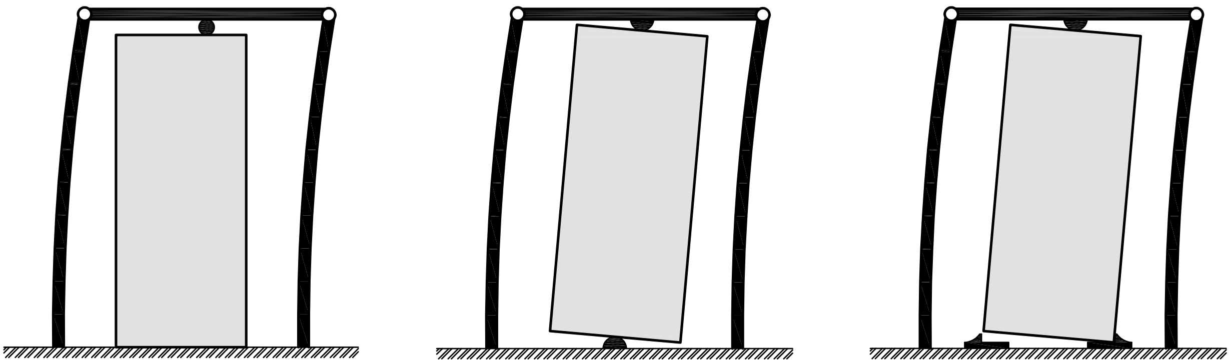
Like an ideal uncoupled system, the isostatic sliding-frame is, in principle, the easiest way to disconnect frame and panels. To achieve this result while avoiding the issues that affect current systems, proper connections (sliders) shall be introduced. They only restrain out-of-plane motions, reproducing the hypothesis typically assumed in the current practice, but in a safer way [see Figure 3 a)].

4.3.2 Double-hinged pendulum (DHP)

The double-hinged pendulum is the proper way to connect the cladding as simple mass without any stiffness contribution [see Figure 3 b)]. This result can be obtained either by connecting panel edges with hinges, or by replacing the top hinge with coupled sliders.

4.3.3 Rocking panel (RP)

Starting from DHP, the rocking panel configuration may be obtained replacing the bottom hinge with a pair of horizontal restraints. These leave the panel free to rock around its bottom corners. Even though this solution looks very similar to the former one, some differences in statics and in kinematic behaviour need to be highlighted [see Figure 3 c)].



a) b) c)

Figure 3 — Isostatic and dissipative design criteria: schemes of design strategies

4.4 Parameters

ISO 20987 shall apply. In addition to the provisions of ISO 20987, the following applies.

Among the main parameters that characterize the seismic behaviour of the connection, the following one is added:

slide - free linear relative displacement capacity with null or negligible reaction.

The main behaviour parameters are provided for each x, y, z direction defined in ISO 20987 specifying possible interaction effects.

4.5 Classification

ISO 20987 shall apply. In addition to the provisions of ISO 20987, the following applies.

Connections present in existing buildings, where sufficient information about their strength and/or ductility is not available, can be classified as unknown.

Existing connections can be classified as insufficient when a specific calculation under the expected seismic action shows their inadequate strength.

5 Isostatic systems

5.1 General

For buildings with isostatic arrangements of cladding panel connections, the structural analysis under seismic action shall refer to the frame system following the conventional design practice of such structures. In expectation of large displacements, the second order effects, $P\Delta$, should be taken into account. In addition to the ordinary output data used for the design of member resistance at ultimate limit state (ULS[1)]), the sliding or rotation displacements shall be provided for the design of the pertinent capacities of panel connection devices.

5.2 Analysis of the building

5.2.1 General

For the frame systems considered, capacity design criteria for the proportioning of the connection are applied. It is assumed, as a rule, that the beam-to-column and column-to-foundation connections are properly over-proportioned with respect to the bending moment ultimate capacities of the columns. Floor connections involved in the diaphragm action can refer to some approximate methods.

In any case, the structural connections can be over-proportioned, referring to the forces obtained from a structural analysis performed with behaviour factor q = 1,5

Figure A.1 shows a simplified design flowchart. It shows the required steps to design a cladding to concrete structure connection. Specific suggestions regarding the isostatic systems structural model analysis are given in 5.2.2 and 5.2.3.

5.2.2 Suggestions for the structural model

For the numerical model of the structure, the ordinary linear elements (beam type) can be used, positioned along the axis of the members. Different eccentricities between the members should be reproduced using link rigid elements at their joints. The connections between the elements shall be faithfully represented with their degrees of freedom in the different planes. It should be considered that, if the connections are modelled with no deformability (e.g. fixed built-in full support or hinged

1) ULS: state at which the material stresses are limited to the point at which the bearing elements can withstand the design loads and maintain the safety and integrity of the structure.

support), the results of the analysis can lead to very high joint forces. The actual deformability of the connections, even small, can substantially lower these forces. More reliable results can be obtained if the actual deformability of the connections is reproduced in the model.

The floor elements can be modelled as linear elements concentrating their mechanical properties along the axis. To reach the actual points of their connections, link rigid elements can protrude from the axis. The diaphragm action of the floors shall be properly represented, implicitly by the layout of their members or explicitly through the options provided by the computation code.

If the cladding panels are introduced as members in the model, they can be reproduced as linear elements distributing their weight along the axis. Their supports shall faithfully reproduce the isostatic arrangement of the connections. To reach the actual points of the connections, where some response parameters are needed, rigid link elements can protrude from the panel axis.

If the cladding panels are introduced as masses in the model, their total mass, M, shall be transferred to the sustaining members in a ratio, R_y, depending on the connection arrangement.

For one-storey structures with vertical panels in the horizontal orthogonal y direction, this ratio, R_y, is given by Formula (1):

$$R_{\mathrm{y}} = \frac{0{,}67\,Mh}{h_{\mathrm{o}}} \tag{1}$$

where

- h is the height of the panel;
- h_o is the elevation of its upper support connected with the roof deck;
- M is the total mass of the cladding panels in the model.

In the in-plane horizontal x direction, the same ratio, $R_{\mathrm{x}} = R_y$, can be assumed for a pendulum support arrangement. A null ratio, $R_{\mathrm{x}} = 0$, can be assumed for a cantilever arrangement with upper sliding connections.

For one-storey structures with horizontal panels in the orthogonal y direction, their mass, M, shall be shared between the two lateral supporting columns, amplified as a function of their elevation h_i [see Formula (2)]:

$$R_y = \frac{0{,}5\,Mh_i}{h_o} \tag{2}$$

where h_{o} is the elevation of the roof deck.

In the in-plane horizontal x direction, their mass shall be transferred to the lateral columns with the same amplification, based on the constraint degree of the corresponding support.

5.2.3 Rocking systems

The vertical panel of Figure 4 keeps its stability in its plane until the horizontal top force, H_{o} [see Formula (3)], is smaller than the limit force

$$H_{\mathrm{o}} = \frac{Gb}{2h} \tag{3}$$

where

- G is the weight of the panel;
- b and h are geometrical quantities indicated in Figure 4.

If $H > H_o$, the panel starts rocking around its lower corner like an inverted pendulum with a restoring force, H_o, that remains constant for small displacements. At the reverse motion, the panel sits back on the base side and starts a new opposite cycle similar to the previous one. To capture such vibration motion, a refined dynamic analysis should be carried out for the solution of the non-linear algorithms inclusive of the unilateral effects of the base supports.

Considering this, the small value of the limit force, H_o, can prevent the rocking motion only for low actions. For practical design applications, a simplified approach can be used, based on a linear elastic structural analysis for each of the two possible structural schemes: integrated and isostatic. The design approach can therefore adopt a first model corresponding to the integrated system with cantilever panels fully fixed at their base and connected with an equivalent hinge to the roof and a second model referred to the isostatic system with pendulum panels connected with two end hinges.

Starting with the integrated system, the first analysis refers to the serviceability limit state (SLS[2]) seismic action, evaluated using the pertinent elastic response spectrum. Its outcome provides the forces and displacements. If the corresponding connection forces are not greater than H_o, the calculated displacements are used for the verification of the drift limits. If they are greater, the analysis of the isostatic model is necessary.

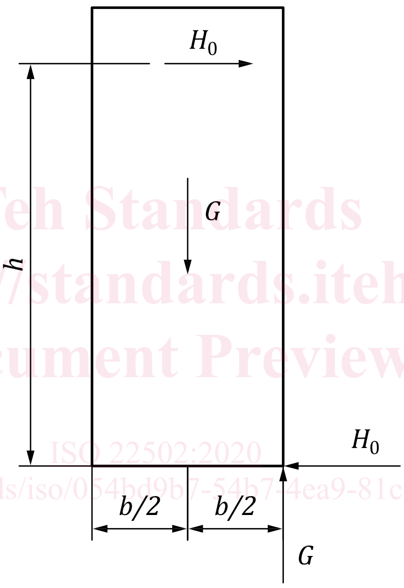


Figure 4 — Vertical panel force equilibrium

The second analysis of the integrated system refers to the ultimate limit state seismic action (no-collapse requirement), evaluated using the pertinent design response spectrum with the behaviour factor q = 1,0. Its outcome provides the forces and displacements. If the corresponding connection forces are not greater than H_o, the forces calculated in the structure are used for the strength design. If they are greater, the analysis of the isostatic model is necessary.

When necessary, the isostatic system is analysed neglecting the restoring force, H_o. The panels only contribute to the response of the structure as masses without any stiffness. Thus, they can be modelled as indicated in 5.2.2. For SLS, the elastic response spectrum is used. The resulting displacements are verified against the required drift limits. For the ULS, the design response spectrum is used. The behaviour factor q, of the frame systems and the resulting forces are used in the strength designs.

In any case, the forces in the panel connections for their strength design, taking into account the impulsive effects of the dynamic action, shall be taken at least equal to $2H_o$.

2) SLS: state at which the structure is supposed to be comfortable and usable taking into account vibrations, deflections and cracks.

5.3 Analysis of conventional systems

5.3.1 General aspects

The term "conventional systems" used in these rules is for the reinforced concrete buildings with the existing fastening systems of cladding panels, which have been extensively used in the past and may still be used at present in zones with low to medium seismicity.

The existing design practice for the conventional systems usually has been based on the model that is not explicitly considering the interaction between the main structural system and the claddings in the plane of the façade. Such approach cannot identify eventual complex interaction between the structure and the panels leading to possible failure of the fastening system and to the fall of the panels during strong earthquakes. Some of such systems, in case of small seismic demand and/or structures with large over-strength and stiffness, can still provide sufficiently safe design solutions.

A suitable design procedure is provided in 5.3.2 and 5.3.3. It can be used for strengthening existing structures as well as for the design of new ones.

5.3.2 General design methodology

These rules are strictly limited to those fastening systems described in Clause 6. When the applied fastening system is different from those presented in Clause 6, the system shall be experimentally and analytically investigated (taking into account the 3D behaviour of the structure) to provide the basic data needed in the proposed methodology. These data include, but are not limited to, the mechanism of the structure-to-panel interaction, deformation and strength capacity, equivalent stiffness, and, in the case when refined inelastic response analysis is chosen, the hysteretic models for the structure and the fastening system.

Furthermore, these rules are limited to fastening schemes presented in Figure 5 a) for vertical panels and Figure 5 b) for horizontal panels. In particular, the vertical panels are attached to the upper beam with two connections giving bilateral restraint in y (orthogonal) direction and bilateral essentially sliding freedoms in x (horizontal) and z (vertical) directions, while at the base they are supported with two pinned connections providing restraints in all the three directions. Any horizontal panel is attached to the lateral columns with two connections at the upper part and with two connections at the lower part giving bilateral restraint in y (orthogonal) direction, unilateral support in z (vertical) direction and bilateral partially sliding freedom in x (horizontal) direction.

The approach has two possible levels of complexity and it is based on the following main considerations:

a) weak interaction between the panel and the bare frame (i.e. the stiffness of the fastening devices is small compared to the stiffness of the structure itself) can be expected in conventional systems until certain deformation threshold is exhausted. Until this deformation limit is reached, the system behaves essentially as isostatic and relatively simple traditional structural models can be used, neglecting the structure-to-cladding interaction. The relevant deformation capacity of the addressed conventional systems is provided in 6.3;

b) after the deformation limit is reached, more complex model shall be used considering the interaction between the panels and the bare structure through the fastening system. Relevant input parameters for the addressed conventional systems are provided in 6.3;

c) if the more refined model does not prove the adequacy of the system, a different cladding connection system shall be chosen.