CONNECTION SYSTEMS FOR PRECAST CONCRETE ELEMENTS

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ABSTRACT

Recently the industrialized production of precast concrete elements intended to construct precast buildings has reached a high quality standard.

In the precast concrete building field all solutions have one aspect in common: the issue of mutual connection grade between precast elements.

It is frequent to resort to highly technological solutions finalized to link mechanically precast elements obtaining a less articulated structural organism.

Linking precast columns to the foundation works without having to use grouted pockets is one of the crucial points many solutions have had to deal with.

The following paper introduces a connection system named “continuity connection” tweaked to link precast columns to foundation works or portions of columns between each other. This system is able to create a mutual frame tie between parts restoring the reinforcement bars’ structural continuity without having to overlap them.

Main features of this system is the possibility to erect columns, no matter their dimension or weight, without the additional use of bracing to keep the columns temporarily in position.

The performance of the system is guaranteed by various tests carried out, both static and cyclic, which have demonstrated its reliability also with seismic loads.

Keywords: Innovative Precast Structures, Connections, Optimization, And Structural Robustness

INTRODUCTION

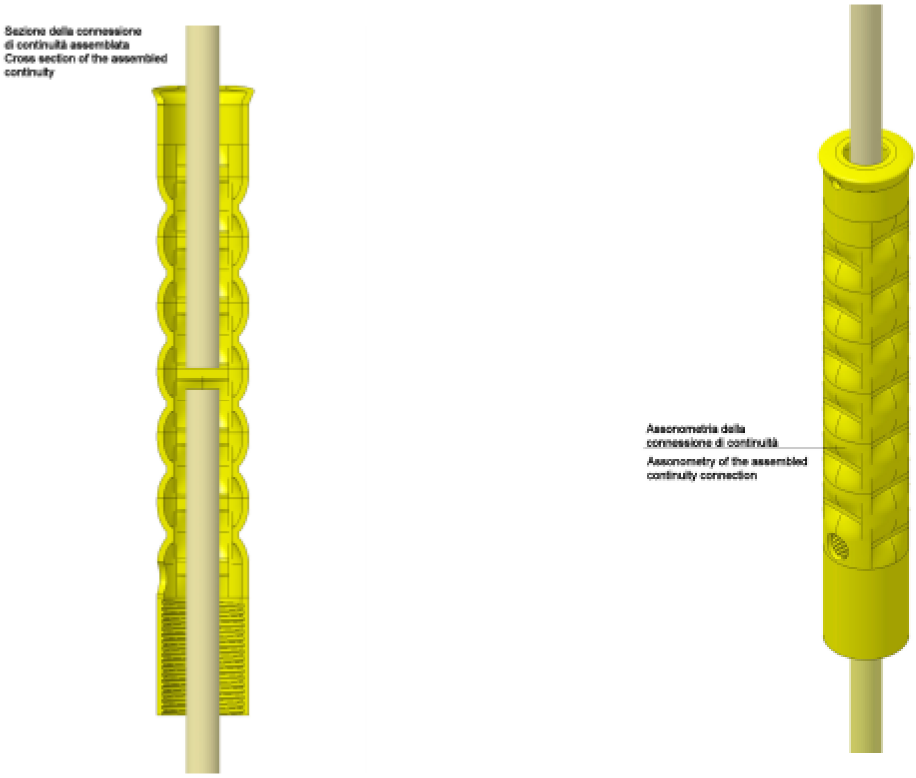
Since its beginning the precast concrete industry dawn has had to deal with problems related to how to link elements one to another.
Connecting precast columns to foundation works, combining portions of columns with each other, the bonding of precast concrete walls to foundation works are some of the problems in the joining of concrete elements to one an other (precast or not).

In the past the solutions suggested have had in common the will to retrieve the structural continuity of the manufacts reinforcement bars: it is possible to encounter solutions based on connecting reinforcements via threaded sleeves, others use metal elements with which they execute a wet joint between rebars.

In this paper we are introducing the “Continuity Connection”, a rebar linking system for precast elements, that offers for the first time an important innovation: the possibility to erect columns without the additional use of bracing to keep the columns temporarily in position.

DESCRIPTION OF THE SYSTEM

The Continuity Connection guarantees, by means of a conveniently shaped sleeve, the transfer of the forces acting on the column's reinforcement bars to the ones present in the foundation works retrieving a perfect mechanical continuity (the same concept is applicable to two different parts of a precast column that has to be mechanically jointed).

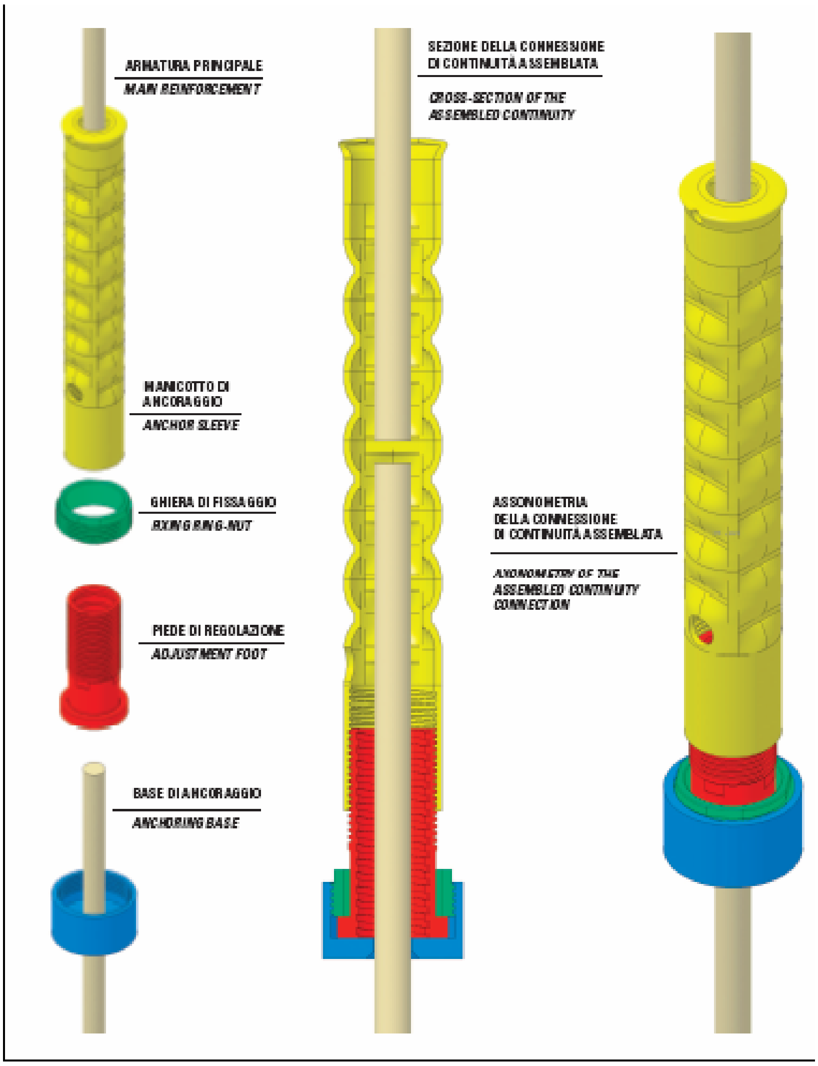


des. 1: Continuity system details.

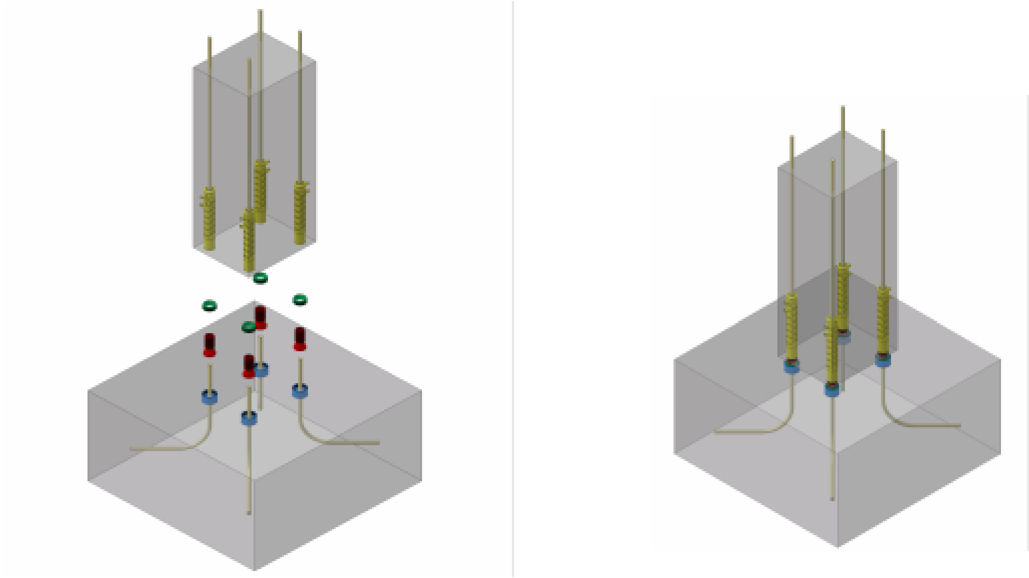
The System bases its functioning principle on exploiting the adherence theory: the extremities of two reinforcement bars to be mechanically jointed are precisely positioned (via template) in a reshaped metal sleeve; the sleeve is then filled with a highly resistant and doubly expanding mortar, purpose-made. The expansion effect due to the mortar and the sleeve's confining effect "weld" the two reinforcement portions together.
The experimental trials have proved that the system put into practice allows transferring a 600 kN force without any of the reinforcement bars sliding out of the sleeve.
The innovation introduced by the Continuity Connection is symbolized by the choice of assigning to the sleeve, besides the static function above mentioned, the capacity to erect columns without the additional use of bracing to keep the columns temporarily in position, this way all the transitional erection works can be put aside.

It is made up of:

a) a *anchor sleeve*, conveniently shaped tubular metal element capable of assuring high adhesion strength to the internal and external surface. This element is positioned in the precast manufact during production;
b) a *adjustment foot*, a hollow metal element screwed into the sleeve after the manufact's production;
c) an *anchoring base* equipped with reinforcement rebar, positioned during the foundation work phases;
d) a *fixing ring-nut*, a hollow metal element interjected between the elements system producing a mutual mechanical connection.



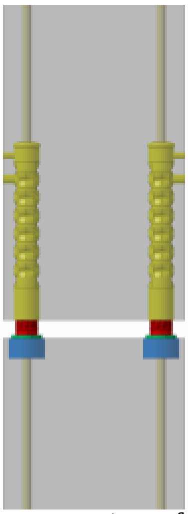
des. 2: details of the entire system used to control height adjustment and plumb verticality during the erection phases.



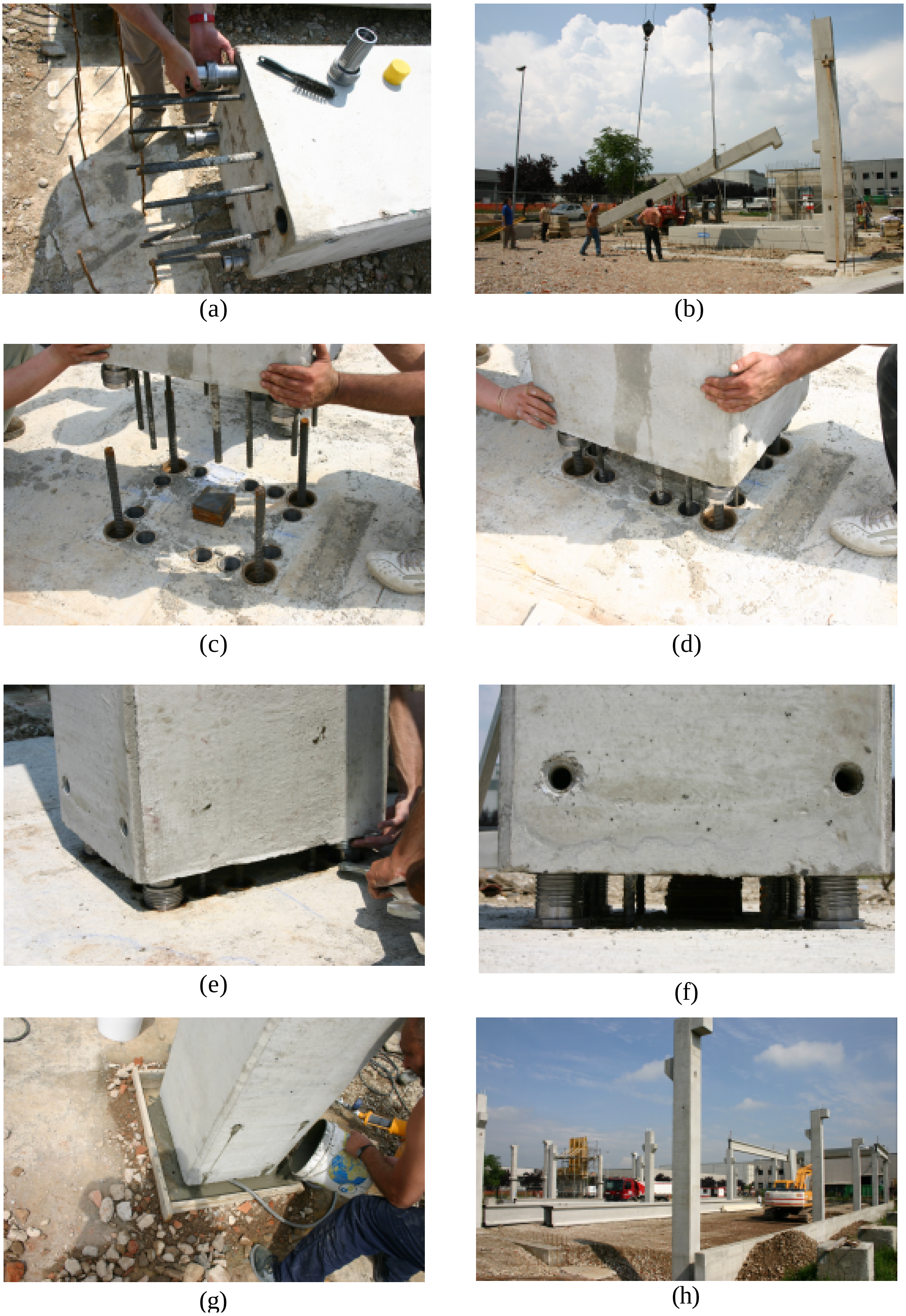
a) b)

des. 3: portrayal of the connection during the element's erection (a) and at connection completed (b).

The mechanical behaviour of the system is progressive. During the transitory stage related to the erection, the mechanical joint between column and foundation works takes place through the fixing ring-nut that placed between the adjustment foot (assembled to the column) and the anchoring base (in foundation) creates a mechanical connection between the two elements. This makes it possible to erect the column and adjust height and verticality conveniently operating on the adjustment feet without using struts or other additional bracing system: it results in a precise, safe, fast and extremely economical erection.
After the element's erection and its exact plumb verticality, the anchoring sleeves have to be filled with the purpose-made mortar, capable of developing incredibly high resistance in an extremely short time.
The connection between two portions of column is analogue to the one described above:



des. 4: portrayal of the connection of two portions of column .



ph. 5: Erection sequence: (a) adjustment feet installed in the column; (b) erecting the column; (c) e (d) placing the column in the foundation work; (e) plumb verticality

adjustment; (f) tightening of the ring-nut; (g) mortar injection; (h) overview of the construction site.

FEATURES OF THE SYSTEM

The features of the Continuity system are:

a) Coupling tolerances

The system allows connection between elements with tolerances at least twice those in the existing similar systems.

b) Adjustability

The adjustment feet allow graduation of the element's verticality avoiding using extra props.

c) Ductility

The new system's concept is strongly dependent on the chosen materials. The system uses high ductility steel which is known to be more resistant than those with high strength that may be fragile at times.

d) Fire resistance

The completely embedded system, is automatically protected against fire without the need for additional protection after installation. Nothing can be seen on the outside of the column; all the metal parts have a protective coating.

e) High mechanical resistance

The tests and certification have proven that the system possesses high mechanical resistance. The continuity connection is designed to withstand 160% bar yield of the rebars conventionally used in the elements.

f) High confinement

Being inside the manufact the system's elements don't prevent adopting confinement reinforcement in the terminal points of concrete elements as prescribed in the main normative, the ideal solution in terms of anti-seismic performance.

TRIAL VALIDATION

The features of the continuity connection system and its single components have been tested undergoing several experimental trials in the labs of the university of Pavia, the Structural Mechanical Department and at the EUCENTRE (European Centre for Training and Research in Earthquake Engineering).

The aim of these trials was to quantify the actual strength and resistance of the connection system via a series of cyclical almost-static tests in order to assess their effective collapse mechanism response.

A) Trial machinery

A special MTS 210 frame was used for the tests, developed for static and dynamic testing and for axial/torsion stress (photo 6). It is made up of:

- two stiff uprights;
- a stiff height adjustable cross-member fitted with an upper clamp;

- a hydraulic piston controlled by pressurised oil to which is connected a lower clamp.

(a)

(b)

ph. 6: Trial machinery: (a) MTS 210 frame; (b) detail of the lower header; (reference MTS – Material Testing System)

Here are the main characteristics of the machine:
- axial load capacity: 500 kN (110 kip);
- two types of hydraulic wedge grips sized to reflect the above max load;
- max working pressure of the grips: 62 MPa (9000 psi);
- working temperature: 18°C - 65°C (0°F - 160°F);
- max optimised frequency of the cyclical tests: approx. 1 Hz;
- control during loading and/or shifting.

B) Test protocal

The test protocol was agreed on the basis of current international reference norms such as ACI133 "*Acceptance criteria for mechanical connectors for steel bar reinforcement*" and ACI550.1R-01 "*Emulating Cast-in-Place Detailing in Precast Concrete Structures*".
In order to get international acknowledgement the tests consisted of a sequence capable of representing several verification criteria and conditions for different scenarios to suit each prototype of connection.

The prototypes were tested in this way:
• increasing monotonic controlled load tests, from 0 to 153 kN (0÷67% of the expected nominal strength).
• cyclical loading/unloading tests (100 complete cycles) from 30 to 153 kN (15÷67% of the expected nominal strength).
• cyclical loading/unloading tests (10 complete cycles) from 34 to 285 kN (15÷125% of the expected nominal strength).
• cyclical loading/unloading tests (10 complete cycles) from 34 to 342 kN (15÷150% of the expected nominal strength).
• increasing monotonic collapse tests.

Test speed was arranged in the test protocol so as to keep direct comparative test results, in particular:

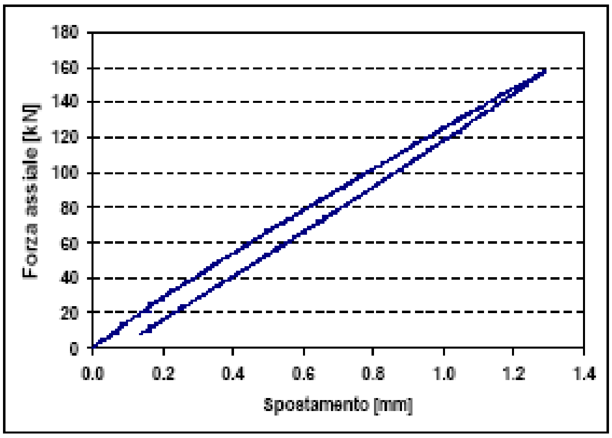
• The resulting speed range was 0.5 - 20 kN/s depending on the type of test involved (monotonic or cyclical) and the number and amplitude of the foreseen cycles;

• The maximum effective length of the test for a single prototype was of about 2 hours.

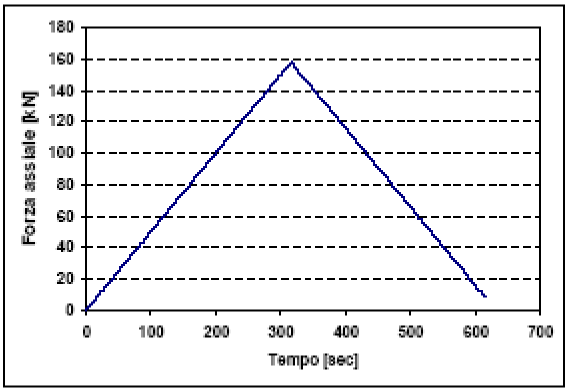
The tests were carried out with controlled loads to reach the prototype's elastic limit and from there on to a displacement control.

C) Experimental trials details

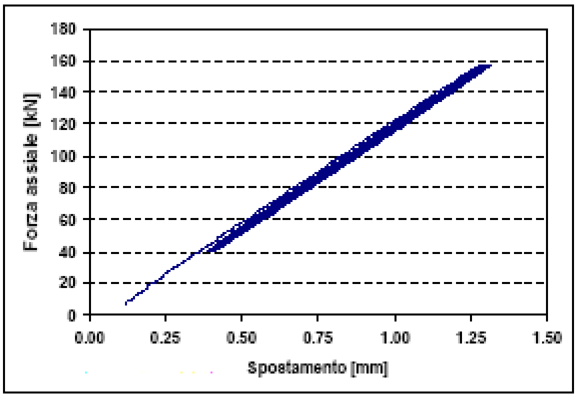
The results obtained during the various test campaigns follow.



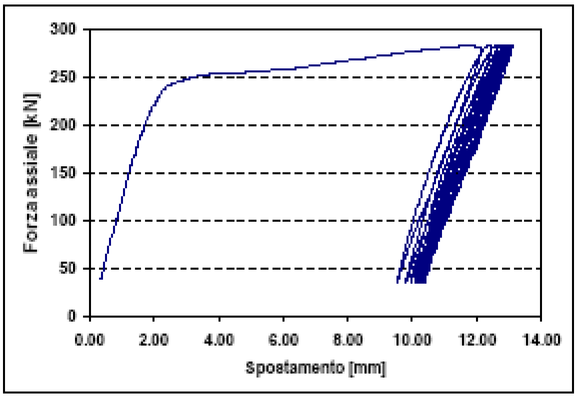
diag. 7: strength–displacement curve during the monotonic load tests up to 67% (153 kN) of the expected nominal strength.



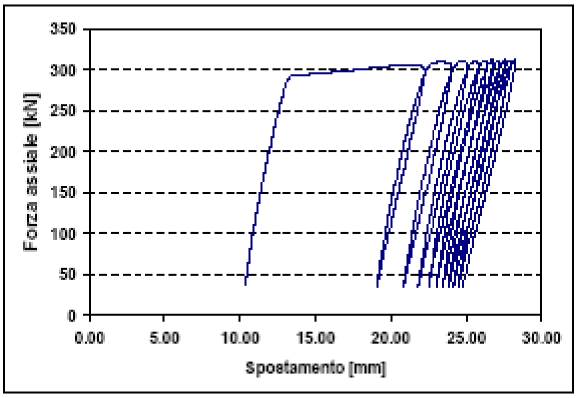
diag. 8: strength–time curve during the monotonic load tests up to 67% (153 kN) of the expected nominal strength.



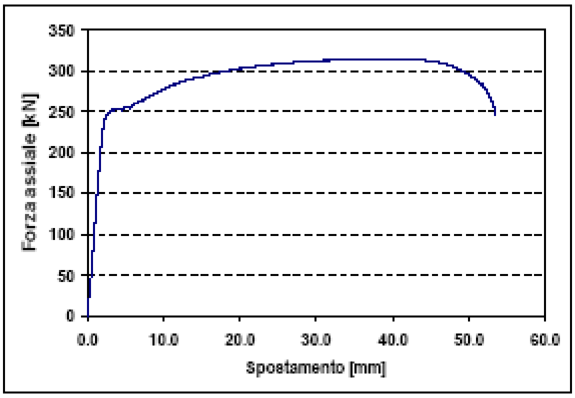
diag. 9: strength–displacement curve during the cyclic load/unload trials from 15% (35 kN) to 67% (153 kN) of the expected nominal strength.



diag. 10: strength–displacement curve during the cyclic load/unload trials from 15% (35 kN) to 125% (285 kN) of the expected nominal strength.



diag. 11: strength–displacement curve during the cyclic load/unload trials from 15% (35 kN) to 150% (312 kN) of the expected nominal strength.



Fy = 252 kN
F_{max} = 314 kN
? y = 3,2 mm
? (F_{max}) = 38,7 mm
? u = 53,5 mm

diag. 12: strength–displacement curve with increasing monotonic load up to ultimate load.

(a)

(b)

(c)

ph. 13: Test Set-up (a); damage sequence of the ultimate load test: (b) reinforcement rebar yielding point; (c) ultimate load breaking point external to the sleeve

Furthermore to find the upper limit over which the two rebars start slipping out of the sleeve an experimental campaign with two Diwidag Ø32 mm rebars was carried out. These trials were held in the labs of the OMECO s.r.l. research centre in Monza (MI), a trial laboratory licensed by SINAL (National System for laboratory licensing) at n.0003, N.90 from SIT (Calibration service in Italy) in conformity with European regulation UNICEI EN ISO/IEC 17025. The need to use Diwidag rebars was related to the fact that other rebars yield and break at lower load levels in comparison to the connection system limit.

Test protocol

The test protocol was agreed on the basis of current international reference norms such as ACI133 "*Acceptance criteria for mechanical connectors for steel bar reinforcement*" and ACI550.1R-01 "*Emulating Cast-in-Place Detailing in Precast Concrete Structures*".

In order to get international acknowledgement the tests consisted in a sequence capable of representing several verification criteria and conditions for different scenarios to suit each prototype of connection.

The prototypes were tested this way:

• increasing monotonic collapse tests.

The set of speed values was arranged to ensure that the results could then be compared for similar test pieces, in particular:

• The speed interval considered is lower than 0.5 kN/s.

The trials were carried out under load control to the elastic limit of the specimen and from there switched to a displacement control.

Experimental trials details

The results obtained during the various test campaigns follow.

	PROVA DI TRAZIONE / *TENSION TEST*			
Identif. N. *Identif. N.*	Dimens. Provetta *Specimen dimens.* (mm)	Temp. *Temper* (°C)	Carico max totale Total Tensile Strength (N)	Posizione di rottura *Break position*
3600/B	*Campione intero Full sample*	+20	602000	Sfilamento barra d'armatura *Detachment reinforcement bar*
3600/C	*Campione intero Full sample*	+20	586000	Sfilamento barra d'armatura *Detachment reinforcement bar*

The test results point to how the continuity connection has been designed to resist over 160% of the yielding limit of the rebar with the maximum diameter insertable in the system. This amount fully satisfies even the higher California State standards (while in the rest of the USA the limit is equal to 150% or 125% depending on the current seismic risk).

CONCLUSIONS

The “Continuity Connection” system brings interesting innovations to the concrete precast world. The latter makes the use of the system to connect elements faster with more immediacy and extreme precision, furthermore it allows an engineering optimisation of the metal inserts embedded in the concrete manufacts. The following main features are outlined:

no bracing: entails an undisputed increase in erection speed and lower laying prices;

adjustable laying: the system allows a wide range of adjustability on the foundation tolerances and when verticalizing the elements to be linked. This makes it possible to recover erection and/or production mistakes not only of precast elements but also of the in situ ones, favouring erection accuracy;

system strength: the intrinsic high strength capacity of the connection (that always exceeds 160% of the yielding value of the reinforcement rebars resulting in a perfect continuity). This means it can be used under any kind of static or dynamic strain, resulting adaptable to norms and regulations of all the industrialized countries;

universality: the anchoring sleeve can be combined with rebars with different diameters from Ø12 to Ø32 mm. Always allowing elevated coupling tolerances between the rebar and the anchoring sleeve. Thanks to this universality there’s no longer the need to combine a different kind of sleeve for different rebar diameters, avoiding inconvenient production mistakes and simplifying the designer’s work;

The anchoring sleeve’s doubled adherence: The 3D modelling of the sleeve is purposely designed to favour internal and external adherence of system embedded in the manufact’s concrete. Resulting in an adhesion mechanism similar more to the one of a reinforcement rebar than to the one of classic metal insert. The doubled adherence, unique feature at an international level, besides avoiding the interruption of the reinforcement and the confinement in critical areas such as the column/foundation connection, exploits the external sleeve adherence optimising the internal action transmission.