RECOMMENDATION DOCUMENT FOR THE DESIGN OF PREQUALIFIED PRECAST CONCRETE BOLTED CONNECTIONS FOR SEISMIC APPLICATIONS (SA_LJ2018)

Referring to:
HPKM® 24, 30, 39 Column Shoes, HPM®-EQ 24L, 30L and 39L Anchor Bolts

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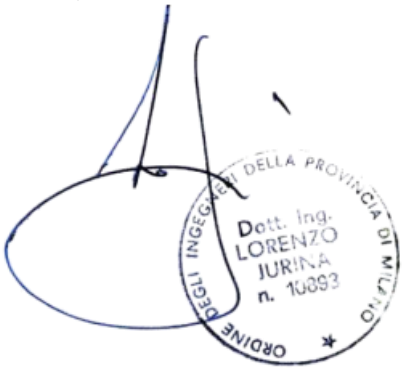

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This document contains: 13 pages including 4 Annexes
This document is followed by the report *"Experimental research on precast concrete bolted connection for seismic applications"* issued on 03/12/2015

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Use this document reasonably

- This document contains recommendations and design provisions based on a detailed research program on the cyclic behaviour of bolted precast connections, as better described in the technical report "*Experimental research on precast concrete bolted connection for seismic applications*".
- This document reflects exclusively the opinion of the authors on the design of precast concrete column-to-foundation connections equipped with HPM®-EQ Anchor Bolts and HPKM® Column Shoes by Peikko Group Corporation, according to the conducted tests and applicable Regulations.
- This document may be withdrawn by the issuing Body or by the Holder in case HPM®-EQ Anchor Bolts and HPKM® Column Shoes characteristics differ from what is herein specified.
- The authors do not assume any legal liability or responsibility for the structural design of the connections. It remains the responsibility of the Designer to dimension the connection system and to assure that results are suitable for the specific application.
- This document has a 6-year validity and it expires when new Codes that require different performances from the current ones are adopted.

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1. Definitions

anchor-bolt: a rebar-like building product fabricated by Peikko Group Corporation embedded in a reinforced concrete foundation for allowing the bolted connection with the precast concrete column through column shoes

behaviour factor: factor used for design purposes to reduce the forces obtained from a linear seismic analysis, in order to account for the non-linear response of a structure, associated with the material, the structural system and the design procedures

column: structural element, supporting gravity loads by axial compression or subjected to a normalised design axial force greater than 0.1

column shoe: a building product fabricated by Peikko Group Corporation with a shape of a pocket embedded in the precast column and anchored through anchor bars

drift: relative difference of displacement between the top and the bottom of a story, divided by the story height

ductility: the ability of the connection to undergo large amplitude cyclic deformations in the inelastic range without a substantial reduction in strength. Substantial reduction refers to a reduction equal to 20% of the maximum strength reached during the quasi static cyclic test

ductile connection: connection between two or more precast elements that experiences yielding as a result of the earthquake design displacements

energy dissipation: the energy absorbed by the connection during the cyclic loading due to its hysteretic behavior

frame building: structural system in which both the vertical and lateral loads are mainly resisted by spatial frames whose shear resistance at the building base exceeds 65% of the total shear resistance of the whole structural system

intermediate moment frame: beam-column frame or two-way slab-column frame without beams forming part of the seismic-force-resisting system complying with ACI 318-14, 18.4

performance level: a limiting structural damage state used for establishing building design performance objective

prequalified connection: a ductile and energy dissipative precast concrete connection equivalent to a monolithic one, investigated experimentally through an appropriate number of quasi-static cyclic tests, as required in EN 1998-1, 5.11.2.1.3

primary seismic member: a member considered as part of the structural system that resists the seismic actions, modelled in the analysis for the seismic design situation and

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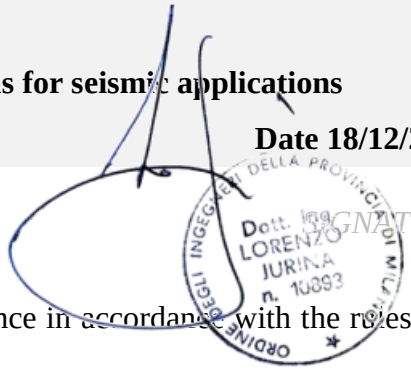

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fully designed and detailed for earthquake resistance in accordance with the rules of a recognized seismic code

quasi static cyclic test: an incremental static deformation applied slowly to a specimen so that inertia effects and strain rate effects on materials are negligible

seismic code: an approved document with rules on the seismic design of structures

special moment frame: a precast beam-column frame complying with ACI 318-14, 18.2.3 through 18.2.8 and 18.9

strong connection: connection between one or more precast elements that remains elastic while adjoining members experience yielding as a result of earthquake design displacements

2. Symbols

A_c	cross-sectional area of the column
A_h	dissipated energy per cycle - drift
B	column's width
DCL	low ductility design according to EN 1998-1
DCM	medium ductility design according to EN 1998-1
DCH	high ductility design according to EN 1998-1
f_{cd}	design value of the compressive strength of the concrete in column
$f_{cd,mortar}$	design value of the compressive strength of the mortar in the joint
H	column's depth
K_e	initial stiffness calculated according to Annex 2b
K_{sec}	secant stiffness calculated according to Annex 2b
L_c	column's height
$M_{Ed,joint}$	design value of the bending moment in the joint
N_{Ed}	design value of the compressive axial load in the column
$n_{d,column}$	design value of the compression ratio in the column above the joint
$n_{d,joint}$	design value of the compression ratio in the joint
q_0	basic value of the behavior factor
SSR	shear span ratio = $M_{Ed,joint} / (V_{Ed,joint} \cdot L_c)$

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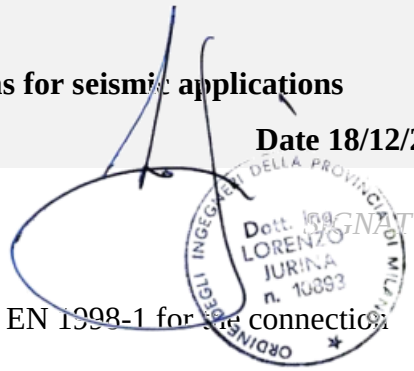

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$req.\mu_{\Delta,EN1998}$	required displacement ductility from EN 1998-1 for the connection
T_1	fundamental period of the structure
T_C	period at the upper limit of the constant acceleration region of the response spectrum
$V_{Ed,joint}$	design value of the shear force in the joint
$\mu_{\Delta,d}$	design value for displacement ductility of the prequalified connection
δ_y	yield displacement calculated according to Annex 2b
ξ_{tot}	total equivalent damping factor calculated according to Annex 3a
ξ_{visc}	viscous damping factor according to Annex 3a
ξ_{hyst}	hysteretic damping factor according to Annex 3a

3. Statement

(1) It is herein stated that Peikko HPKM®–HPM®-EQ precast concrete bolted connections can resist seismic loads in a satisfactory ductile and energy-dissipative manner based on the results of quasi-static cyclic tests conducted in the *Laboratorio Prove Materiali* (Testing Materials Laboratory) in Politecnico di Milano, Italy. The experimental set up followed the regulations of ACI 374.2R-13.

(2) Precast and cast-in-place specimens were compared regarding ductility, energy dissipation, stiffness and strength degradation. The cast-in-place specimens fulfil all the reinforcing details of EN 1998-1-1 for DCH design. In particular, one of them followed the requirements of ACI 318-14 for special moment resisting frames.

(3) The characteristic value of the displacement ductility was measured from the hysteresis curves. The hysteresis curve referred to the drift pattern of Annex 2a. The yield displacement was measured according to the recommendation of ACI 374.2R-13, 4.7 (Annex 2b). The maximum post yield displacement referred to the previous guideline document and is associated with a strength reduction of 20% or collapse.

(4) The total equivalent damping factor ξ_{tot} per cycle was calculated according to Annex 3a and consists of the viscous component ξ_{visc} (taken equal to 2%) and the hysteretic one ξ_{hyst} calculated from the dissipated energy.

(5) Initial and secant stiffness per cycle were measured according to Annex 2b.

(6) Based on (3), (4) and (5), it can be assessed that the final results satisfy the local ductility demands of EN 1998-1, 5.2.3.4(3) and 5.11.2.1.3, and the performance levels stated in ACI 374.2R-13 (Annex 4a, 4b).

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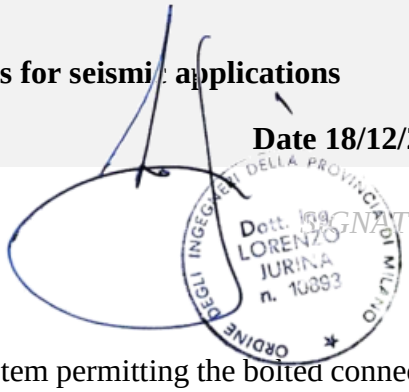

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4. System description and product definition

(1) Peikko HPKM®–HPM®-EQ connection is a system permitting the bolted connection of precast reinforced concrete columns to foundations (Annex 1) through column shoes and anchor bolts.

(2) The HPKM® Column Shoes consist of steel plates (base and side plates) and reinforcing bars, which assure the anchoring of the shoes in the column (anchor bars).

(3) The HPM®-EQ/L Anchor Bolts consist of ribbed reinforcing steel, two hexagon nuts and two washers. One of the ends of the anchor bolt is provided with a forged anchor head and the other with a thread. The anchor bolts are delivered with part of the thread debonded with a heat shrinkage tube; the other part is lubricated. Forces are transferred through the bond of the ribbed parts and the forged anchor head. The exact dimensions of the anchor bolts and the debonded length are shown in Annex 1.

(4) The satisfactory structural performance of the column shoes against static loading is fully covered by ETA-18/0037 and that of the anchor-bolts by ETA-02/0006.

(5) The anchor bolts are cast into foundation so that the debonding length is fully embedded into concrete (Annex 1). After the placement of the column on the levelling nuts, the holes in the base plates of the shoes are filled with epoxy resin. The tightening of the connection is secured by rotating the upper nut according to Annex 1; then the joint between column and foundation is filled with non-shrink high strength fibre mortar.

(6) The characteristics of the materials to be adopted are described in Paragraph 5.

(7) The surfaces both at the base of the column and at the top of the foundation shall be rough according to EN 1992-1-1 6.2.5(2) (Annex 1). The use of a profiling plate with a minimum number of 4 keys per direction, such as Peikko PPS® Profiling Plate (Annex 3b), is mandatory.

(8) The reinforcing details for the column and the foundation are shown in Annex 1.

5. Materials and cross-sectional geometry

(1) The present document covers different dimensions of square concrete cross-section, different number and layouts of column shoes and anchor bolts (Annex 1).

(2) This document does not cover columns of circular geometry.

(3) The concrete grade has to be from C25/30, according to EN 1998-1 5.5.1.1 to C50/60.

(4) The reinforcing steel has to be of type C according to EN 1998-1 5.5.1.1.

(5) Washers have to be of anti-lock geometry, quenched and tampered carbon steel material and with a minimum hardness of 465 HV1.

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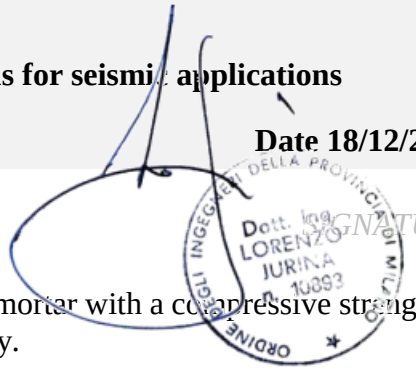

(6) The use of a steel fibre-reinforced, non-shrink mortar with a compressive strength at least 30% higher than that of concrete is mandatory.

(7) Epoxy resin inside the holes of the base plate is mandatory to secure the anchoring between anchor bolt and column shoe.

6. Ductility Based Design according to EN 1998-1

(1) The statement in Paragraph 3 refers to column to foundation connections described in Annex 1 under compressive axial force; from now on characterized as *prequalified connections*.

(2) Precast reinforced concrete columns fixed at their base with the prequalified connections of Annex 1 shall be classified according to EN 1998-1 as primary seismic elements and considered equivalent to cast-in-situ ones within the design ductility limits as described in 6(4).

(3) The prequalified connections of Annex 1 refer to medium (DCM) and high ductility (DCH) structures as defined in EN 1998-1. For low ductility structures (DCL) to be designed in low seismicity areas with a design ground acceleration < 0.78 m/s^2 (EN 1998-1 5.3.1) the conventional Peikko HPKM®–HPM® bolted joints are permitted.

(4) The design ductility is based on the conservative assumption of a safety factor equal to the recommended partial safety factor for concrete found in EN 1992-1-1, thus equal to 1.5. The design ductility ($\mu_{\Delta,d}$) for the prequalified connections of Annex 1 becomes then equal to:

4 / r for compression ratio $n_{d,joint} \leq 15\%$
3 / r for compression ratio $n_{d,joint} > 15\%$

where

$n_{d,joint} = N_{Ed} / (A_c \cdot f_{cd,mortar})$ (1)

N_{Ed} is the compressive force taken from the seismic analysis

A_c is the cross-sectional area of the column

$f_{cd,mortar}$ is the strength of the fibre mortar against compression

r = 1.5 in case of short columns with a shear span ratio SSR ≤ 2.5

(5) Both compression ratios ($n_{d,column} = N_{Ed} / (A_c \cdot f_{cd})$ of the column part above the joint and that of Eq. (1)) must not exceed the maximum values defined in EN 1998-1 5.4.3.2.1 and 5.5.3.2.1; thus 0.65 for medium ductility design (DCM) and 0.55 for high ductility design (DCH).

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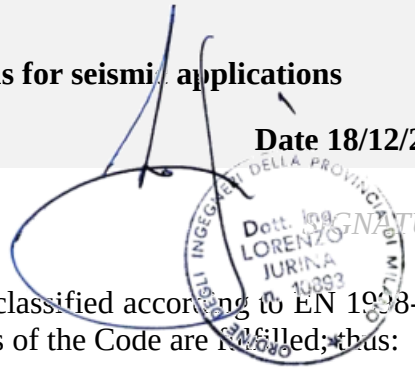

(6) The prequalified connections of Annex 1 are classified according to EN 1998-1 as overdesign-free when the local ductility provisions of the Code are fulfilled; thus:

$\mu_{\Delta,d} \geq \text{req.}\mu_{\Delta,EN1998}$ (2)

where

$\mu_{\Delta,d}$ is the ductility design value according to 6(4) of the present document

$\text{req.}\mu_{\Delta,EN1998}$ is the minimum required displacement ductility imposed by EN1998-1 5.2.3.4

(7) The local ductility condition of the critical regions of primary seismic elements is deemed to be satisfied if the minimum required displacement ductility is at least equal to the following values:

$\text{req.}\mu_{\Delta,EN1998} = q_o$ for $T_1 \geq T_C$ (3a)

$\text{req.}\mu_{\Delta,EN1998} = 1 + (q_o - 1)\, T_C / T_1$ for $T_1 < T_C$ (3b)

where

q_o is the corresponding basic value of the behaviour factor from the seismic code

T_1 is the fundamental period of the building

T_C is the period at the upper limit of the constant acceleration region of the spectrum.

(8) Bending and shear resistance of the joint shall be computed in accordance with EN 1992-1-1 6, using the value of the axial force from the analysis of the seismic design situation.

(9) The reinforcing of the columns shall adequately cover all the requirements of EN 1992-1-1 6 and EN 1998-1 5.

7. Design according to ACI 318-14

(1) The prequalified connections of Annex 1 can be used as ductile ones only for the case of intermediate moment frames (ACI 318-14, 18.4).

(2) For special moment frames the prequalified connections of Annex 1 should be overdesigned according to ACI 318-14, 18.9.2.2.

(3) The reinforcing of the column and the foundation should fulfil all the requirements found in Chapter 18 of ACI 318-14.

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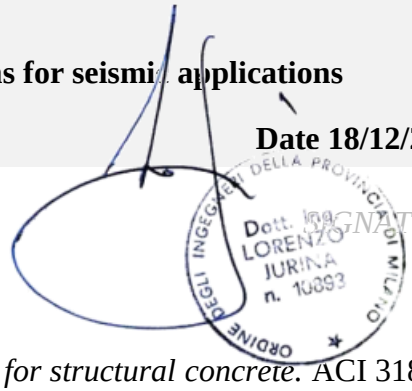

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8. References

[1] ACI Committee. *Building code requirements for structural concrete*. ACI 318-14, American Concrete Institute, 2014.

[2] ACI Committee. *Guide for testing reinforced concrete structural elements under slowly applied simulated seismic loads.* ACI374.2R-13, American Concrete Institute, 2013.

[3] CEN (European Committee for Standardization). *Eurocode 2: Design of concrete structures. General rules and rules for buildings*. EN 1992-1-1: 2004, December 2004.

[4] CEN (European Committee for Standardization). *Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*. EN 1998-1: 2004, November 2004.

[5] ETA 18/0037. *Peikko HPKM Column Shoes*.

[6] ETA 02/0006. *Peikko HPM/L Anchor Bolts*.

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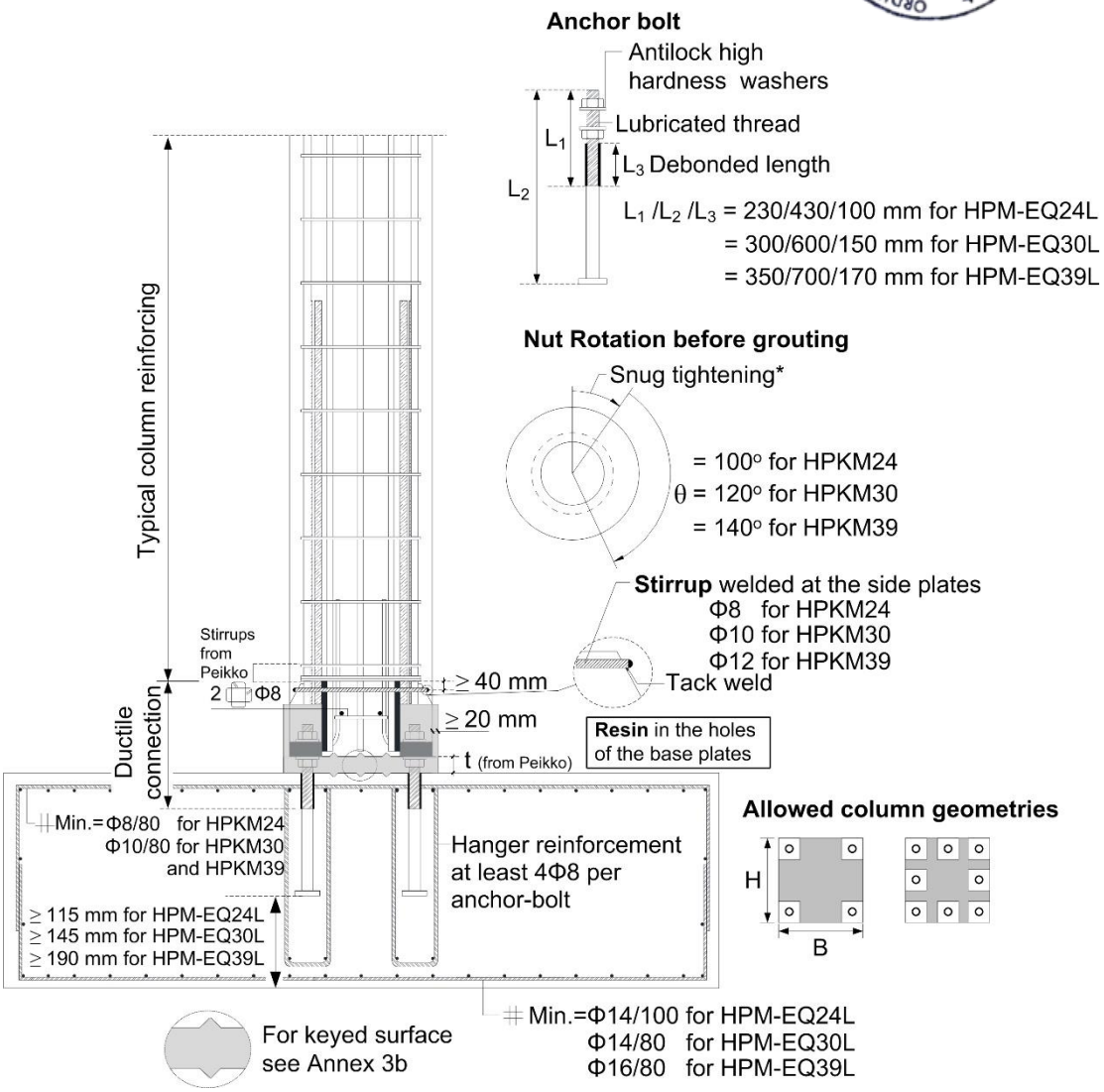

*Snug tightening as defined in RCSC (Research Council on Structural Connections) *"Specification for Structural Joints using High-Strength Bolts"*, December 31, 2009

Annex 1: Prequalified connection with short bolts (Type L) for HPKM® 24, 30 and 39

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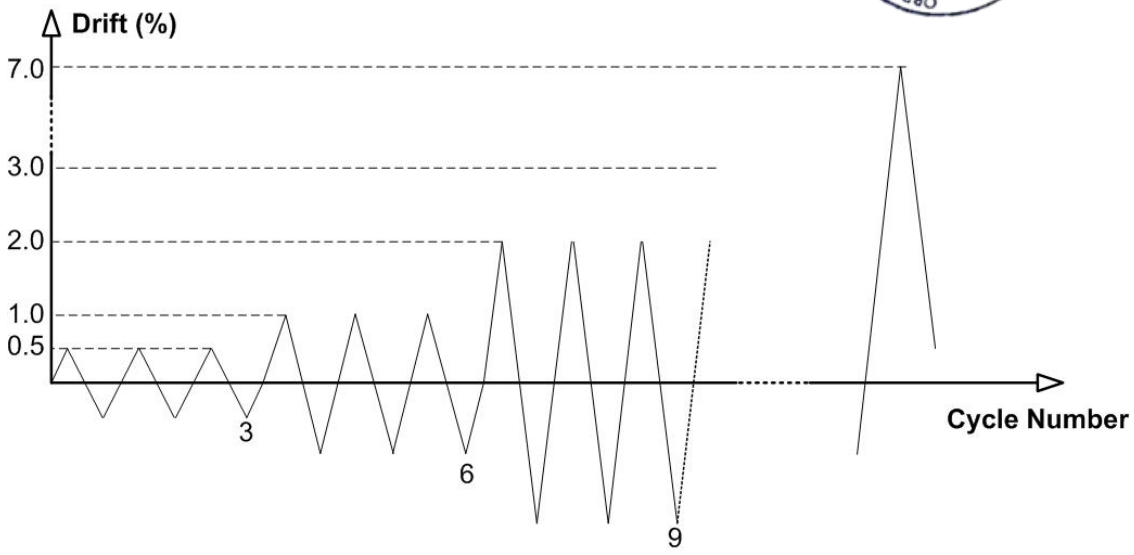
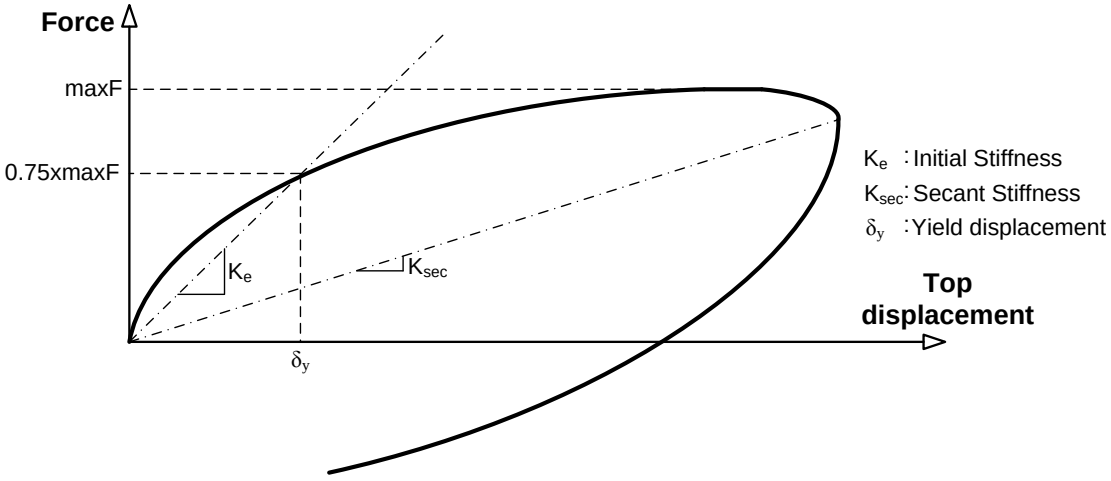


(a)



(b)

Annex 2: a) Imposed drift pattern according to ACI 374.2R-13 b) Yield displacement δ_y, initial stiffness K_e and secant stiffness K_{sec}

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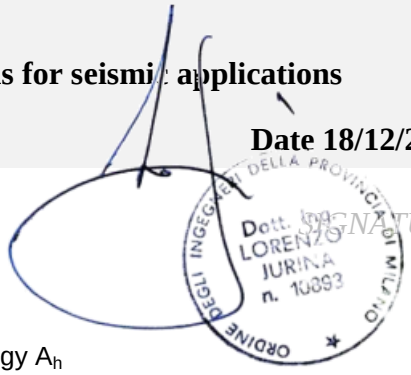

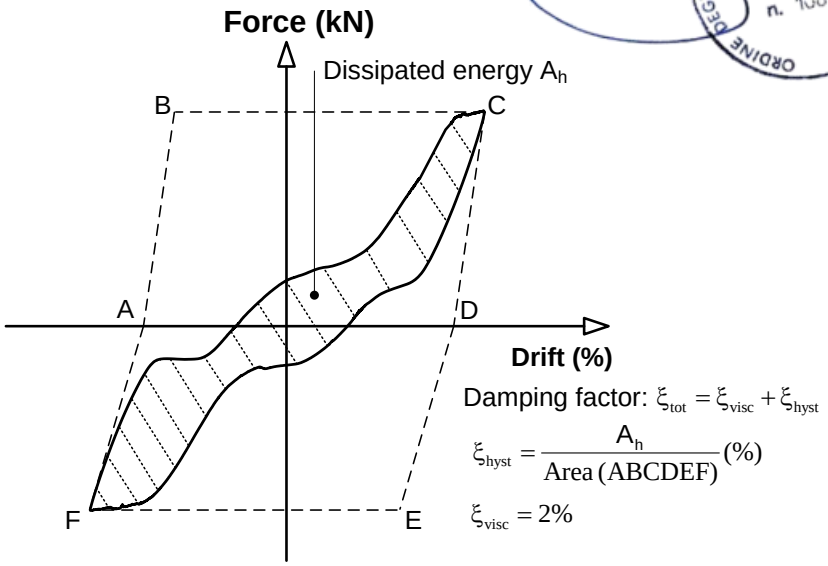

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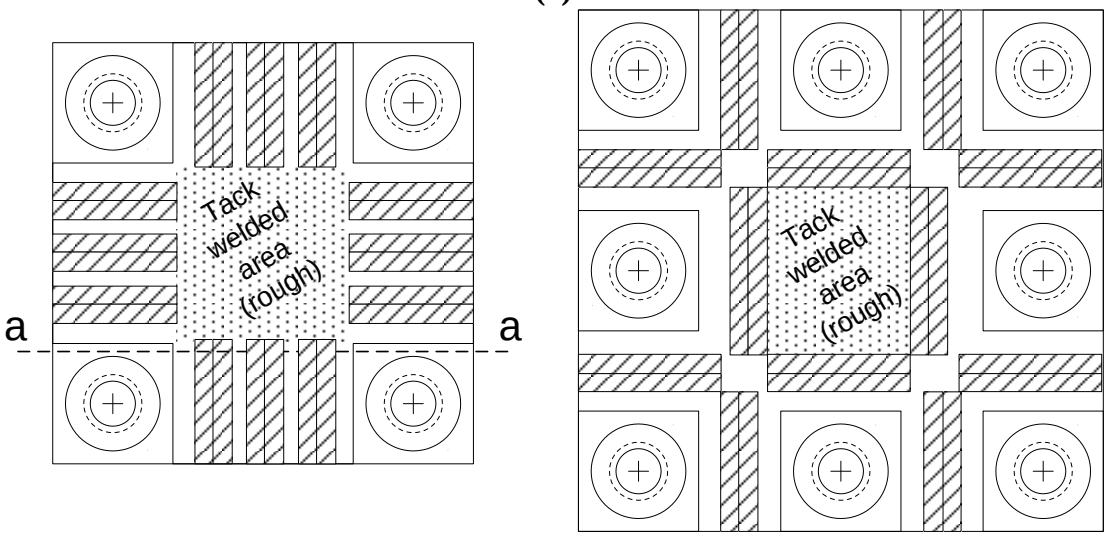

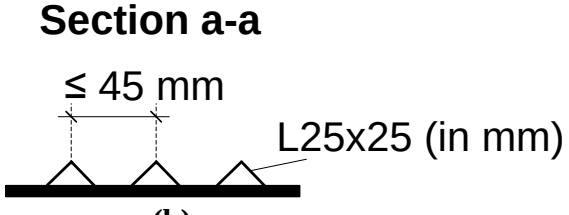

(b)

Annex 3: a) Calculation of total equivalent damping factor ξ_{tot} (ACI 374.2R-13)
b) Profiling plates for achieving a keyed surface in the joint

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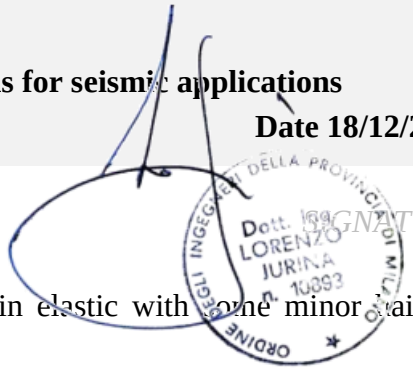

Operational level: The structural elements remain elastic with some minor hairline cracks.

Immediate occupancy: Post-earthquake damage of the structural elements allows the structure to be safely reoccupied. Residual deformations are negligible.

Both previous performance levels refer to a lateral drift ratio approximately equal to 1%. This value is valid for frame buildings.

Life safety: Severe post-earthquake damage of the structural elements takes place but the risk of total or partial structural collapse is low. Residual deformations of 1% drift are expected in frames. The life safety performance level refers to a lateral drift ratio greater than 1% and lower than 2% for frame buildings.

Collapse prevention: Post-earthquake damage of the structural elements is substantial, the structure is on the verge of partial or total collapse. The structural elements cannot be repaired. Residual drifts reach values up to 2%.

(a)

Performance level	**Acceptable by ACI 374.2R-13**	**Performed by the Prequalified Connection (Annex 1)**	**Drift ratio**
Operational	Minor hair line cracking; no concrete crushing and permanent deformation	Same performance	0.4% transient
Immediate Occupancy	Minor hair line cracking; limited yielding possible at few locations; no crushing	Same performance	1% transient
Life Safety	Spalling of cover and shear cracking less than 3.2 mm wide	Better performance with no spalling and no shear cracks	3% 1% transient 2% permanent
Collapse prevention	Extensive cracking and hinge formation; low or zero reparability	Better performance with no spalling or crushing; high reparability	4% Transient or permanent
Collapse	Collapse initiation	Better performance No collapse, strength degradation ≤ 20%	> 4% and ≤ 5%
		Better performance No collapse with strength degradation ≤ 20%	> 5% and ≤ 6%
		Collapse initiation	> 6 %

(b)

Annex 4: a) Definition of structural performance levels according to ACI 374.2R-13
b) Comparison of ACI 374.2R-13 structural performance levels with the prequalified connections

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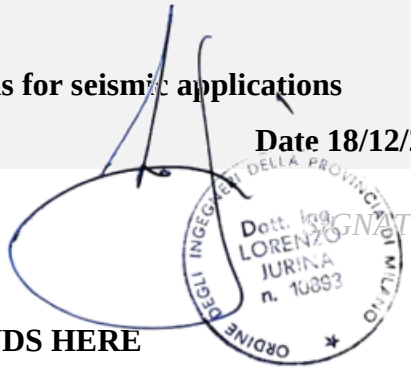

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