Simplified design of connections of concrete claddings to concrete structures

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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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

The current design practice of reinforced concrete buildings 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. They can be used also for multi-storey buildings with proper modifications.

With respect to the overall arrangement of connections and to the relative degree of interaction between cladding panels and the main structure, three solutions are specifically identified.

The first is an isostatic arrangement of panel connections 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 second is an integrated arrangement of fixed connections that integrates the panels in the resistant structural assembly with a dual wall-frame system behaviour. High forces may arise in the connections with this choice.

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

Reference is also made to traditional or conventional connections, those commonly used whenever the panel-structure interaction was disregarded in design. Those are intended as a particular case of isostatic arrangement, and might be used for low seismicity areas, assuming the relevant clauses in the present document are complied with. For such connections, indications about possible strengthening measures for existing buildings are also provided.

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 present document is divided into three major sections, isostatic, integrated and dissipative systems. Each one of them provides design rules for analysis of the system itself but also provides design rules for calculation of the specific cladding to concrete structure connections.

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

2 Normative references

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

3 Terms and definition

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 https://www.electropedia.org/
3.1 Behaviour factor – $q$:

factor by which the elastic design spectrum in linear analysis is reduced. Directly or indirectly linked, to the ductility and deformation demands on members and connections.

3.2 Ductility classes, DCM – medium ductility and DCH – high ductility:

both classes correspond to buildings designed, dimensioned and detailed in accordance with specific earthquake resistant provisions, enabling the structure to develop stable mechanisms associated with large dissipation of hysteretic energy under repeated reversed loading, without suffering brittle failures.

3.3 Limit states, SLS – serviceability and ULS – ultimate limit state

prescribed state of a structure according to the design code. SLS is the state at which the structure is supposed to be comfortable and usable taking into account vibrations, deflections and cracks. ULS is the state at which the material stresses are limited to the point at which the bearing elements can withstand the design loads and keep the safety and integrity of the structure.

3.4 Traditional or conventional systems:

reinforced concrete buildings with the existing fastening systems of cladding panels, which have been extensively used in the past and are still used at present with the assumption that the interaction between the panels and the structure can be disregarded in design.

4 Generalities

4.1 Cladding panel orientations

Vertical panel orientation referred to a system of orthogonal axis, 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 is presented on Figure 1 a). 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.

The same reference system is associated in Figure 1 b) to a horizontal panel, for which usually the connections A, B, C and D are 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 due to the superimposed panels may act.
Figure 1 – Cladding panel orientations a) vertical b) horizontal

Table 1 – Symbols and graphic schemes for supports

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Graphic scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f )</td>
<td>fixed (bilateral)</td>
<td>▼ ▶◄ ▲</td>
</tr>
<tr>
<td>( f^+ )</td>
<td>fixed (unilateral in + direction)</td>
<td>▲ ▶</td>
</tr>
<tr>
<td>( f^- )</td>
<td>fixed (unilateral in - direction)</td>
<td>▼◄</td>
</tr>
<tr>
<td>( s )</td>
<td>sliding (bilateral)</td>
<td>↔, ↕</td>
</tr>
<tr>
<td>( d )</td>
<td>dissipative</td>
<td>∧∧∧</td>
</tr>
<tr>
<td>( / )</td>
<td>omitted</td>
<td>[empty]</td>
</tr>
</tbody>
</table>

In Table 1 a general description of the symbols and graphic schemes is given 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

<table>
<thead>
<tr>
<th>Direction</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x )</td>
<td>( f )</td>
<td>/</td>
<td>( s )</td>
<td>/</td>
<td>( f )</td>
<td>( f )</td>
</tr>
<tr>
<td>( y )</td>
<td>( f )</td>
<td>/</td>
<td>( f )</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>( z )</td>
<td>( f )</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>( d )</td>
<td>( d )</td>
</tr>
</tbody>
</table>

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
Three different theoretical approaches to connect frame and panels may be classified according to three different design criteria.

4.2.1 Isostatic

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, Figure 2 a).

4.2.2 Integrated

Panels and frame have a coupled motion: the system is kinematically paired, 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 must be over-proportioned to carry the higher loads transferred by the frame, according to capacity design rules.

4.2.3 Dissipative

Specific devices can balance the overall building response, reducing the displacement and keeping the load below an imposed threshold, determined by the connections themselves, 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 – must be designed to dissipate energy during the earthquake shock.

![Figure 2 – Design criteria to connect frame and panels](image)

4.3 Strategies to implement isostatic and dissipative design criteria

Although the isostatic and dissipative design criterion are equivalent in kinematic terms, different results may be obtained just changing the way to connect frame and panels, using the same criterion. Taking advantage of this, different Design Strategies (DS) for the structural system may be chosen. Those are represented by different test setups used within this experimental campaign.

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, avoiding the issues that affect in-use systems, the introduction of proper connections (sliders) shall be implemented. They only restrain out-of-plane motions, reproducing the hypothesis typically assumed in the current practice, but in a safer way, 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, Figure 3 b). This result may be obtained either connecting panel edges with hinges, or 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 let 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 must be highlighted, Figure 3 c).

![Figure 3 - Isostatic and dissipative design criteria: schemes of design strategies](standards.iteh.ai)

#### 4.4 Properties

General reference is made to ISO 20987. In addition to what given therein, the following specifications are listed.

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

General reference is made to ISO 20987. In addition to what given therein, the following specifications are listed.

For the connections present in existing buildings, where sufficient information about their strength and/or ductility are not available, the classification of *unknown* can be stated.

The classification of *insufficient* can be given to existing connections when a specific calculation under the expected seismic action shows their inadequate strength.

### 5 ISOSTATIC SYSTEMS

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 "\(P\Delta\)" effects should be taken into account.
account. In addition to the ordinary output data used for the design of member resistance at ultimate limit state, the sliding or rotation displacements shall be provided for the design of the pertinent capacities of panel connection devices.

5.1 Analysis of the building

For the one-storey frame systems considered in this clause capacity design criteria for connection proportioning is 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 an over-proportioning of the structural connections can be made referring to the forces obtained from a structural analysis performed with behaviour factor \( q = 1,5 \)

A simplified design flowchart for the required steps to design a cladding to concrete structure connection is given in Annex A. Specific suggestions regarding the isostatic systems structural model analysis are given henceforth.

5.1.1 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. One should consider that, if the connections are modelled with no deformability (e.g.: fixed "built in" full support or hinged support), the results of the analysis could lead to very high joint forces. The actual even small deformability of the connections can lower sensibly these forces. Results that are more reliable can be obtained if also the actual deformability of the connections is reproduced in the model.

The floor elements can be reproduced 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 reproduce faithfully the isostatic arrangement of the connections. To reach the actual points of the connections, where some response parameters are needed, link rigid 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 \( R \) depending on the connection arrangement.

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

\[
R_y = \frac{0.67Mh}{h_o}
\]

where,

- \( h \) is the height of the panel
- \( h_o \) is the elevation of its upper support connected with the roof deck
In the in-plane horizontal x direction the same ratio \( R_x = R_y \) can be assumed for a pendulum support arrangement, a null \( R_x = 0 \) ratio 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 \( h_i \):

\[
R_y = \frac{0.5Mh_i}{h_o} \tag{2}
\]

where,

\[
h_o \quad \text{is the elevation of the roof deck}
\]

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

### 5.1.2 Rocking systems

The vertical panel of Figure 4 keeps its stability in its plane until the horizontal top force \( H \) is smaller than the limit force

\[
H_o = \frac{Gb}{2h} \tag{3}
\]

where,

\[
G \quad \text{is the weight of the panel}
\]

\[
b \text{ and } h \quad \text{are geometrical quantities indicated in the Figure 4}
\]

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

Considering that, 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 develop with a first model referred 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) 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.