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**Simplified design for mechanical connections between precast
concrete structural elements in 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.

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Introduction

This document contains a set of practical provisions for the design of the mechanical connections in precast elements under seismic actions. Design of the connections is carried out in terms of strength verifications. Indications are also provided for defining the actions to be used in design.

If national standards provide alternate formulae for the same typology, those can be used instead of the ones given in this document.

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

1 Scope

This document refers to connections in precast frame systems, either for single-storey or multi-storey buildings. The connections for all orders of joints are considered. Large wall panel and three-dimensional cell systems are not considered.

According to the position in the overall construction and of the consequent different structural functions, the seven following orders of joints are considered:

- a) *mutual joints between floor or roof elements* (floor-to-floor) that, in the seismic behaviour of the structural system, concern the diaphragm action of the floor;
- b) *joints between floor or roof elements and supporting beams* (floor-to-beam) that give the peripheral constraints to the floor diaphragm in its seismic behaviour;
- c) *joints between beam and column* (beam-to-column) that ensure in any direction the required degree of restraint in the frame system;
- d) *joints between column segments* (column-to-column) used for multi-storey buildings usually for dual wall braced systems;
- e) *joints between column and foundation* (column-to-foundation), able to ensure in any plane a fixed full support of the column;
- f) *fastenings of cladding panels to the structure* (panel-to-structure) that ensure the stability of the panels under the high forces or the large drifts expected under seismic action;
- g) *joints between adjacent cladding panels* (panel-to-panel) possibly used to increase the stiffness of the peripheral wall system and provide an additional source of energy dissipation.

Simple bearings working by gravity load friction are not considered. Sliding and elastic deformable supporting devices neither, being all these types of connections not suitable for the transmission of seismic actions.

The document provides formulae for the strength design of a large number of joint typologies.

2 Normative references

There are no normative references in this document.

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:

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

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

3.1

union

generic linking constraint between two or more members

3.2

connection

local region that includes the *union* (3.1) between two or more members

3.3

connector

linking device (usually metallic) interposed between the parts to be connected

3.4

node

local region of convergence between different members

3.5

joint

equipped interface between adjacent members

3.6

system

<joint> set of linking practices classified on the basis of the execution technology

3.7

typical joint

dry *joint* (3.5) with mechanical *connectors* (3.3) generally composed of angles, plates, channel bars, anchors, fasteners, bolts, dowel bars, etc., including joints completed in-situ with mortar for filling or fixing

3.8

emulative joint

wet *joint* (3.5) with rebar splices and cast-in-situ concrete restoring the monolithic continuity typical of cast-in-situ structures and leading usually to “moment-resisting” *unions* (3.1)

3.9

strength

maximum value of the force which can be transferred between the parts

3.10

ductility

ultimate plastic deformation compared to the yielding limit

Note 1 to entry: The ductility values or ranges provided refer to the *connections* (3.2) themselves and, in general, have no direct relation with the global ductility of the structure. Those values are given for the sake of classifying the connection and are not supposed to intervene in the design, which is carried out in terms of *strength* (3.10).

Note 2 to entry: Instead of the plastic deformation of steel element beyond the yield limit, other physical equivalent non-conservative phenomena can be referred to (such as friction).

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3.11
dissipation
specific energy dissipated through the load cycles related to the corresponding perfect elastic-plastic cycle

Note 1 to entry: The values or ranges provided refer to the *connections* (3.2) themselves and, in general, have no direct relation with the global energy dissipation of the structure. Those values are given for the sake of classifying the connection and are not supposed to intervene in the design, which is carried out in terms of *strength* (3.10).

3.12
cyclic decay
decay
strength (3.10) loss through the load cycles compared to the force level

3.13
damage
residual deformation at unloading compared to the maximum displacement and/or evidence of rupture

4 Properties

A connection is composed of three parts: two lateral parts A and C, corresponding to the local regions of the adjacent members close to the connector; and a central part B constituted by the connector itself with its metallic components (see Figure 1).

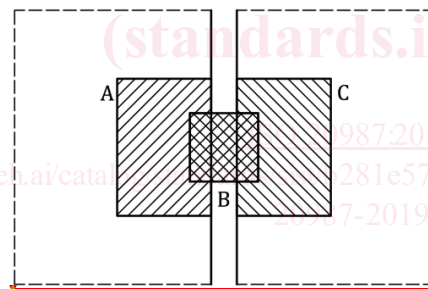


Figure 1 — Scheme of connection

The main parameters which characterize the seismic behaviour of the connection, as measured through monotonic and cyclic tests, refer to the six properties of:

- strength;
- ductility;
- dissipation;
- deformation;
- decay;
- damage.

A ductile dissipative behaviour of the connection can be provided by the steel connector B:

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- when parts A and C have a non-ductile non-dissipative behaviour characterized by a brittle failure, with small displacements, due to the tensile cracking of concrete; and
- if it is correctly designed for a failure involving flexural or tension-compression modes and not shear modes or by other dissipative phenomena like friction.

In this case, for a ductile connection, in addition to a ductile connector, the criteria of capacity design shall be applied, under-proportioning the connector with respect to the lateral parts.

Also, the geometric compatibility of deformations shall be checked (e.g. against the loss of bearing). Non-ductile connections shall be:

- suitably over-proportioned by capacity design with respect to the resistance of the critical dissipative regions of the structure; or
- proportioned on the basis of the action obtained from a structural analysis that does not account for any energy dissipation capacity.

The ductility of the connections can contribute to the global ductility of the structure or not depending on their position in the structural assembly and on their relative stiffness.

5 Classification

5.1 General

For any single type of connection, the strength is quantified by the relevant formulae. The other behaviour properties listed in this clause are quantified by specific numerical values. When this precise numerical quantification is not possible, because of lack of experimental data or excessive variability of performances, the type of connection is classified in qualitative terms corresponding to ranges of values.

5.2 Strength

For strength, the following information shall be given:

- *behaviour models* corresponding to the working mechanisms of the connection;
- *failure modes* of the resistant mechanisms;
- *calculation formulae* for the evaluation of the ultimate strength for any failure mode;
- *other data* concerning the specific properties of the connection.

Reference is made to the strength obtained from cyclic loading tests.

5.3 Ductility

For ductility, the following classification is deduced from the force-displacement diagrams obtained in experiments:

- *brittle connections*, for which failure is reached without relevant plastic deformation;
- *over-resisting connections*, for which failure has not been reached at the functional deformation limit;
- *ductile connections*, for which a relevant plastic deformation has been measured.

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In this classification, intentional friction mechanism is equal to plastic deformation. Brittle connections can be used in seismic zones provided they are:

- over-proportioned by capacity design with respect to the critical regions of the overall structure; or
- proportioned with the action deducted from a structural analysis that does not account for any energy dissipation capacity.

5.3.1 Ductile connections

Furthermore, ductile connections are divided into:

- *high ductility connections*, with a displacement ductility ratio of at least 4,5;
- *medium ductility connections*, with a displacement ductility ratio of at least 3,0;
- *low ductility connections*, with a displacement ductility ratio of at least 1,5.

With ductility ratio lower than 1,5, the connection is classified as *brittle*.

These definitions refer to the connection itself and, in general, have no direct relation with the global ductility of the structure. For any single order of connections, specific indications are given on this aspect, referring both to ductility and dissipation.

5.4 Dissipation

For dissipation, the following classification is deduced from the force-displacement diagrams of cyclic tests and related enveloped area histograms:

- *low dissipation*, with specific values of dissipated energy between 0,10 and 0,30;
- *medium dissipation*, with specific values of dissipated energy between 0,30 and 0,50;
- *high dissipation*, with specific values of dissipated energy over 0,50.

With dissipated energy lower than 0,1, the connection is classified as *not dissipative*.

The theoretical value 1,00 would correspond to the maximum energy dissipated through a perfect elastic-plastic cycle, e.g. by a massive section of ductile steel under alternate flexure, medium dissipation corresponds to well confined reinforced concrete sections under alternate flexure and high dissipation can be achieved with the use of special dissipative devices.

5.5 Deformation

For deformation, indications can be given about the order of magnitude of the relative displacements of the connection at certain relevant limits, such as the first yielding of steel devices, the ultimate failure limit or the maximum allowable deformation referred to its functionality.

Indications about *cyclic decay* and *damage* are given if relevant and when specific experimental information is available.

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6 Floor-to-floor connections

6.1 Cast-in-situ topping

6.1.1 General

Figure 2 shows the details of a floor made of precast elements interconnected by a concrete topping cast over their upper surface. The concrete topping, with its reinforcing steel mesh, provides a monolithic continuity to the floor that also involves the precast elements if properly connected to it. The diaphragm action for the in-plane transmission of the horizontal forces to the bracing vertical elements of the structure can be allotted entirely to the topping. Unless greater dimensions are defined from design, for its structural functions, the concrete topping shall have a minimum thickness, t_{min} , related also to the maximum aggregate size of the concrete, d_g , such as $t_{min} = 2,4 d_g \geq 60$ mm.

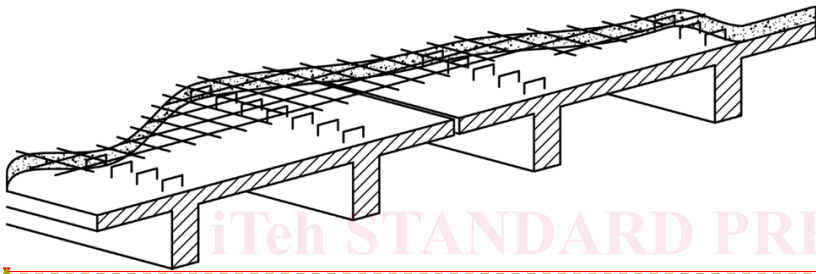
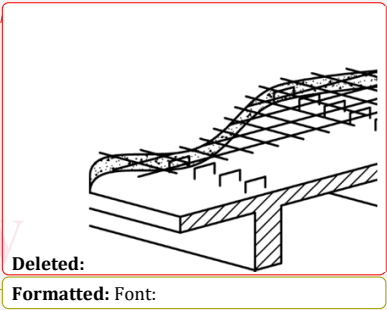


Figure 2— Floor made by precast elements



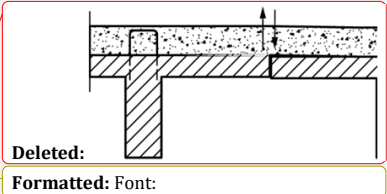
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6.1.2 Strength

Interface shear strength of the connection between the precast element and the topping under seismic action can be evaluated neglecting the friction contribution due to gravity loads. Transverse vertical shear at the joint between adjacent floor elements is diverted into the topping. For the good behaviour of the connection, proper steel links crossing the interface shall ensure, with adequate anchorages, an effective shear tie between the two parts (see Figure 3).



Figure 3— Precast elements with and without interface connections with topping



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6.1.3 Other properties

No specific parameters of seismic behaviour (ductility, dissipation, deformation, decay, damage) have been experimentally measured for this type of indirect connection provided by the cast-in-situ topping that can be calculated like an ordinary reinforced concrete element.

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6.2 Cast-in-situ joints

6.2.1 General

Figure 4 shows the floor-to-floor connection made with the concrete filling of a continuous joint between adjacent elements. It is typical of some precast products like hollow-core slabs. The joint has a proper shape to ensure good interlocking with the transmission of the vertical transverse shear forces, when filled in. For the transmission of the horizontal longitudinal shear forces, the interface shear strength can be improved providing the adjoining edges with vertical indentations. With reference to the diaphragmatic action, this type of connections ensures that the floor has the same performance as a monolithic cast-in-situ floor, provided that a continuous peripheral tie is placed against the opening of the joints. For good filling, the maximum size of the aggregate of the cast-in-situ concrete shall be limited with reference to the joint width.

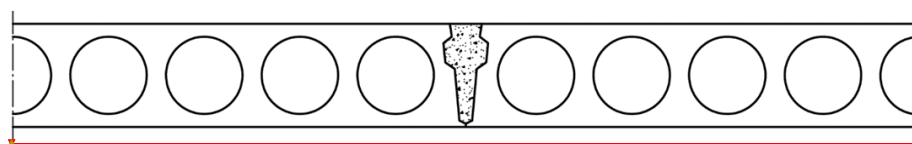


Figure 4 — Floor-to-floor connection made by concrete filling

Other types of floor-to-floor cast-in-situ connections, possibly provided with spliced tying steel links, are not considered in this document.

6.2.2 Strength

The type of connection of concern is usually intended as a continuous longitudinal hinge. Its strength is ensured following the specifications for the erection of the elements given by the manufacturer.

6.2.3 Other properties

No ductility and dissipation capacities are expected from the concerned type of connections that are located away from the critical regions of the structure.

6.3 Welded steel connectors

6.3.1 General

In Figure 5 two types of floor-to-floor welded connections are represented. The solution a) is constituted by two steel angles inserted at the edges of the adjacent elements and fixed to them with anchor loops. On the joint lap, a bar is placed welded in site to the angles, compensating the erection tolerances. Two steel plates inserted at the edges of the adjacent elements and fixed to them with anchor loops constitute the solution b). Over the joint, a middle smaller plate is placed, welded in site to the lateral ones. In both solutions, the steel components may be placed within a recess in order to save the upper plane surface of the finishing. In the first solution, the angles may be replaced with plates placed inclined so to leave in the joint the room for the positioning of the middle bar. These kinds of connections are used to join ribbed floor elements without topping. They are also used to join special roof elements when placed in contact one to the other.

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