Pre-Cast Concrete Connections, Issues and Innovative Solutions

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What is Pre-cast Structure

- Precast concrete structure is constructed by connecting the different structural elements prepared in the controlled environments using advanced construction materials and techniques.

- This is faster construction method with enhanced quality control due to its dedicated and fully equipped pre-casting yard.

Different Type of Connections in Pre-cast Structure

1. **Foundation to Column**
2. **Column to Column**
3. **Column to Beam (Interior, Exterior, Corner)**
4. **Beam to Slab**

Pre-cast Structure Failures

(Earthquake)

1999 Kocaeli-Golcuk & Duzce-Bolu Turkey Earthquake

Precast constructions were majorly used for industrial facilities in turkey. Majority of these structures were near the epicenter of the earthquake. The lack of confinement in column and short column effect. The corbel and flexible diaphragms are the main reasons for the failure occurred. But at the same time there were also some finished structures that survived well (Anderson 2001)

" After earthquake temporary shelter in the form of tents have been used for the people in many locations of the city. Among them twenty prefabricated units were also used in the short term to provide better shelter and comfort compare to the tents. Also it is permanent and can be used for long term".

An earthquake of 6.7 Magnitude January 17, 1994 at California California State Northridge's precast parking structure.

- Faulty connection.
- The structure experienced displacements at each level that were far too large for the non-ductile columns to withstand.
- The parking garage did not meet code due to its lack on continuity and poor ductility. (Dames & Moore Inc. / Donovan 2009).

The 29th May 2012 Emilia Romagna Earthquake

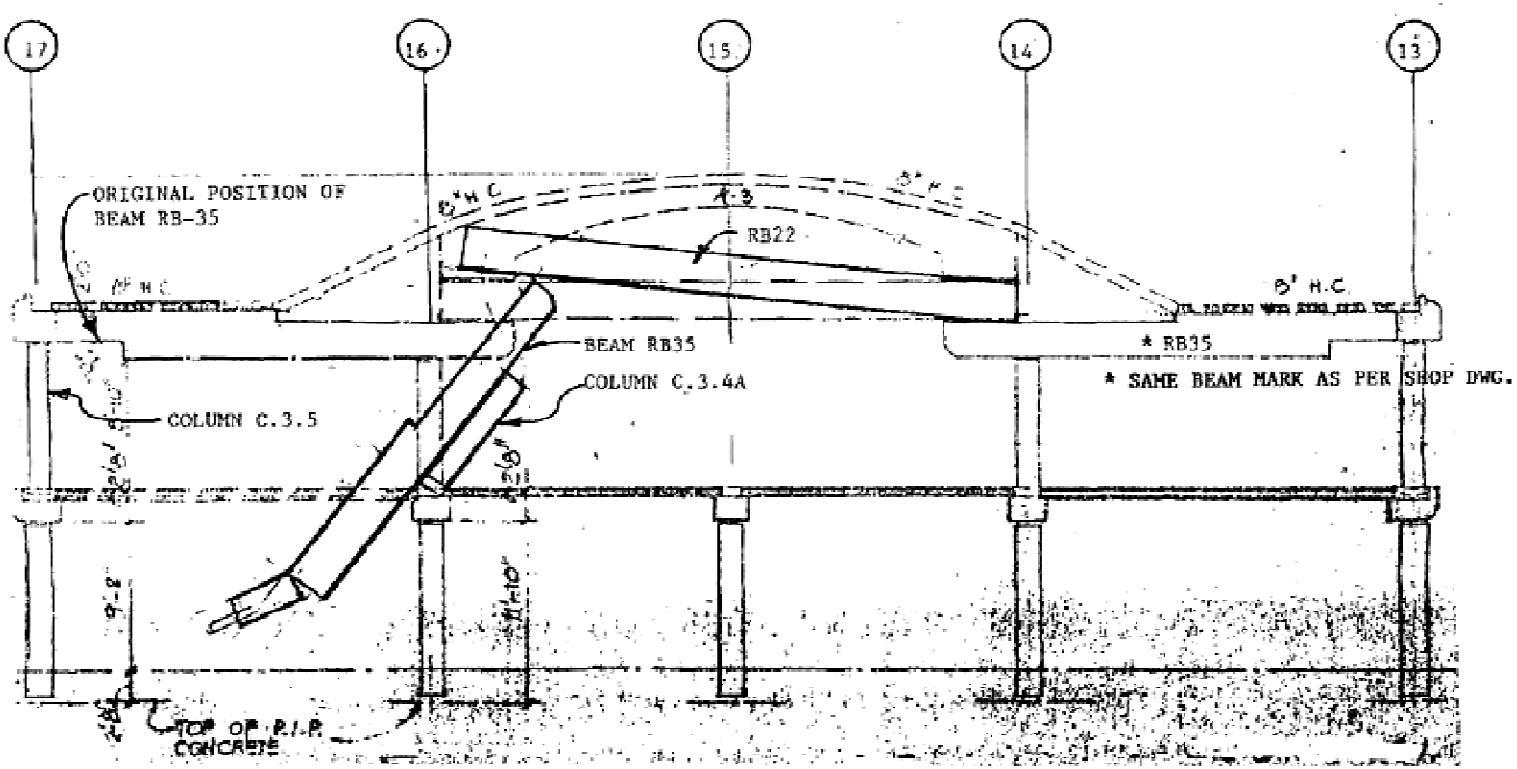
Pre-cast structure failures

(Man Made Mistakes)

Cross Sectional View of RB-35 with other framing members

Credit: OSHA Report of Airside Building Collapsed Beams

- Insufficient embedment of reinforcement
- The ultimate moment capacity of beam RB-35, based upon the as-built condition, was incapable of handling the total ultimate applied moments

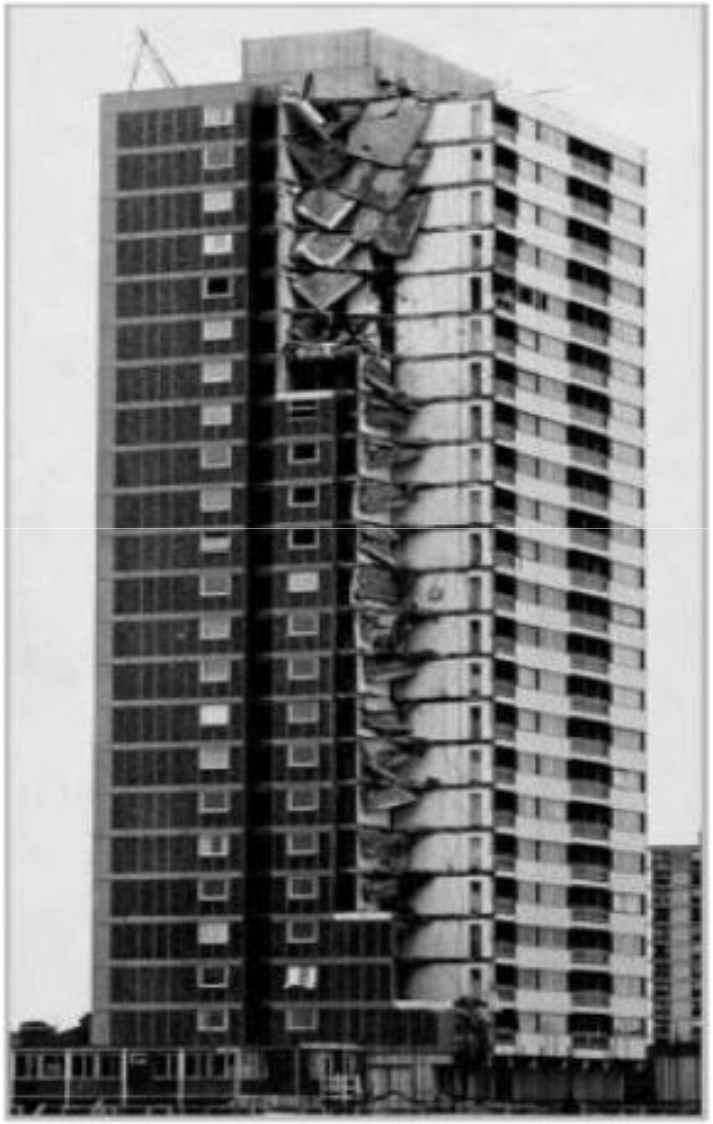


Progressive collapse of Ronan Point Apartment Tower (May 16, 1968)

- Constructed using the Larsen-Neilsen system, a system of factory-built, precast concrete components, originally intended for structures of no more than six stories.

- Precast panels used in the design were joined together without a structural frame.

- No alternate load-paths existed that allowed for redistribution of loads in case of a partial collapse



Investigation of the November 13, 2013 collapse of precast walls at a garage construction site, Ft. Lauderdale, FL – OSHA Report 2014

The precast walls collapsed because the temporary pipe braces were subjected to high tensile forces, resulting in the failure of the foot plate of the brace supporting the top precast wall.

The crane released the double tee before it could be welded to the walls and to the adjoining tees

Investigation Of The February 14, 2011 Partial Collapse of a Precast Parking Structure Under Construction In San Antonio, TX

- Flawed construction of contractor to provide proper support for the precast column base plates due to a lack of grout underneath the base plates.
- Uneven displacement of the nuts caused the columns to tilt, resulting in the collapse.

Connection Failures

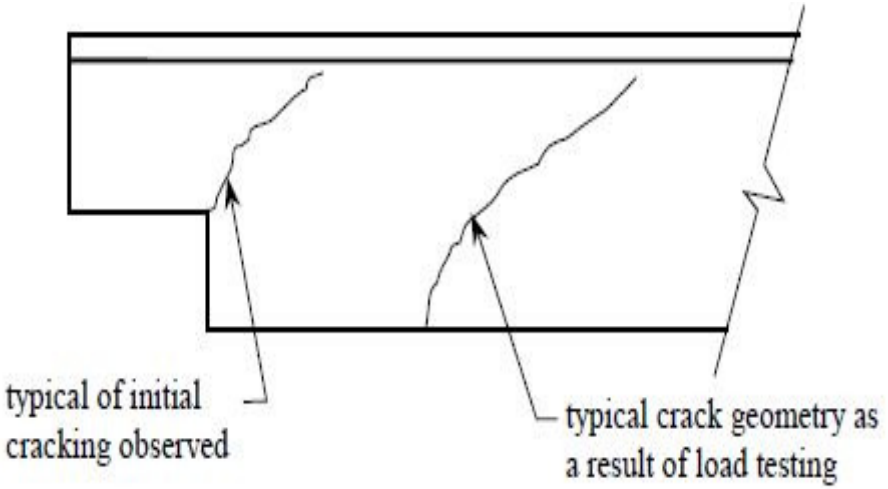
Failure due to wet connection

Failure due to support

Pittsburgh International Airport Parking Garage Precast Double-T Structural Defects

Shear failure cracks due to

- Improper and/or inadequate pre-stressing.
- Improper and/or inadequate bonding between pre-stressed reinforcing strands and concrete.
- Incorrect placement of the hanger and/or reinforcing bars relative to the beams' dapped ends.

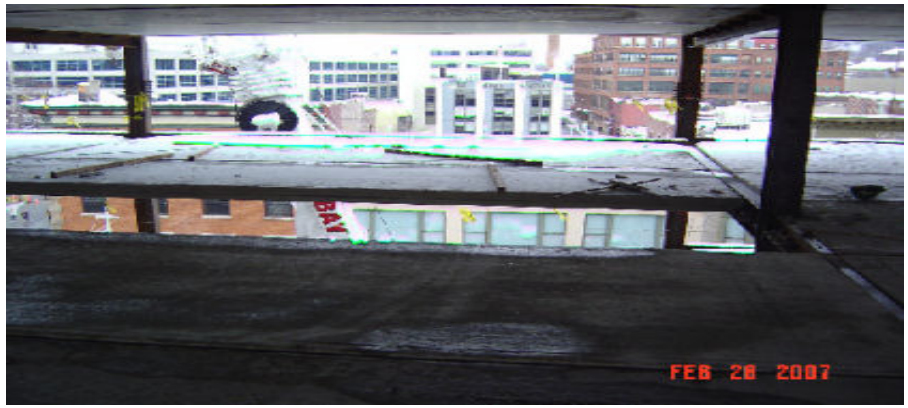


Construction Laborer Dies after Falling off Collapsed Precast Concrete Floor Slab (Feb 2007)

- Number of steel columns including the ones in the collapsed zone were erected out of plumb. The out-of-plumb columns led to increased spacing between the columns resulting in reduced beam support for the slabs located in-between these columns.

- A 4th floor slab adjacent to the collapsed zone was pushed to a vertical position and wedged between the steel beams. (Photo courtesy of OSHA)

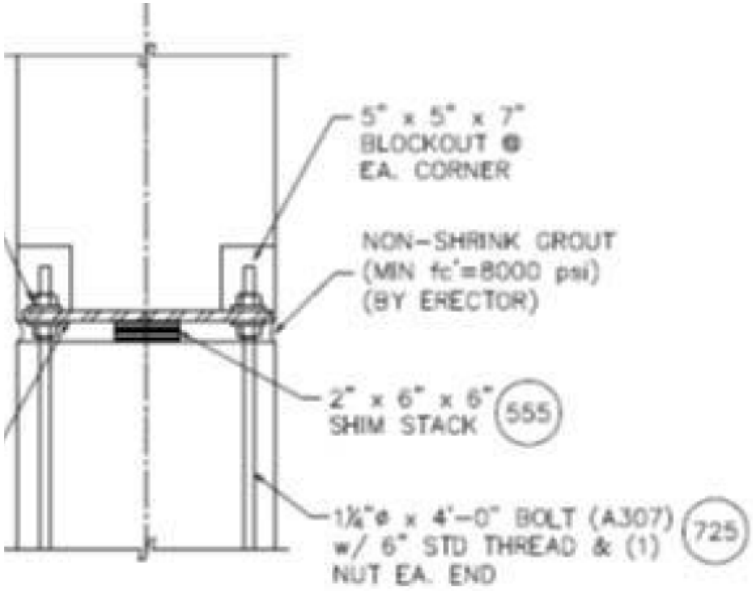
- The domino effect started by the failed slab on the 6th floor crashing through the five floors below and caused the collapse of five more slabs to the ground level.



Slab Collapse Failure

Investigation of The October 10, 2012 Parking Garage Collapse During Construction at Miami Dade College, Doral, FL6

- Poor grouting placed between the column and the footing.
- The increased load on the interior column exceeded the anchor bolts and shim plates capacity.
- When the interior column collapsed, a cascade effect was initiated that led to other columns, inverted tee beams, and double tees to collapse.
- Precast structural members were not adequately supported by welding and bracing (29 CFR 1926.704(a)). These deficiencies added to the structural instability.

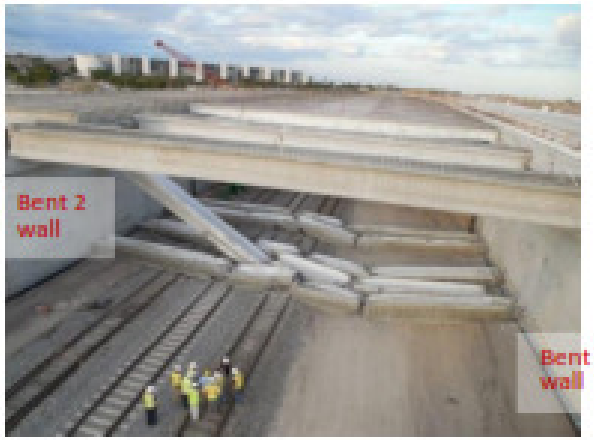


Improper Grouting

Investigation of the November 2, 2013 collapse of concrete beams at Fort Lauderdale-Hollywood Airport runway project

The inadequate horizontal bracing at top of the members in the middle span and end region of the girder initiated the failure and led the sections to collapse also led the other members to over turn.

Beam failure due to inadequate bracing at top

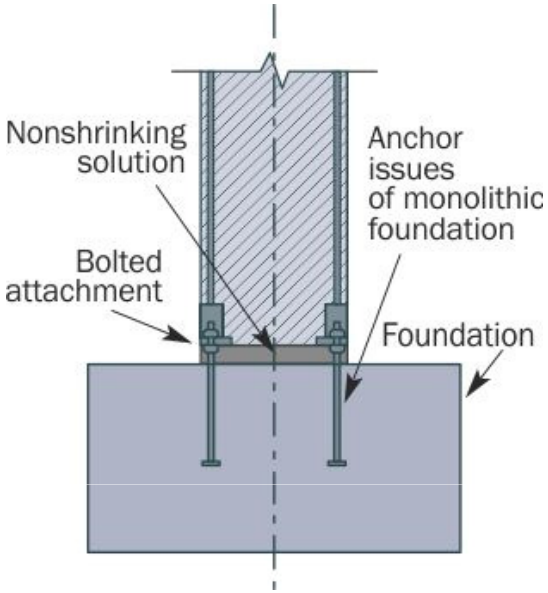


Parking Garage - in Florida - Collapse cause forensics - inadequate Shear walls (2012)

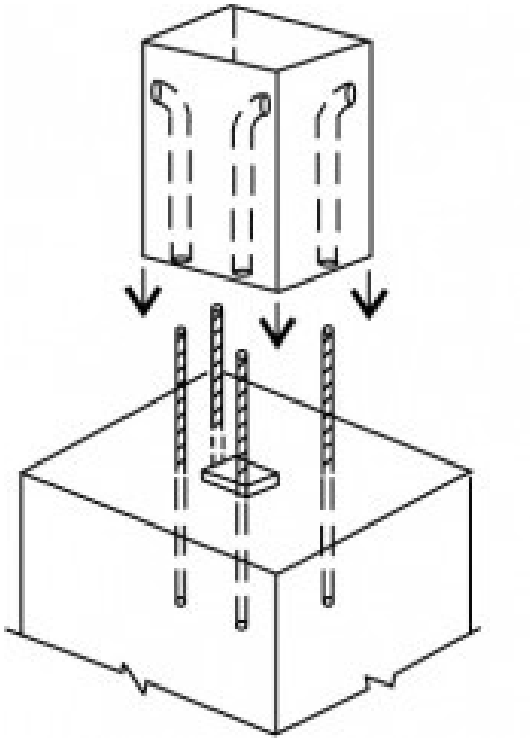
The shear wall design and installation (and ongoing attachment of shear wall precast elements during construction) was inadequate.

Pre-Cast Connection an Overview

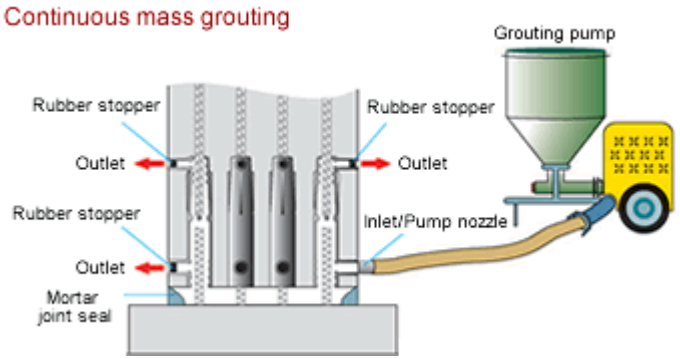
Foundation – Column Connection

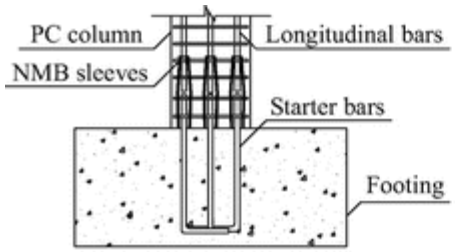


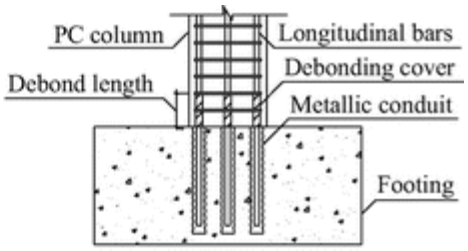
http://oberbeton.ua/en/project-department



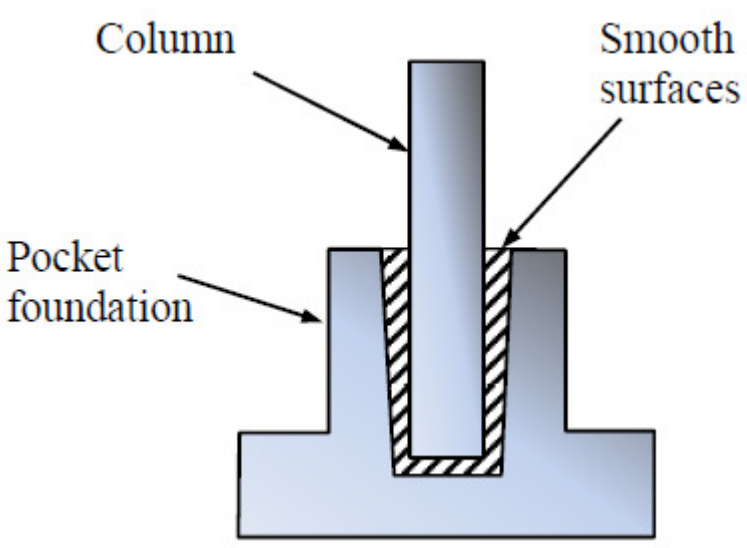
https://www.masterbuilder.co.in/basic-forces-transfer-mechanism-design-structural-precast-connections/

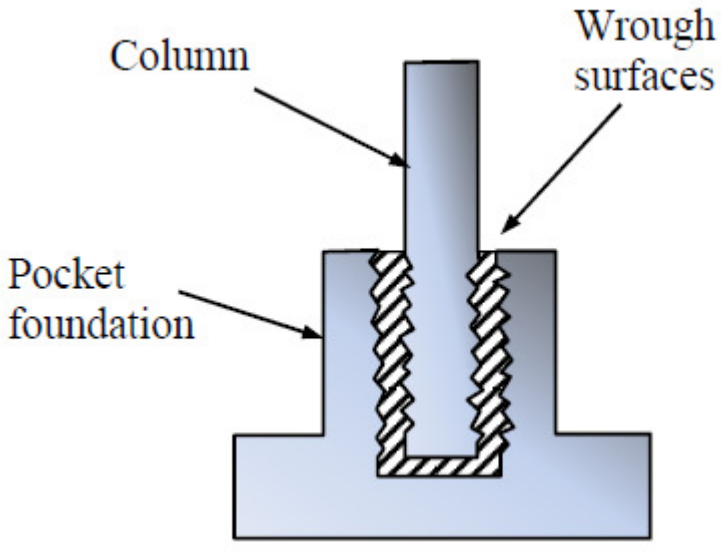




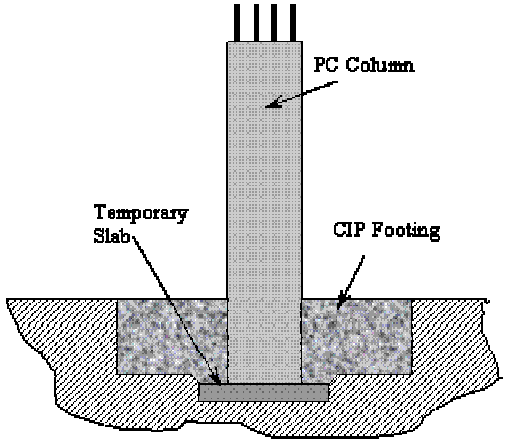


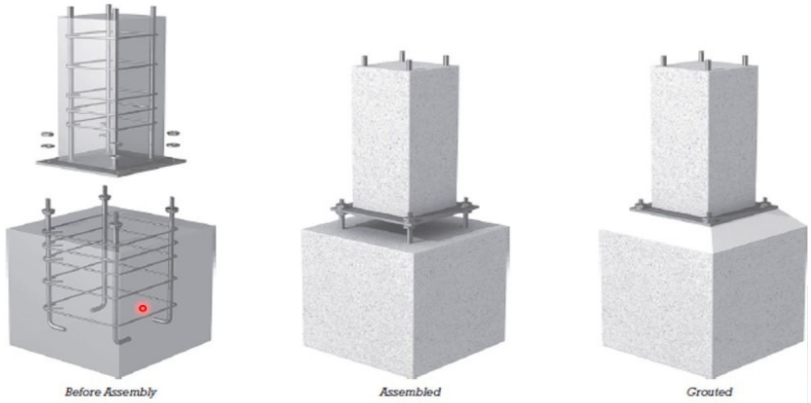
http://ascelibrary.org/doi/full/10.1061/(ASCE)ST.1943-541X.0000062





Pocket Foundation



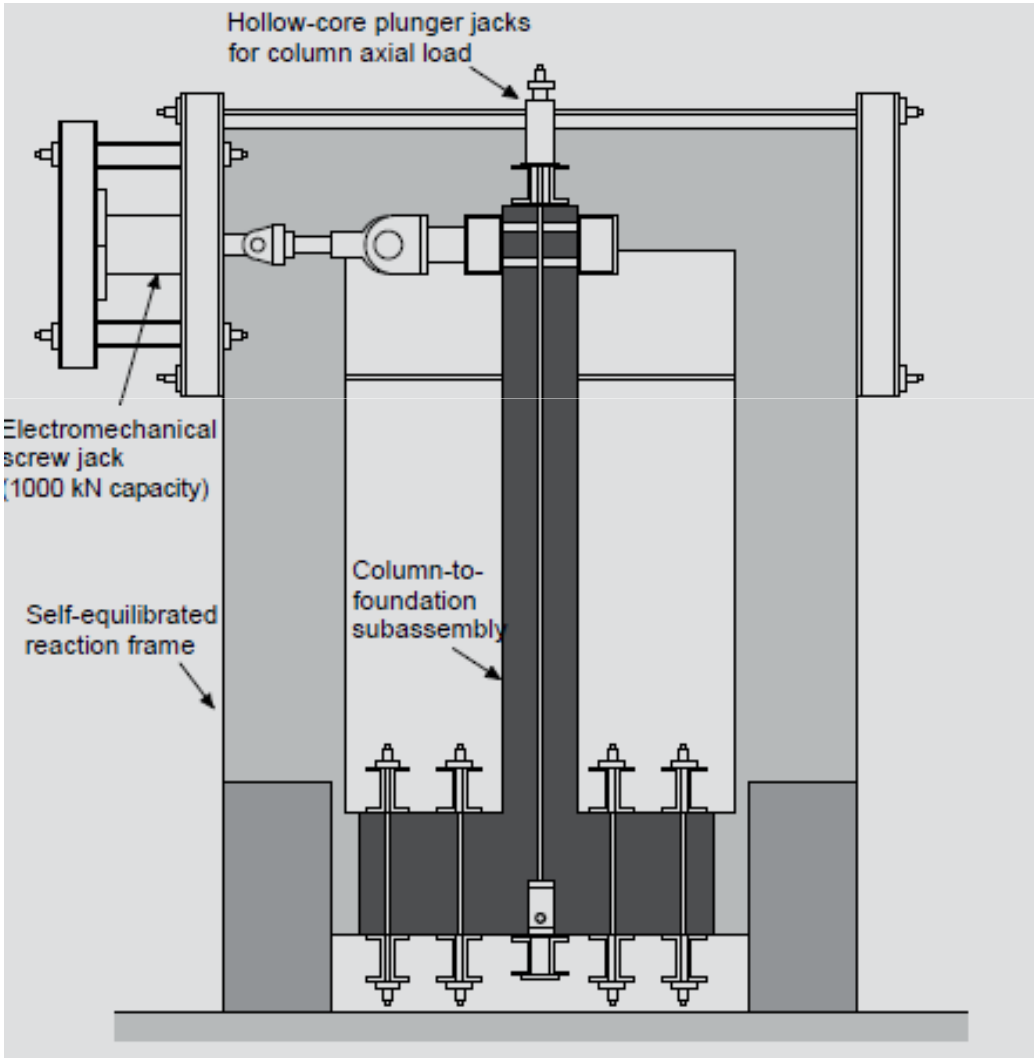


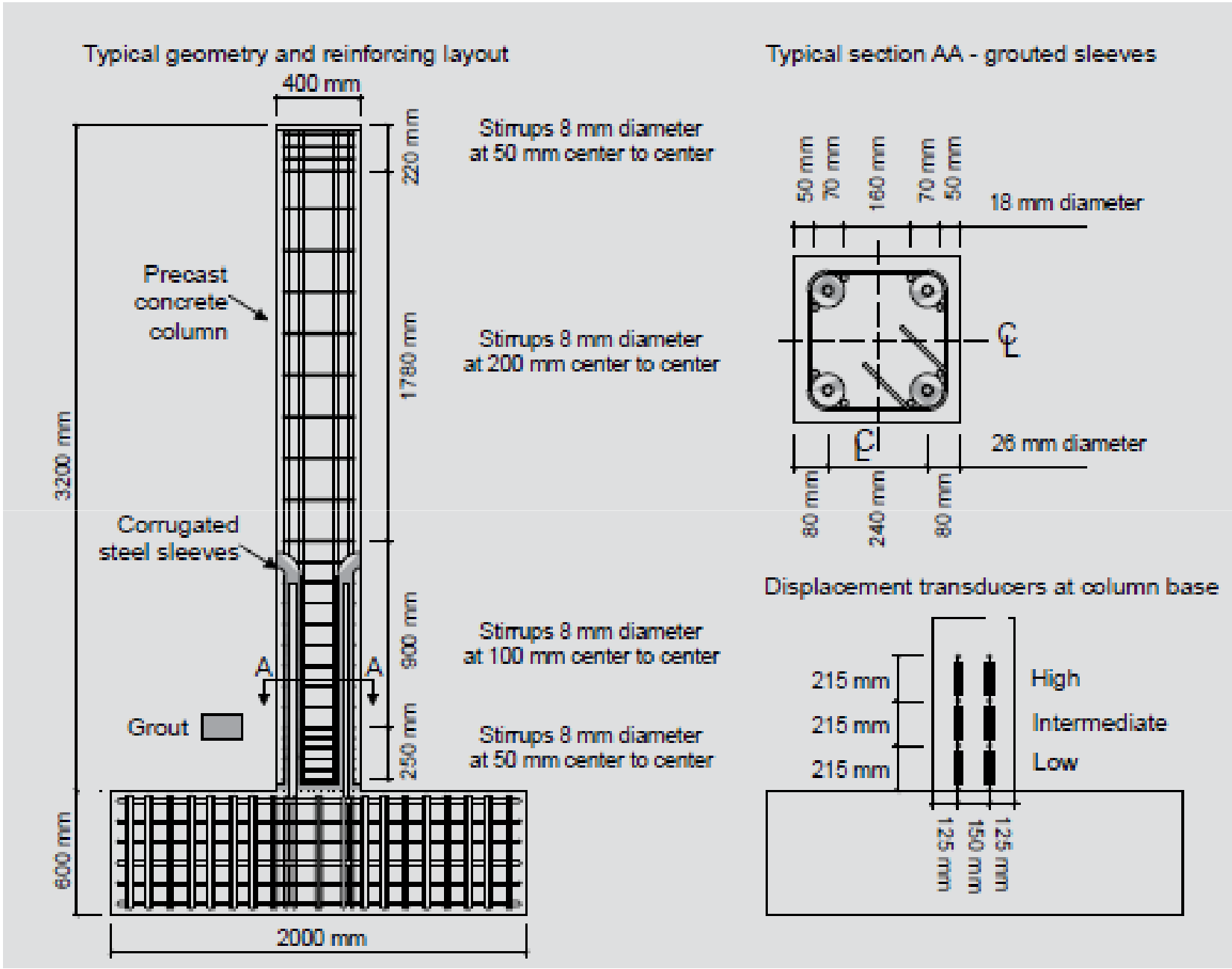
https://www.fhwa.dot.gov/hfl/partnerships/precast_bridge/phase1_final_report.cfm

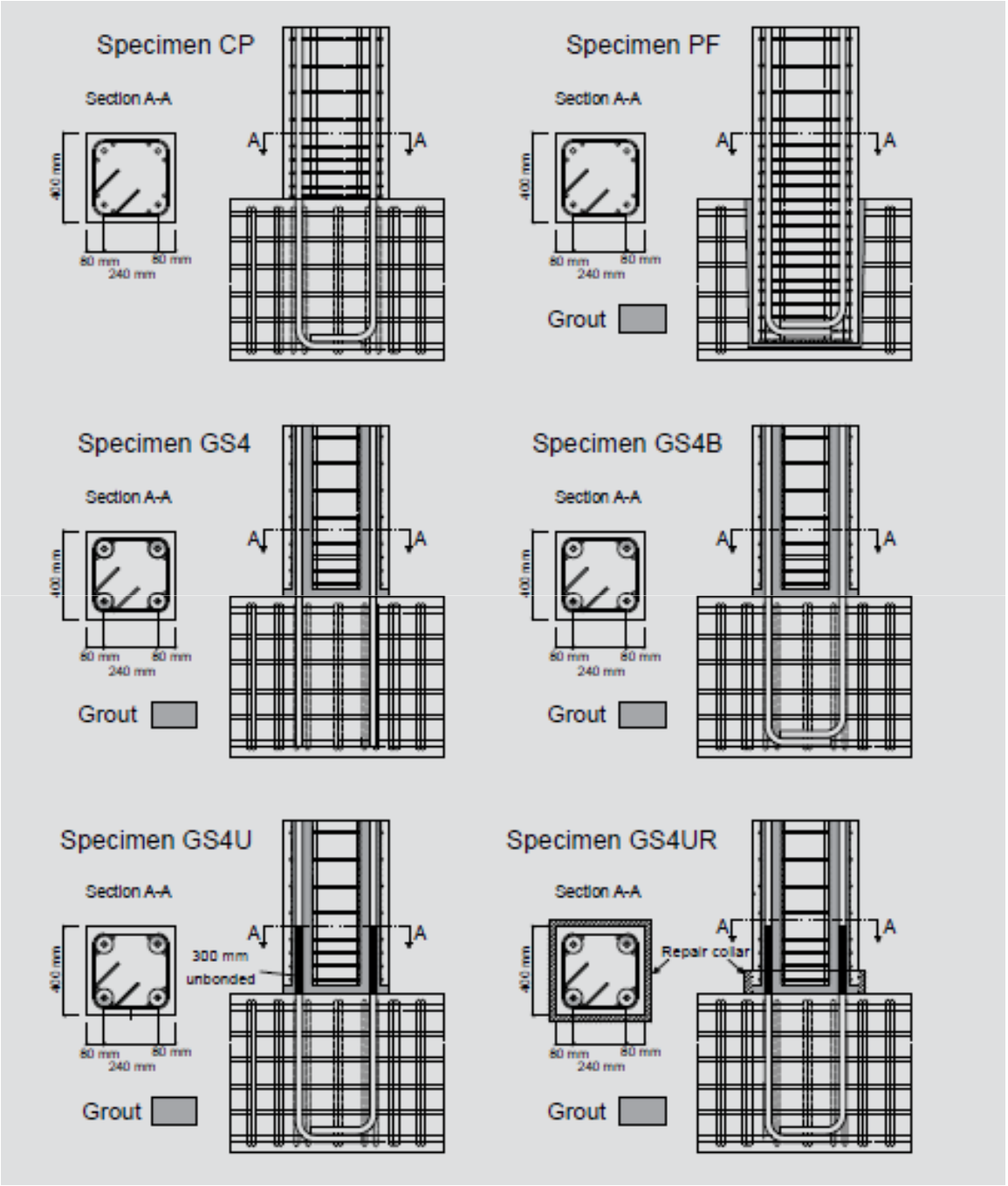
Seismic performance and retrofit of precast concrete grouted sleeve connections

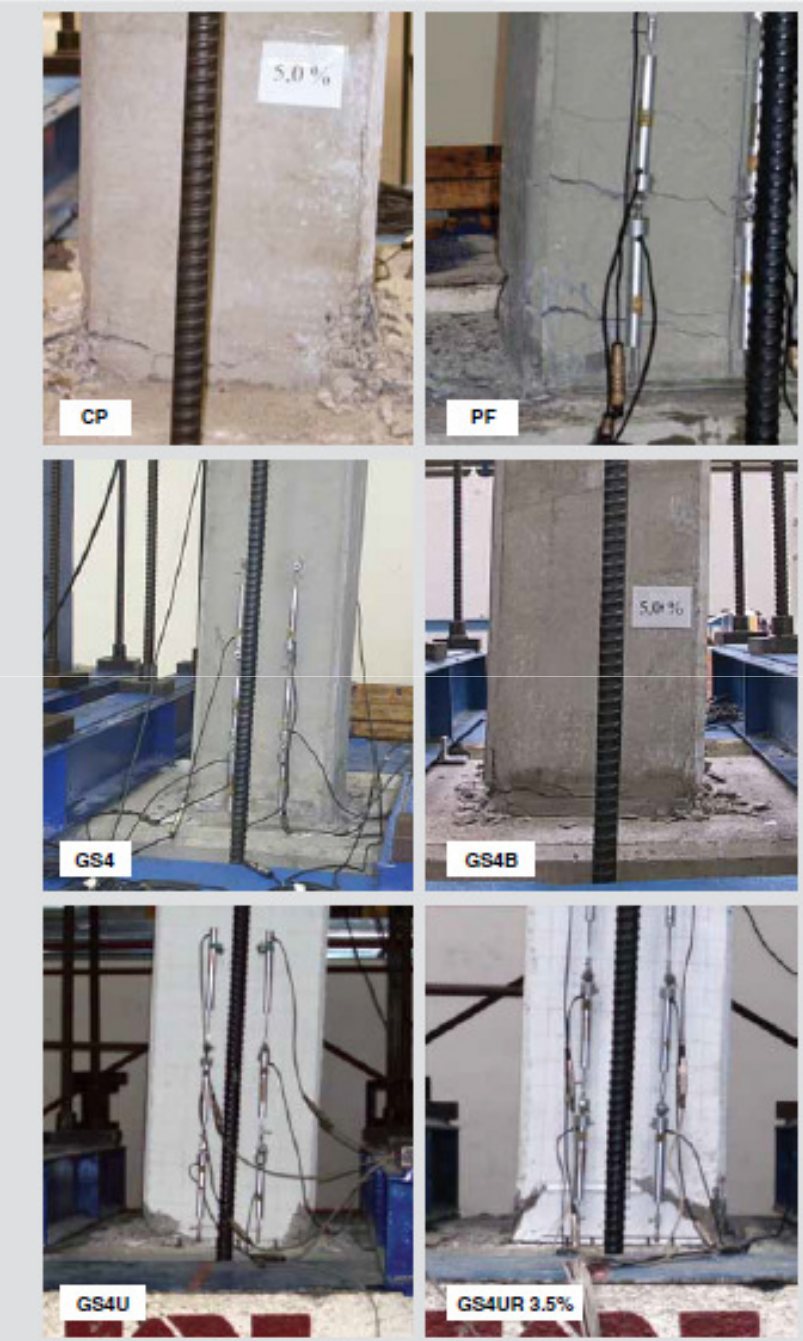
Andrea Belleri and Paolo Riva

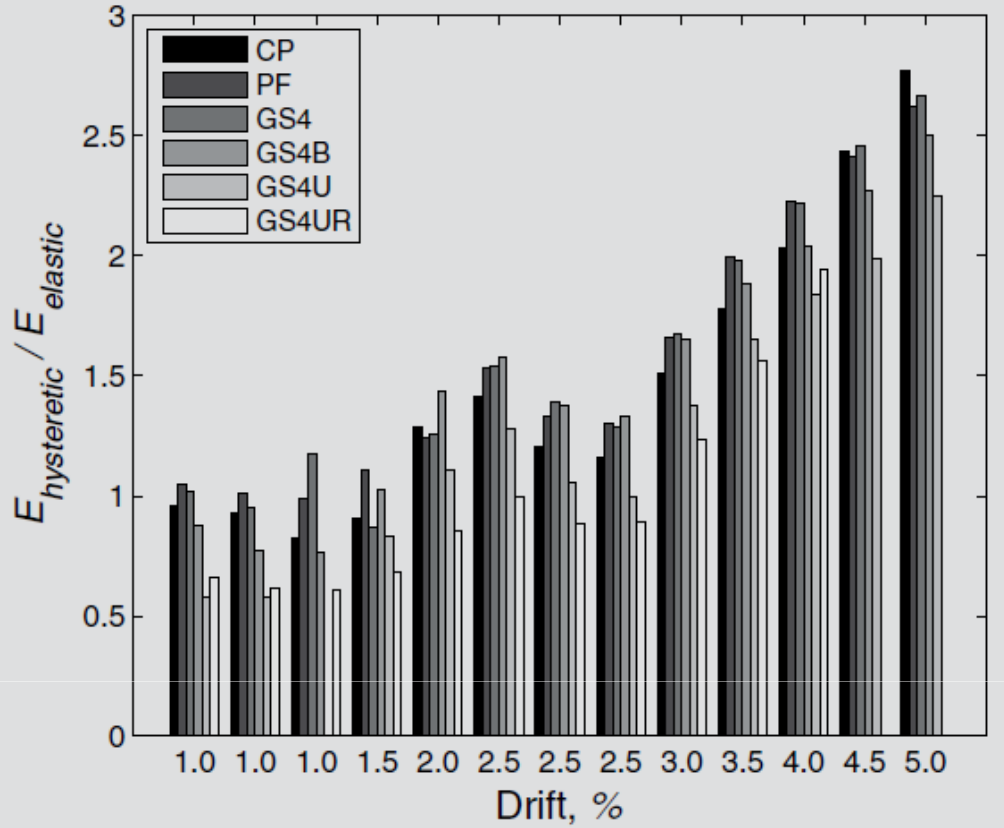
PCI Journal | Winter 2012



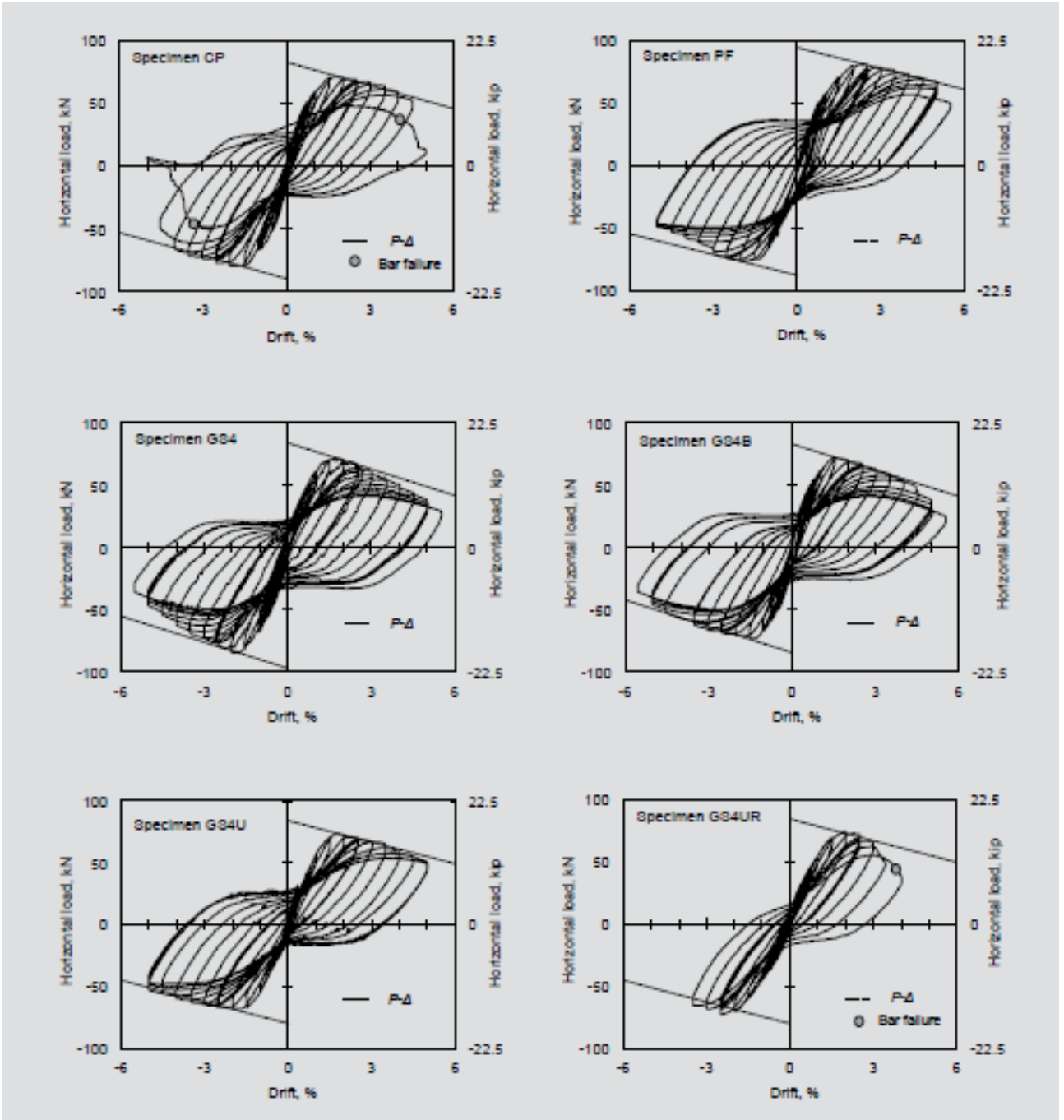

Typical geometry and reinforcing layout
400 mm
220 mm
1780 mm
900 mm
250 mm
3200 mm
600 mm
2000 mm
Precast concrete column
Corrugated steel sleeves
Grout
A
A
Stirrups 8 mm diameter at 50 mm center to center
Stirrups 8 mm diameter at 200 mm center to center
Stirrups 8 mm diameter at 100 mm center to center
Stirrups 8 mm diameter at 50 mm center to center
Typical section AA - grouted sleeves
50 mm
70 mm
160 mm
70 mm
50 mm
18 mm diameter
26 mm diameter
80 mm
240 mm
80 mm
Displacement transducers at column base
215 mm
215 mm
215 mm
High
Intermediate
Low
125 mm
150 mm
125 mm


Specimen CP
Section A-A
400 mm
80 mm
80 mm
240 mm
A
A
Specimen PF
Section A-A
400 mm
80 mm
80 mm
240 mm
Grout
A
A
Specimen GS4
Section A-A
400 mm
80 mm
80 mm
240 mm
Grout
A
A
Specimen GS4B
Section A-A
400 mm
80 mm
80 mm
240 mm
Grout
A
A
Specimen GS4U
Section A-A
400 mm
300 mm
unbonded
80 mm
80 mm
240 mm
Grout
A
A
Specimen GS4UR
Section A-A
400 mm
Repair collar
80 mm
80 mm
240 mm
Grout
A
A





The experimental program showed that grouted steel sleeves are suitable as column-to-foundation connections in seismic regions. The high ductility of the grouted steel sleeve connections is related to the confining effect of the corrugated steel sleeves on the grout. Furthermore, the presence of a highly confined grout prevents buckling of the longitudinal reinforcement.


Specimen CP
P-Δ
Bar failure
Specimen PF
P-Δ
Specimen GS4
P-Δ
Specimen GS4B
P-Δ
Specimen GS4U
P-Δ
Specimen GS4UR
P-Δ
Bar failure
Horizontal load, kN
Horizontal load, kip
Drift, %
100
50
0
-50
-100
22.5
0
-22.5
-6
-3
0
3
6

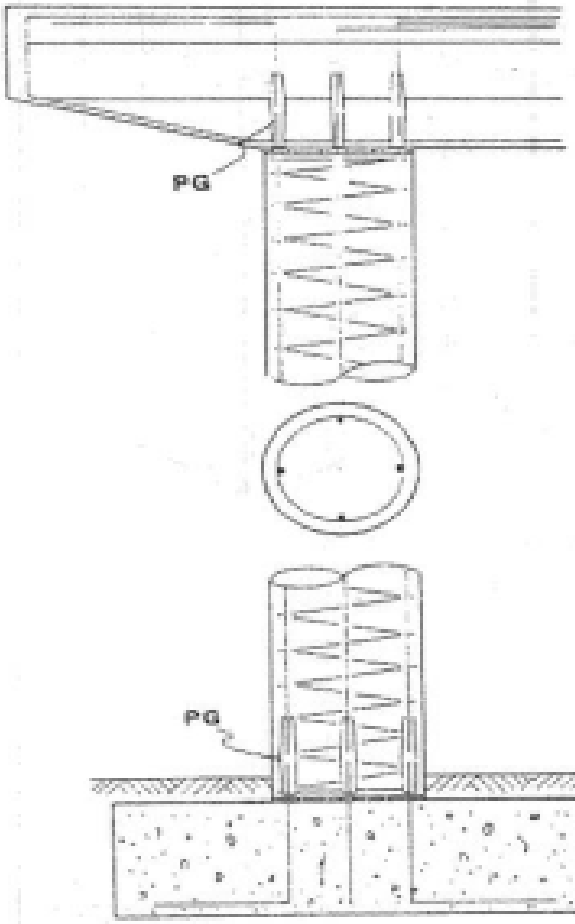
Evaluation of Grout-Filled Mechanical Splices for Precast Concrete Construction

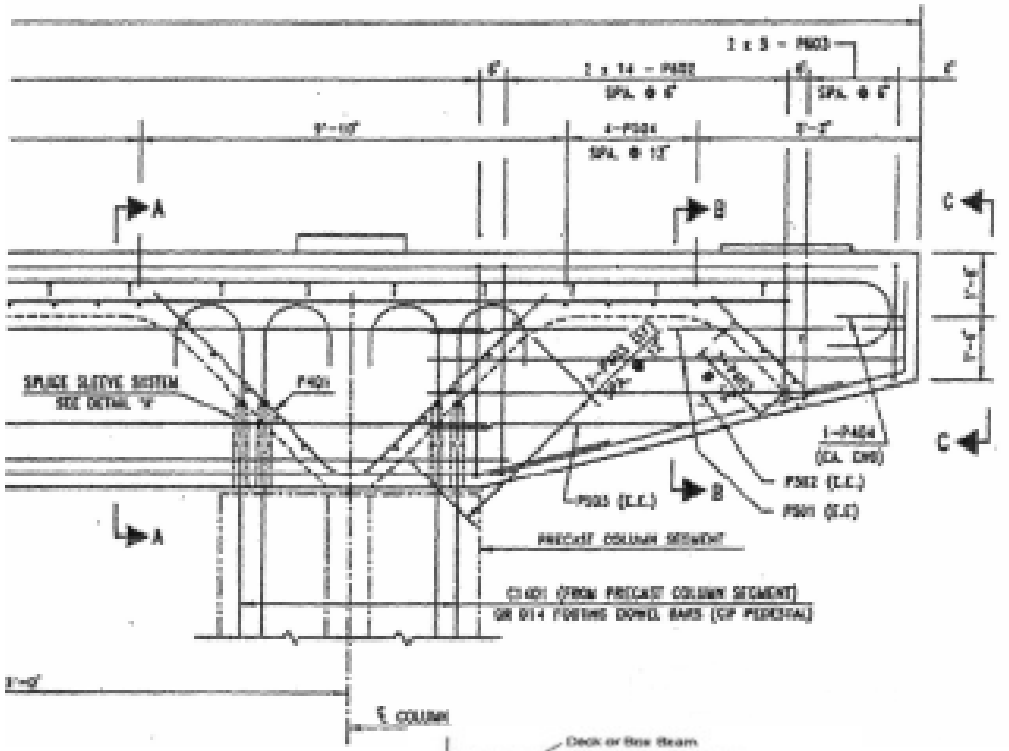
Peter O. Jansson, P.E.

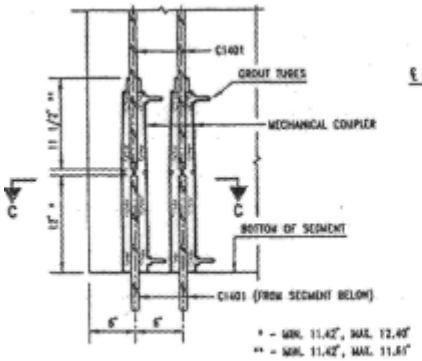
MICHIGAN DEPARTMENT OF TRANSPORTATION
MDOT

Structural Section
Construction and Technology Division
Report 07 TI-2094
Research Report R-1512

2008

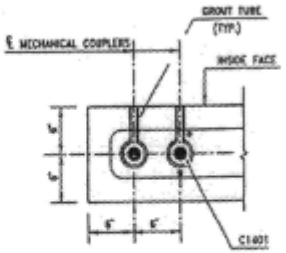






DETAIL 'A' AT MATCHCAST JOINT

SEE SHEET C-39 FOR DETAIL 'A' AT 1/2" JOINT



SECTION C-C

NOTE: AFTER PLACING THE COLUMN SEGMENT, IF THE MECHANICAL COUPLER IS A GROUT SLEEVE (SHOWN) IT MUST BE GROUTED AND THE GROUT NEEDS TO HAVE REACHED A STRENGTH OF 4000 PSI BEFORE THE NEXT SEGMENT CAN BE PLACED

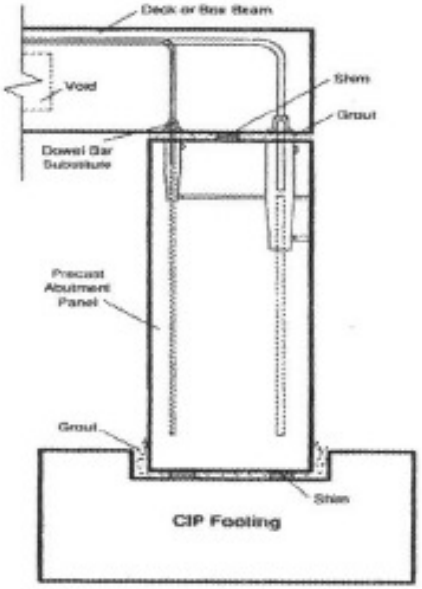


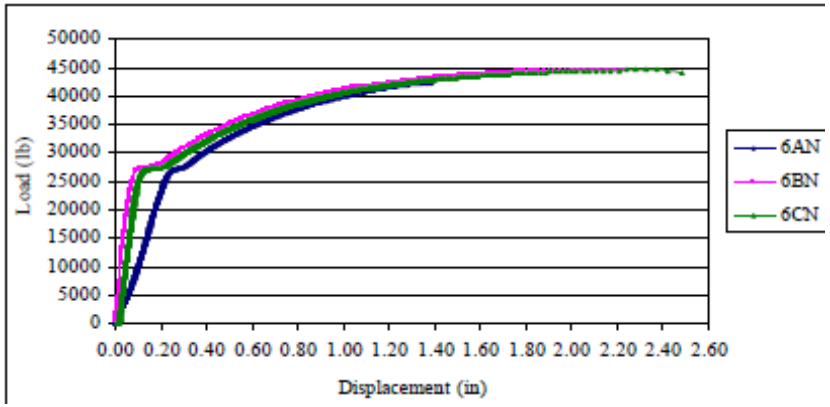
Figure 3.1 Lenton Interlok specimens

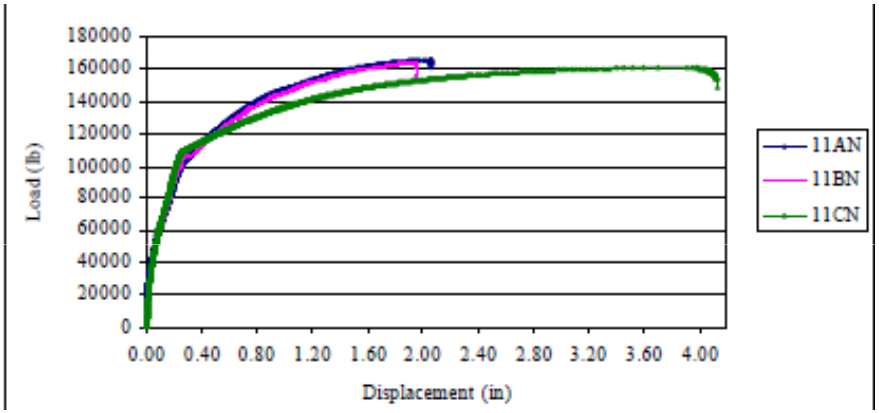
Figure 3.4 Pouring grout in #11 NMB splices

Figure 3.5 Rodding grout in #6 NMB splices

NMB Sleeves with Grouting

Splice fracture of NMB Sleeves

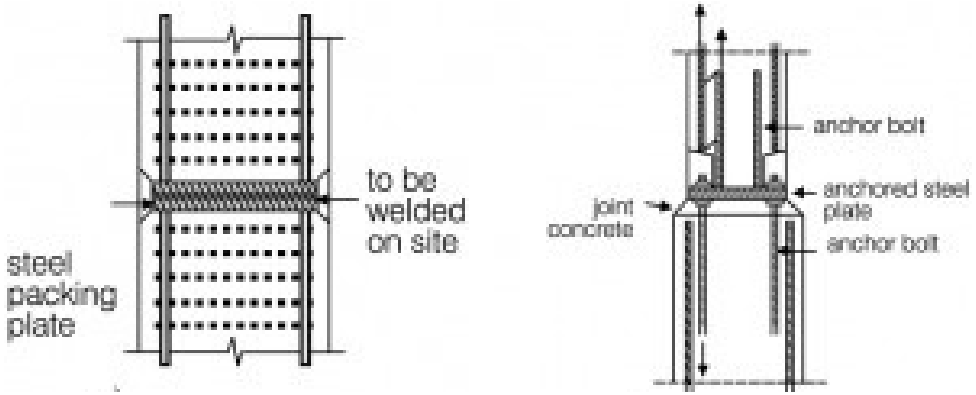




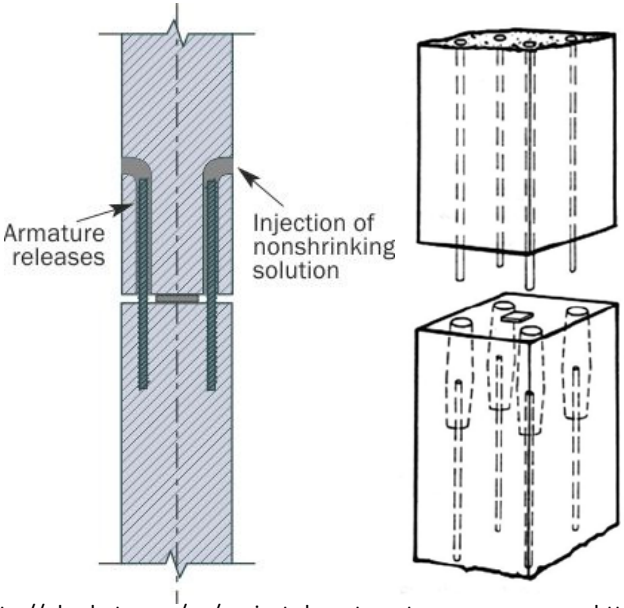
Tensile Failure of Sleeves with rebars

Column to Column Connection

https://www.fhwa.dot.gov/hfl/partnerships/precast_bridge/hif13037/



https://www.masterbuilder.co.in/basic-forces-transfer-mechanism-design-structural-precast-connections/



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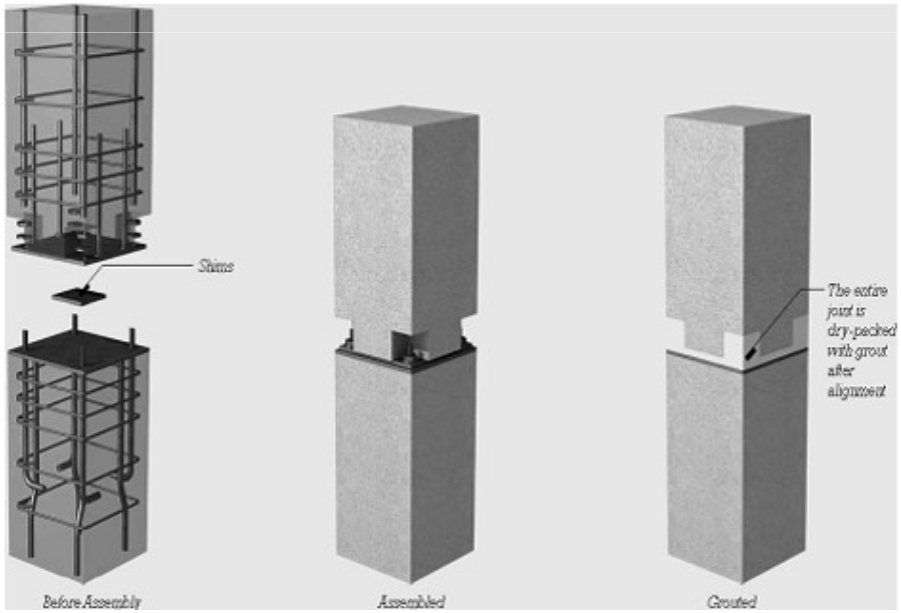
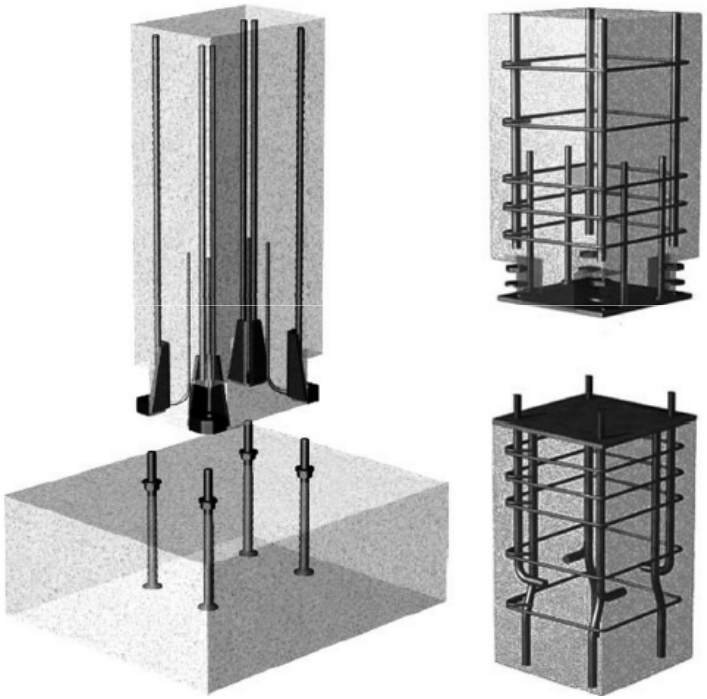


https://civildigital.com/prefabricated-structures-prefabrication-concept-components-advantages-ppt/

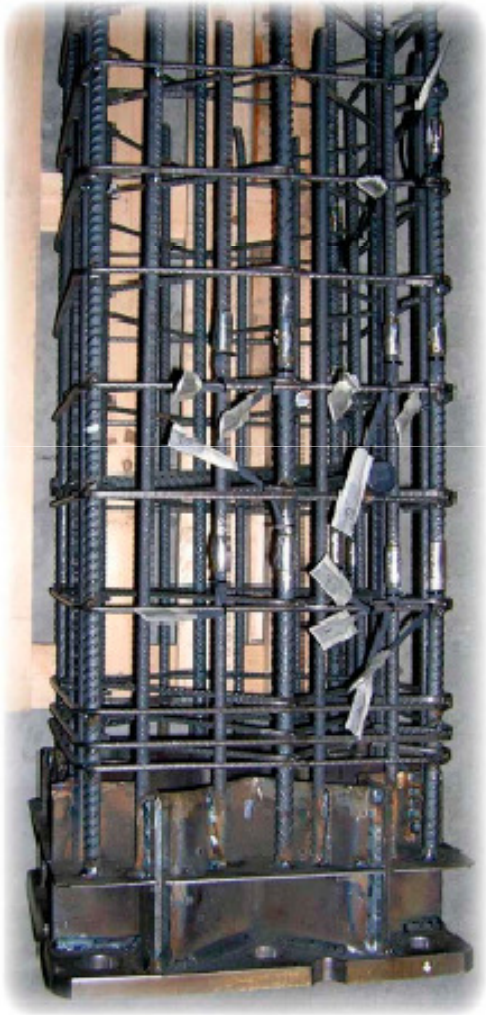
Experimental investigation on static and cyclic behaviour of flanged unions for precast reinforced concrete columns

Maurizio Orlando* and Lorenzo Ruggero Piscitelli

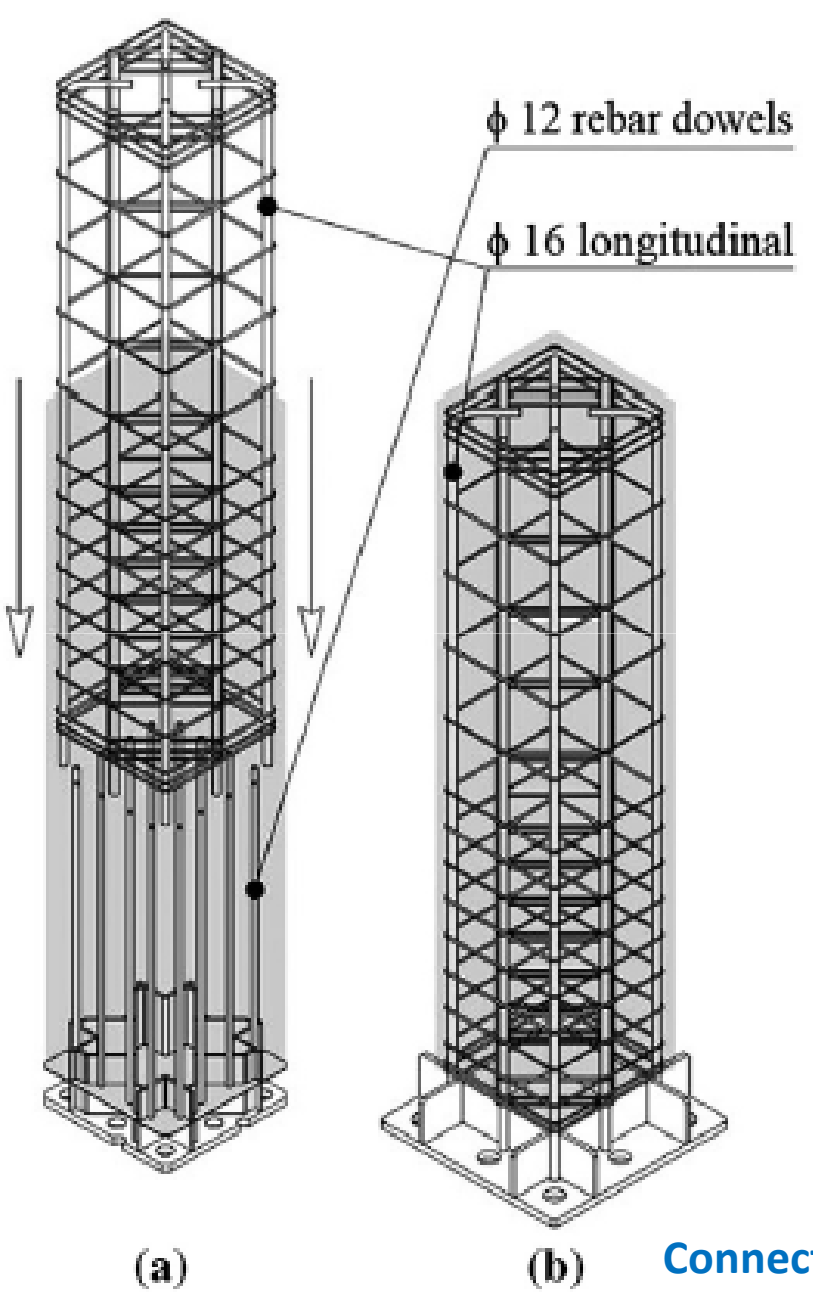
European Journal of Environmental and Civil Engineering, 2016
http://dx.doi.org/10.1080/19648189.2016.1229226

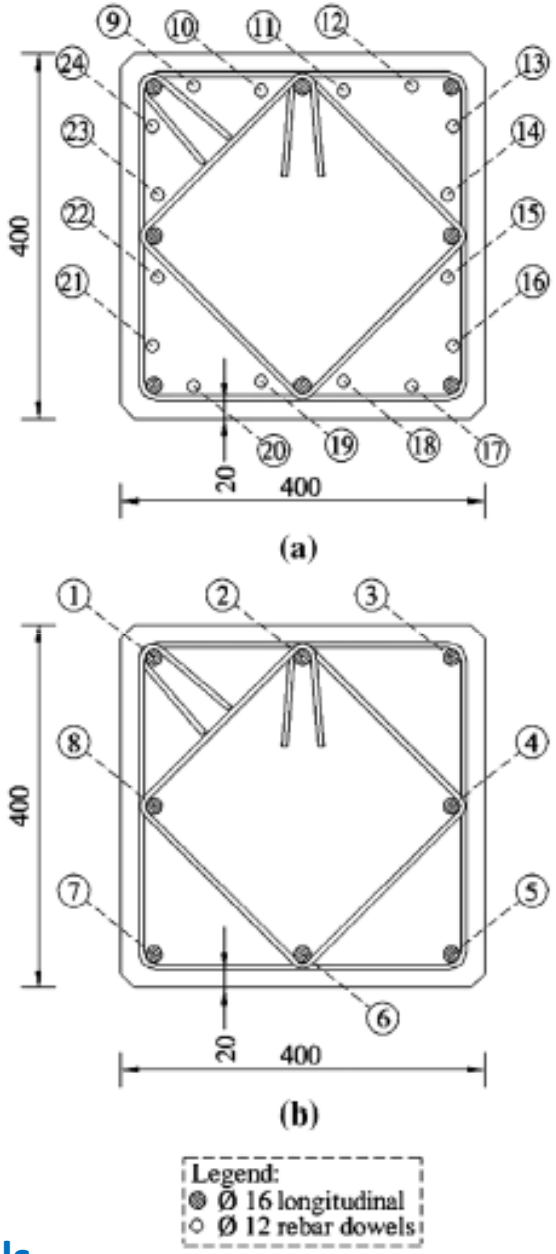


Column to foundation and column to column connection

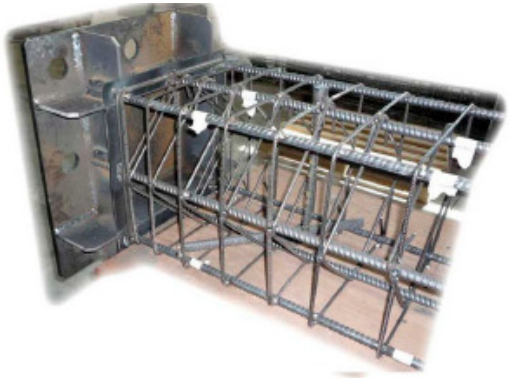


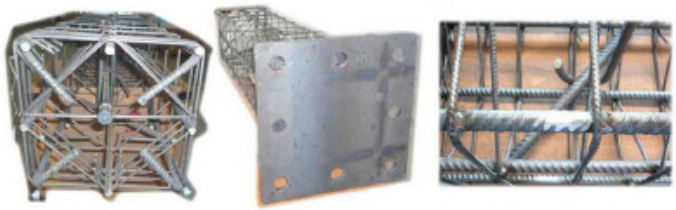
Proposed Connection details



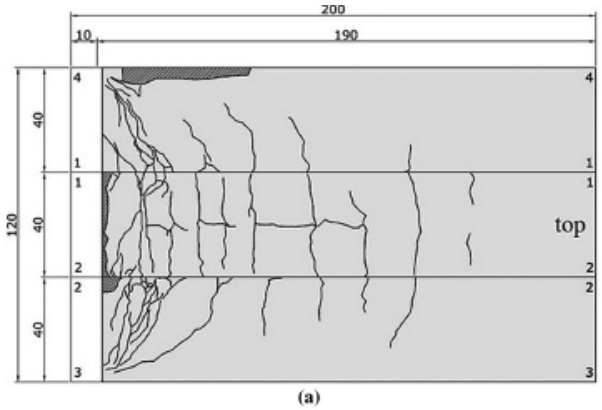


Connection details

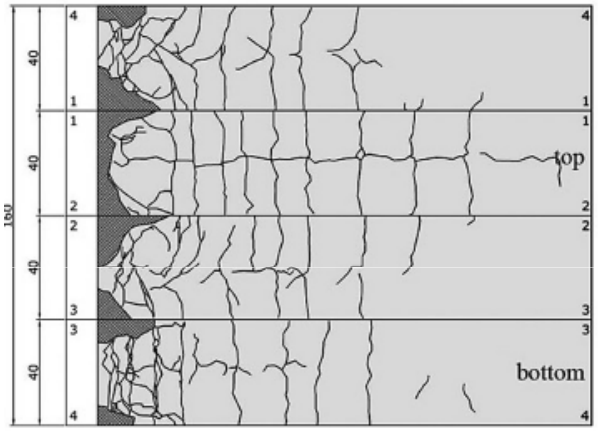




(b)

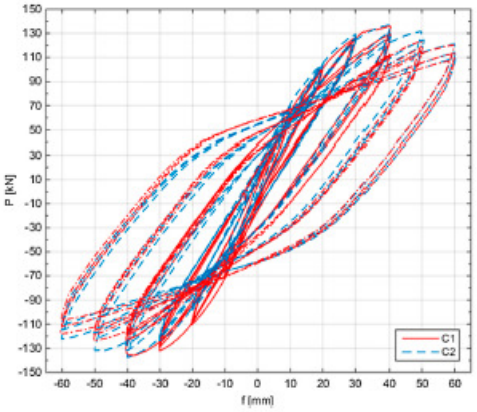


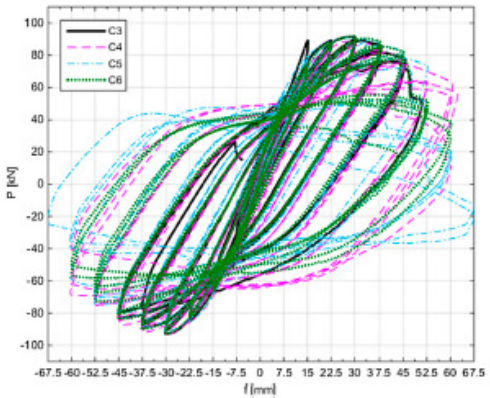
(a)



(b)

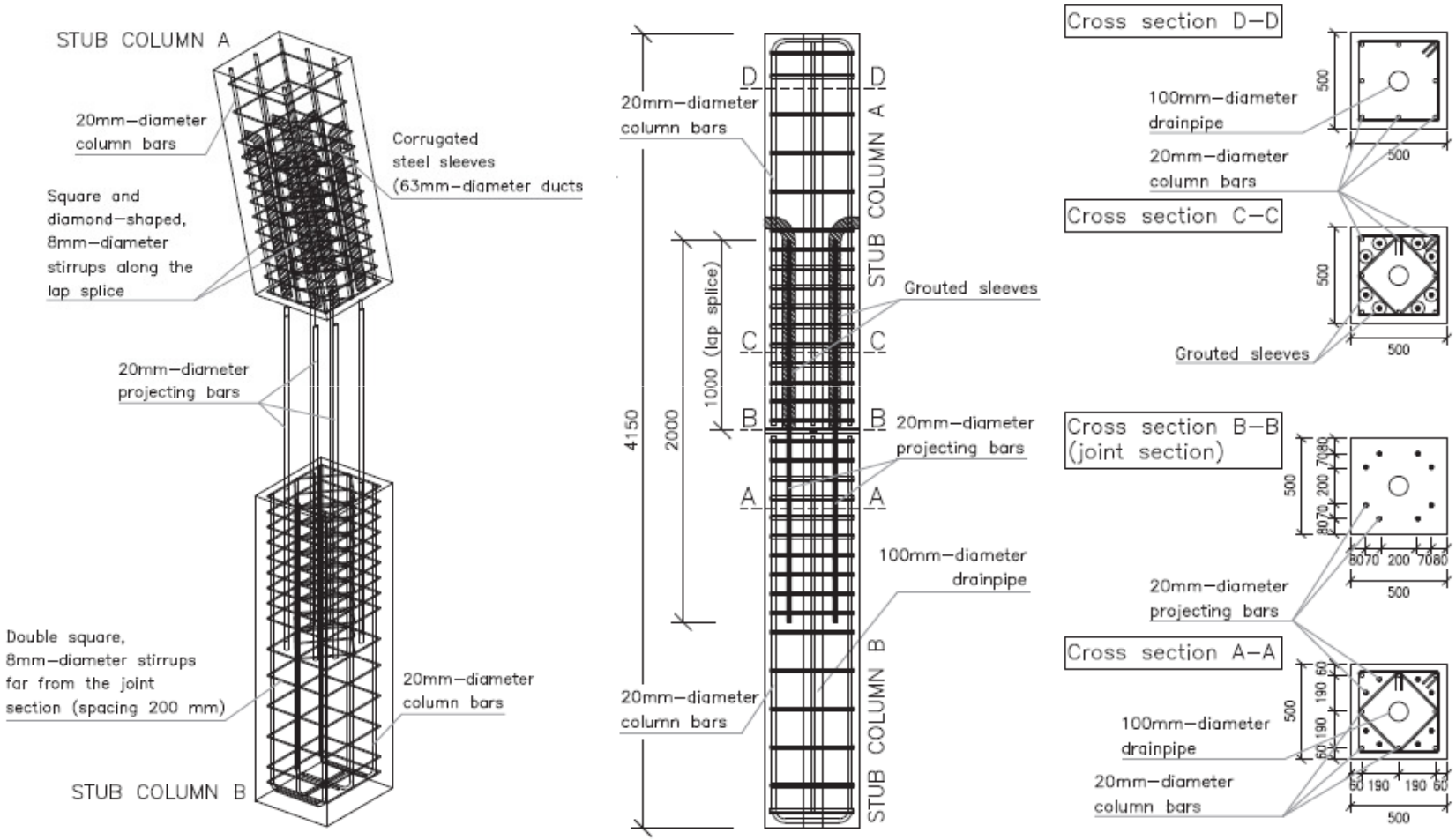
Failure at the joint region





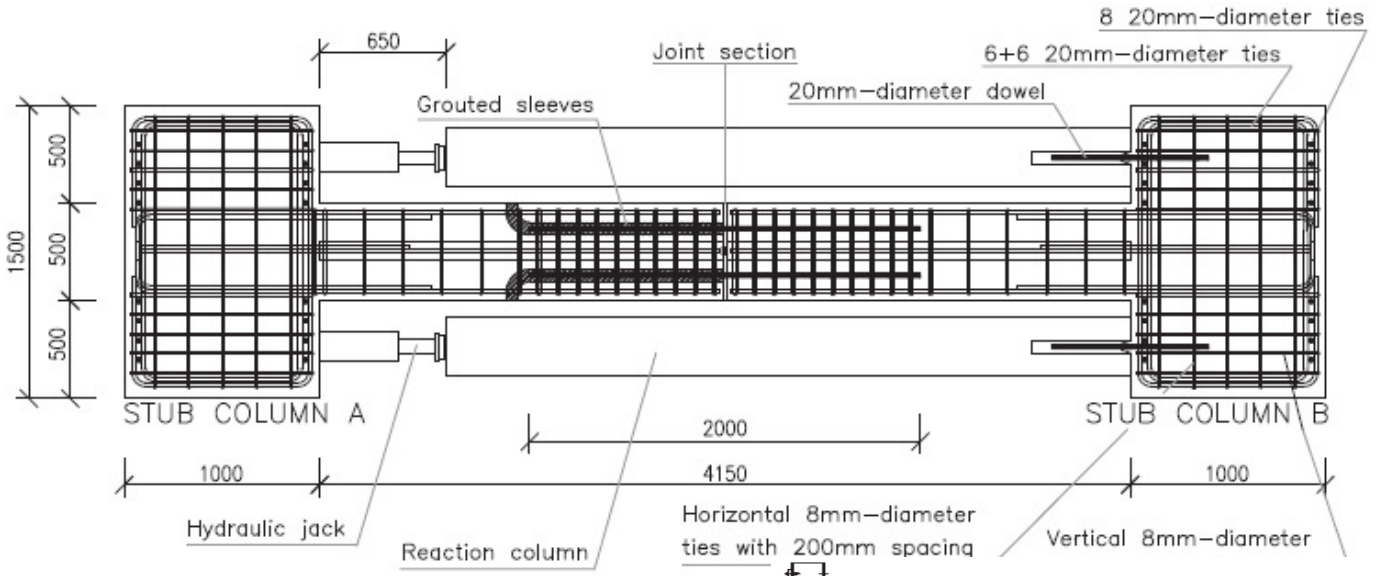
Grouted sleeve connections used in precast reinforced concrete construction – Experimental investigation of a column-to-column joint

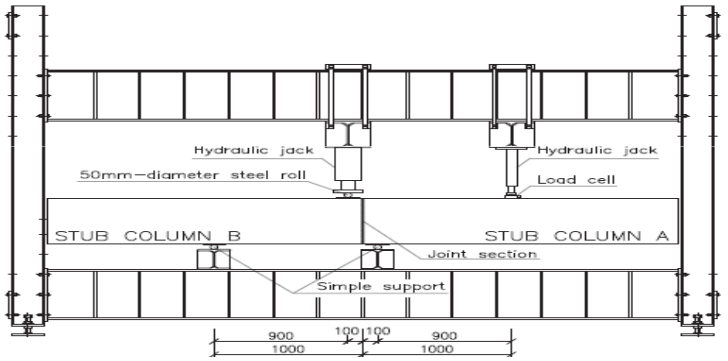
Nerio Tullini *, Fabio Minghini Engineering Structures 127 (2016) 784–803



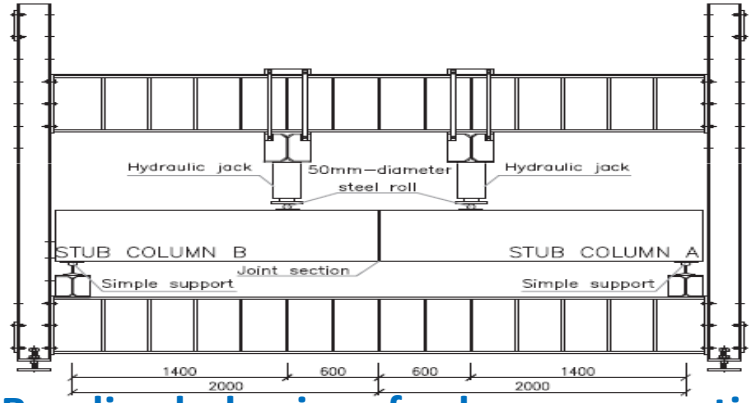
Column to column connection using grouted sleeves

Grouted sleeve connection procedure

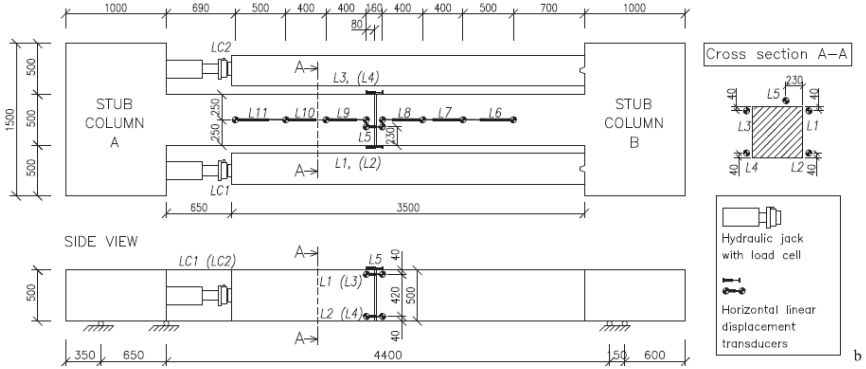




Shear behavior of column connection

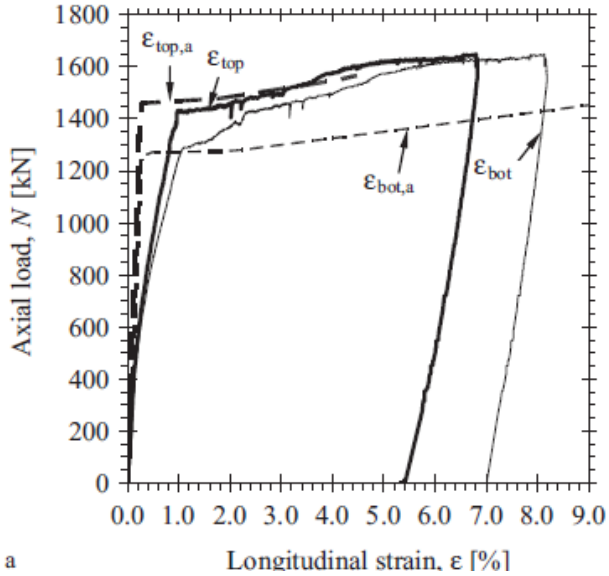


Bending behavior of column connection

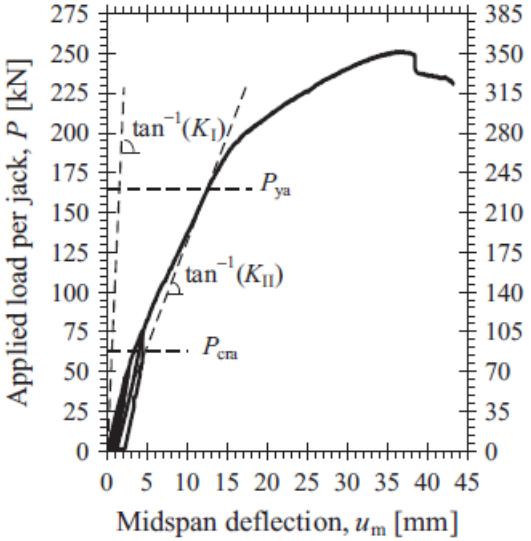


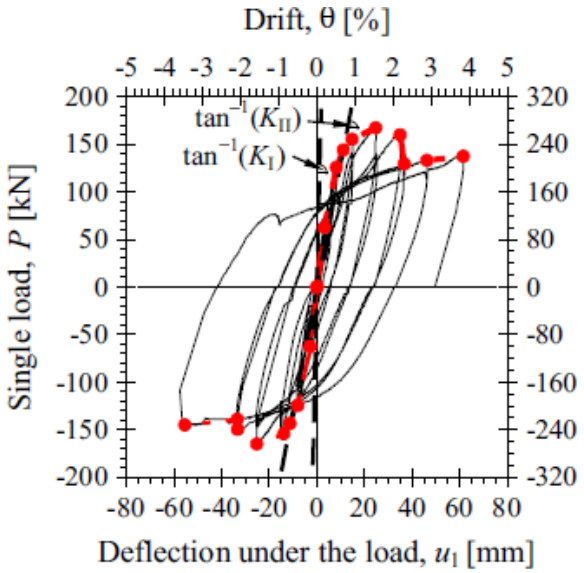
Tensile behavior of Column to column connection

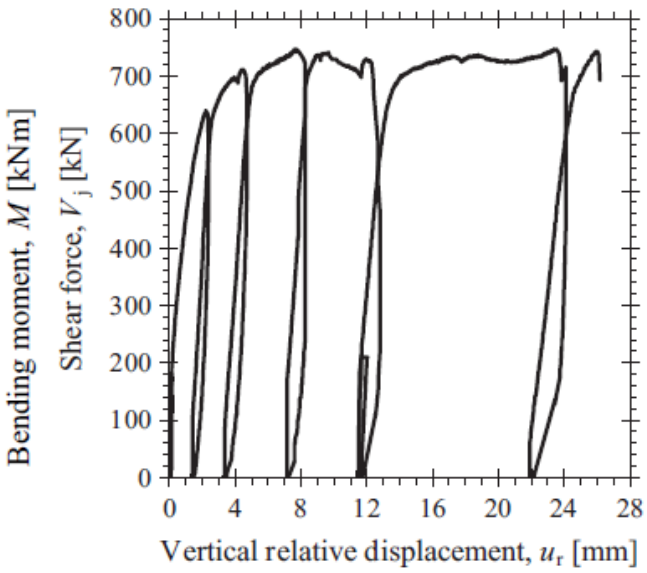
crack pattern at the end of test in the zone where the rupture of the reinforcing bars occurred.



Under Tension

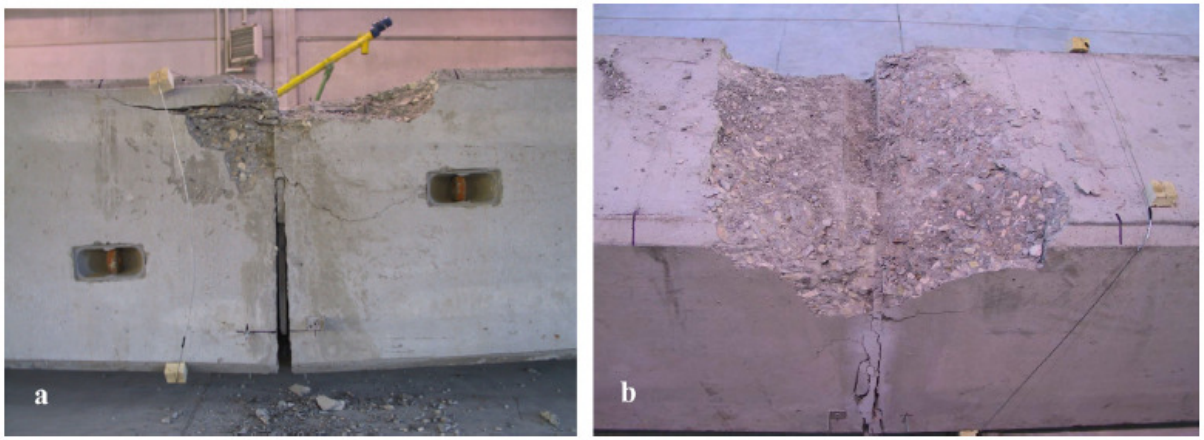




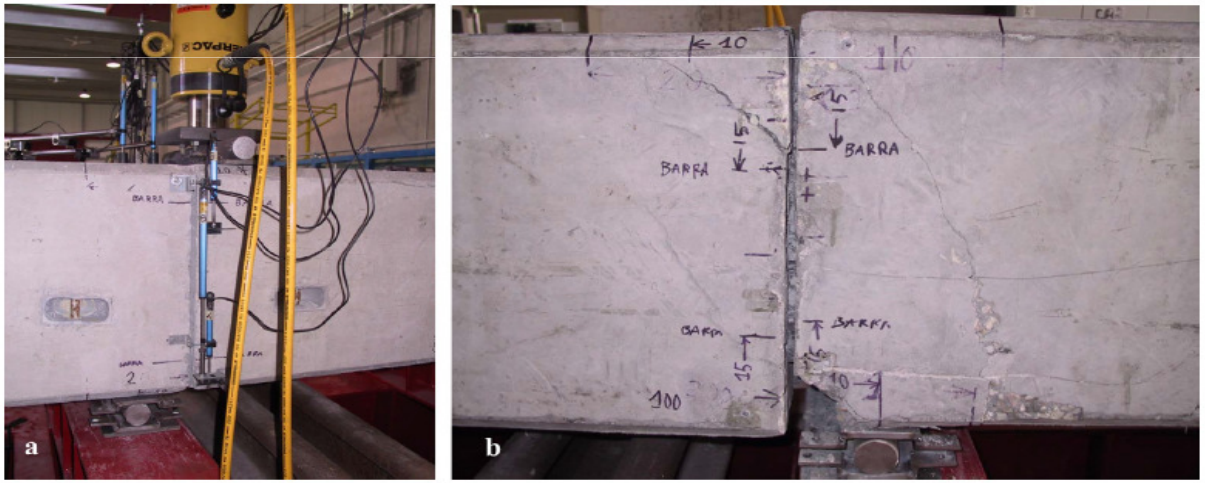


Under Bending

Under Shear



Failure Under Bending

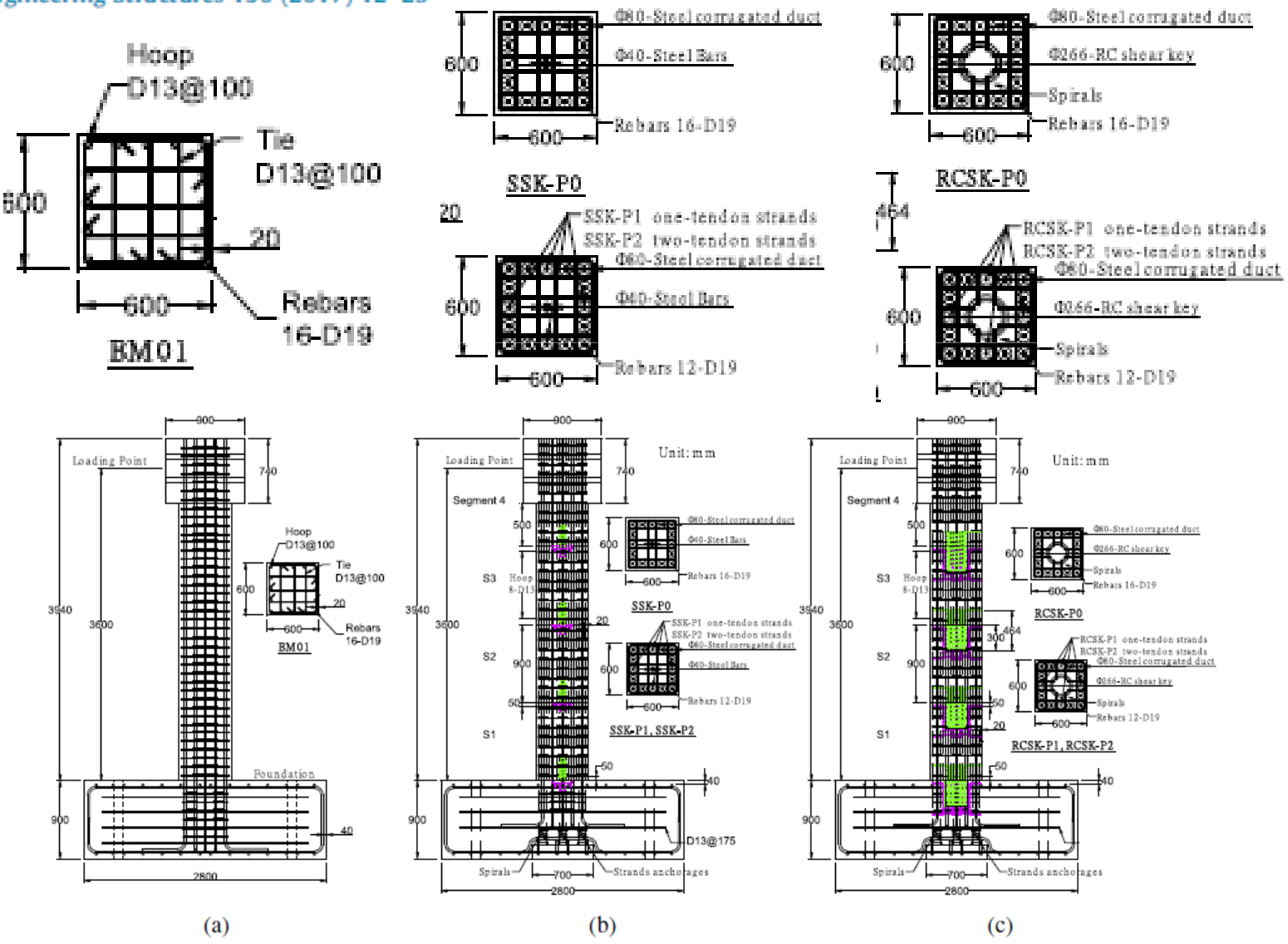


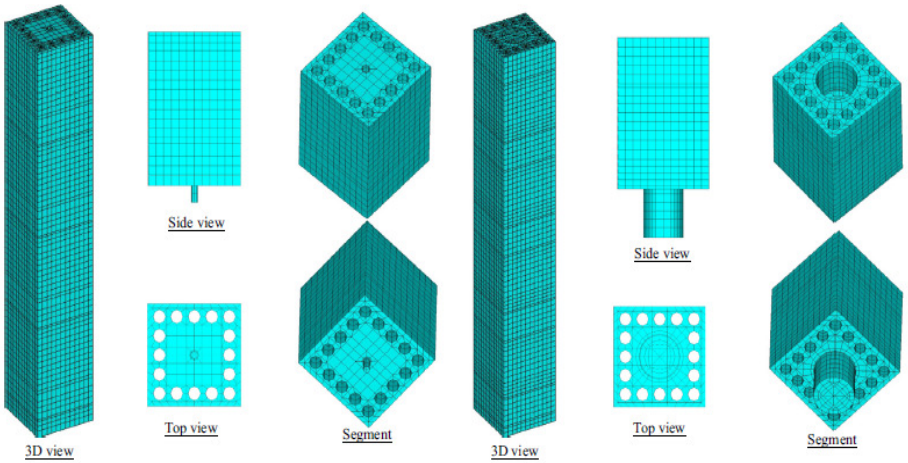
Failure Under Shear

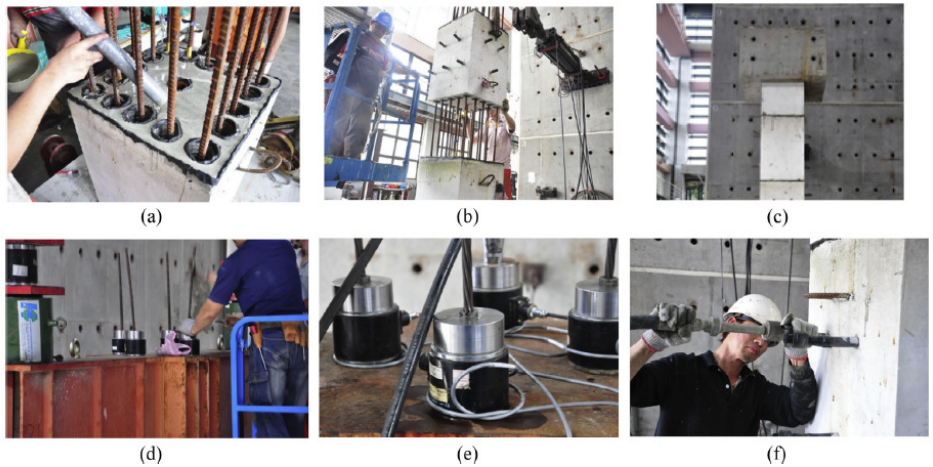
Experimental study and numerical simulation of precast segmental bridge columns with semi-rigid connections

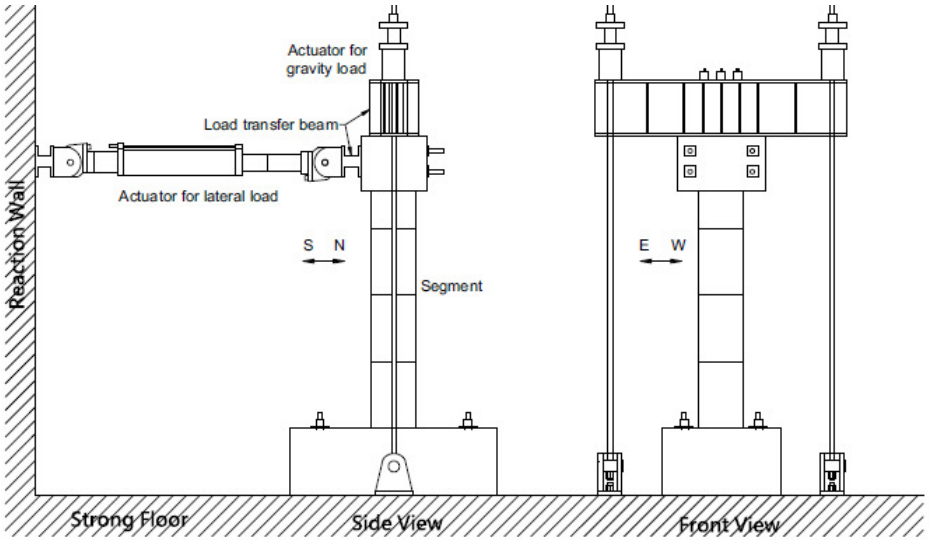
Hsiao-Hui Hung [a], Yu-Chi Sung [a,b,*], Kuan-Chen Lin [b], Chi-Rung Jiang [a], Kuo-Chun Chang [a,c]

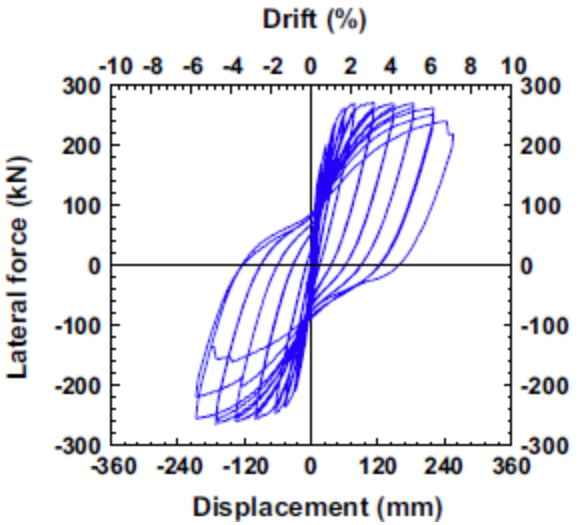
Engineering Structures 136 (2017) 12–25

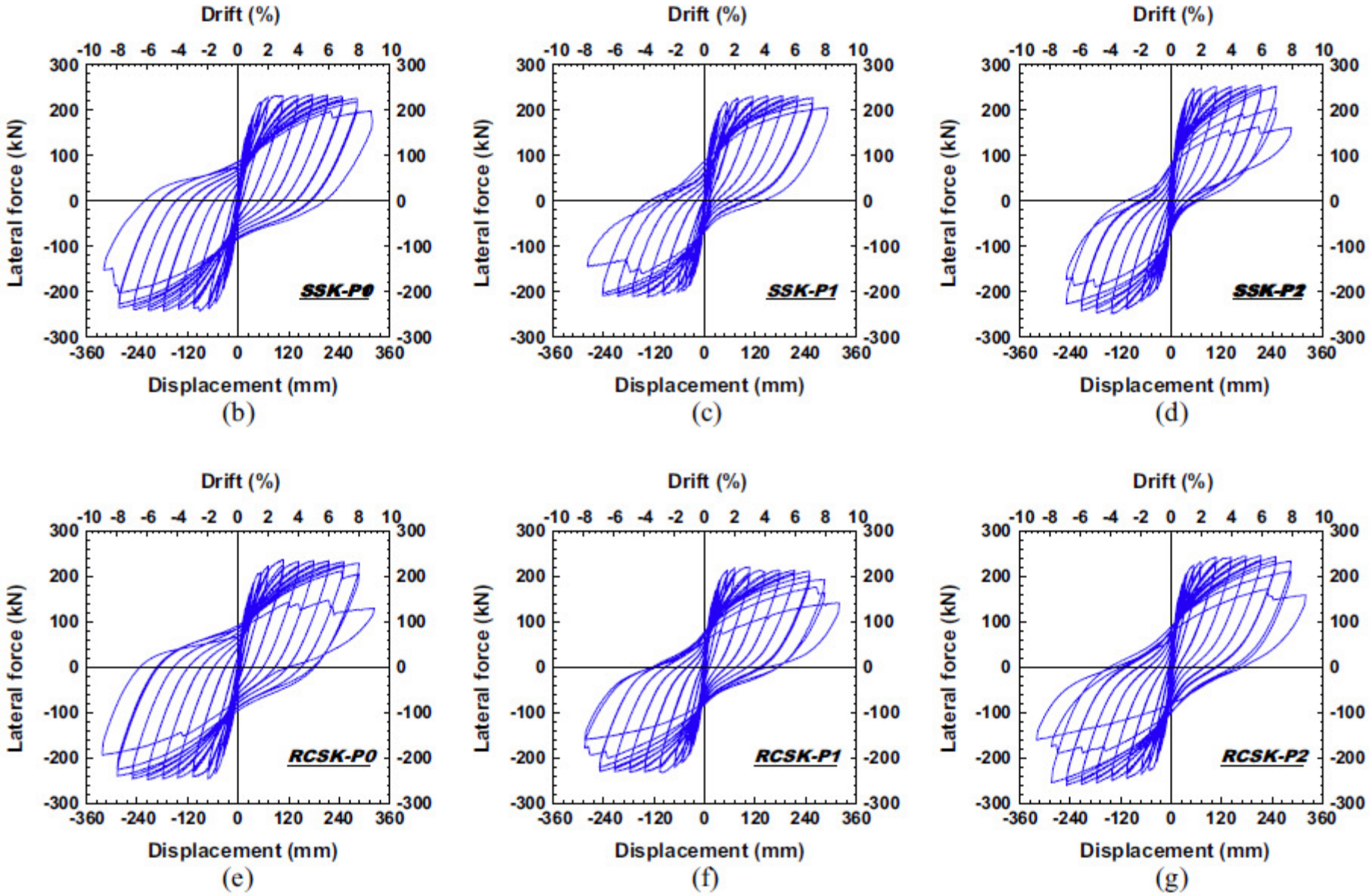



Side view
Top view
3D view
Segment
Side view
Top view
3D view
Segment

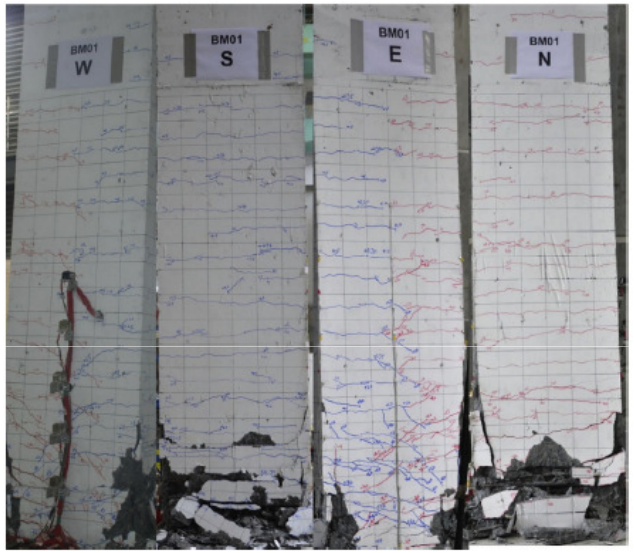

(a)
(b)
(c)
(d)
(e)
(f)


Actuator for gravity load
Load transfer beam
Actuator for lateral load
Reaction Wall
S N
E W
Segment
Strong Floor
Side View
Front View

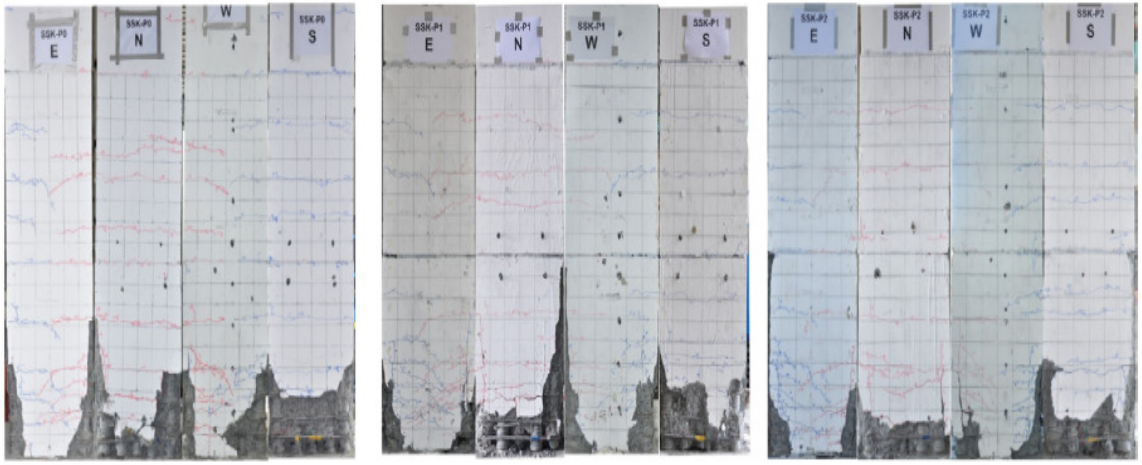

Drift (%)
-10 -8 -6 -4 -2 0 2 4 6 8 10
Lateral force (kN)
300 200 100 0 -100 -200 -300
-360 -240 -120 0 120 240 360
Displacement (mm)



Hysteresis behavior of different column connection

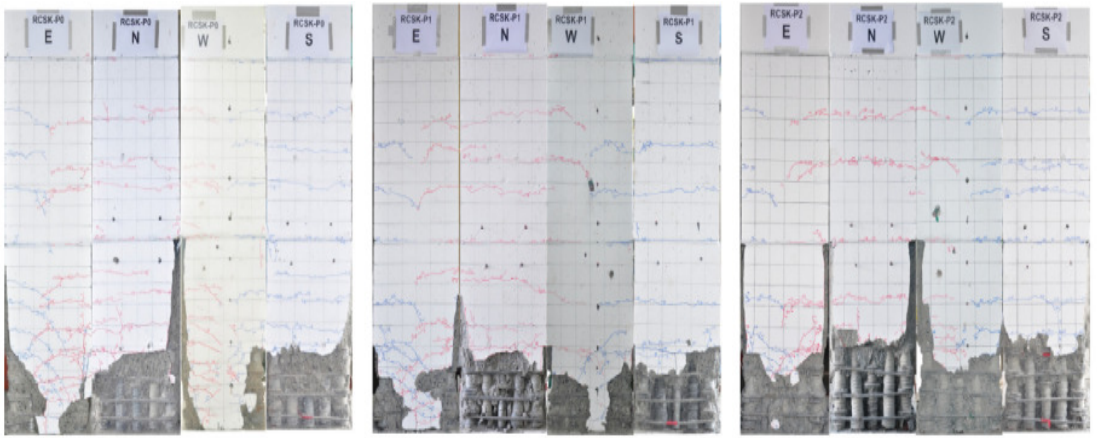


Failure nature monolithic connection



(a) (b) (c)

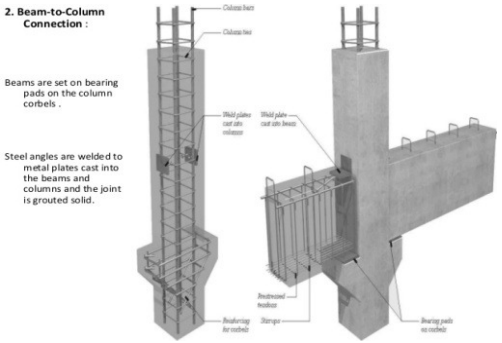
Failure nature Column Connection with shear key

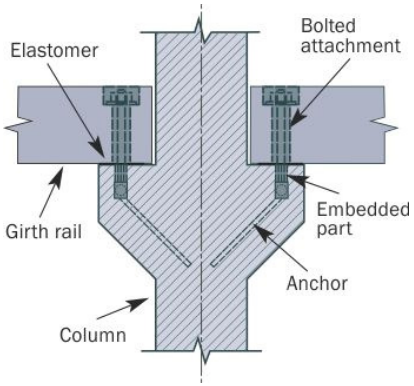


(d) (e) (f)

Failure nature Column Connection with shear key

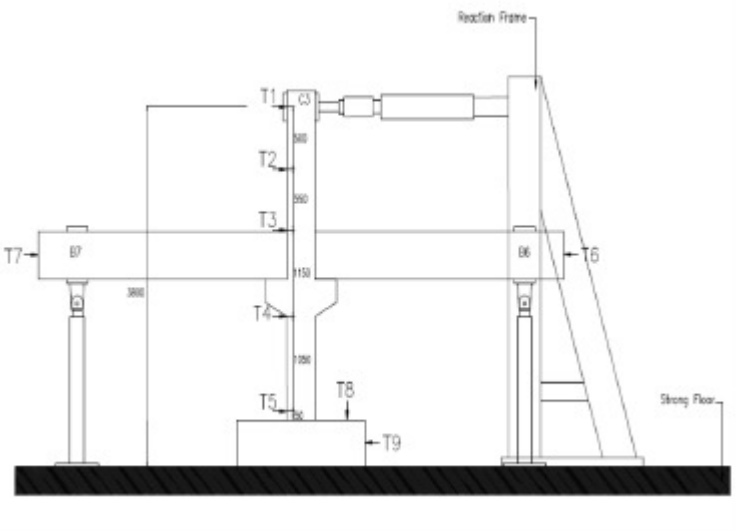
Beam to Column Connections

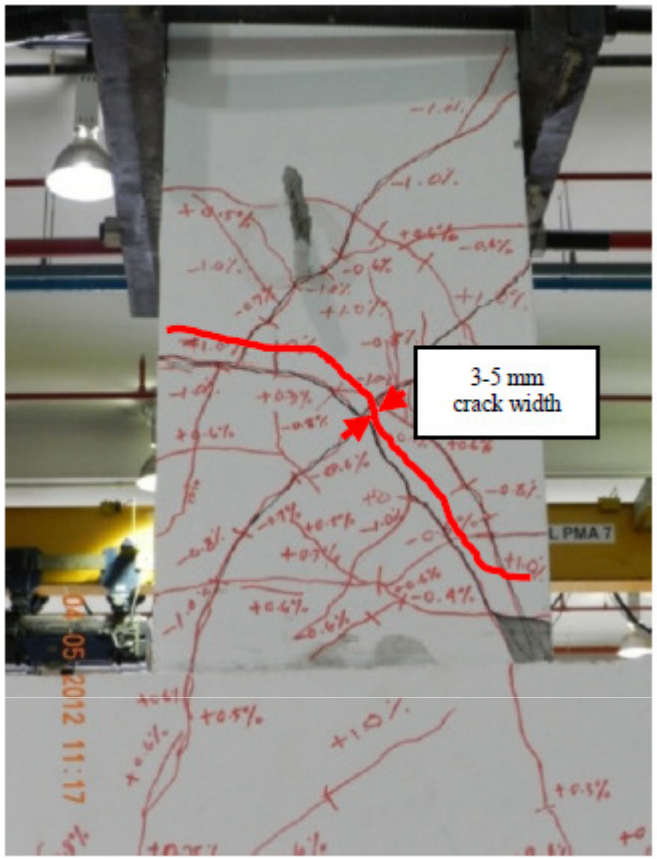


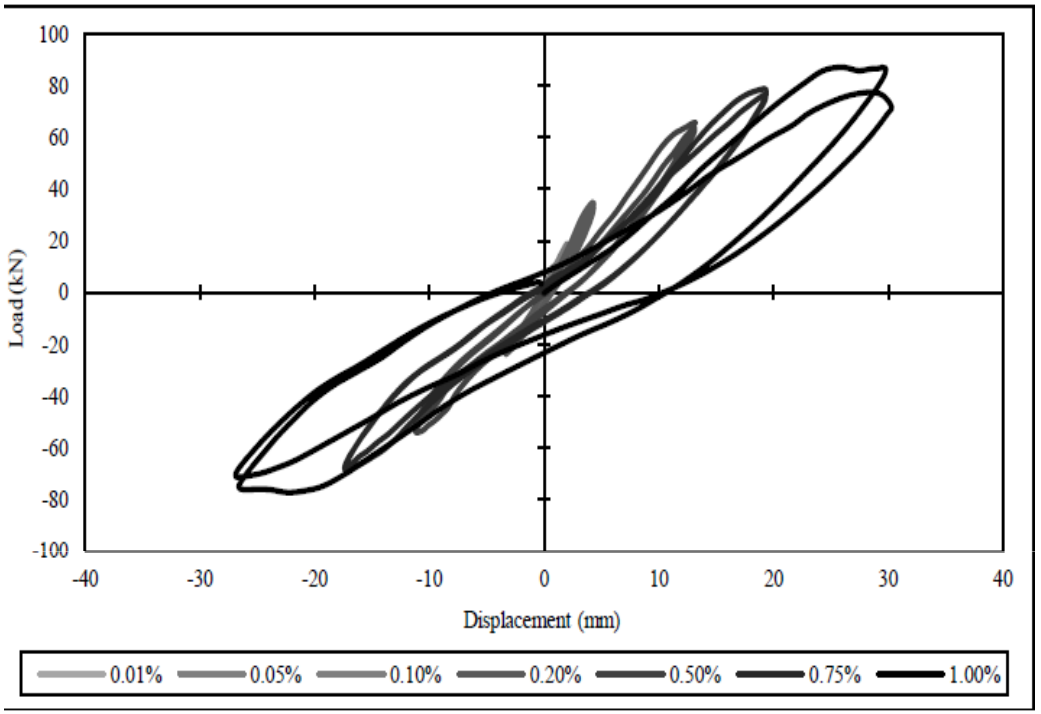


Pre-cast beam to column connection using corbel (fib bulletin 27)

Ghani *et al.* (2013) examined the interior beam column joint with corbel mechanism under cyclic loading



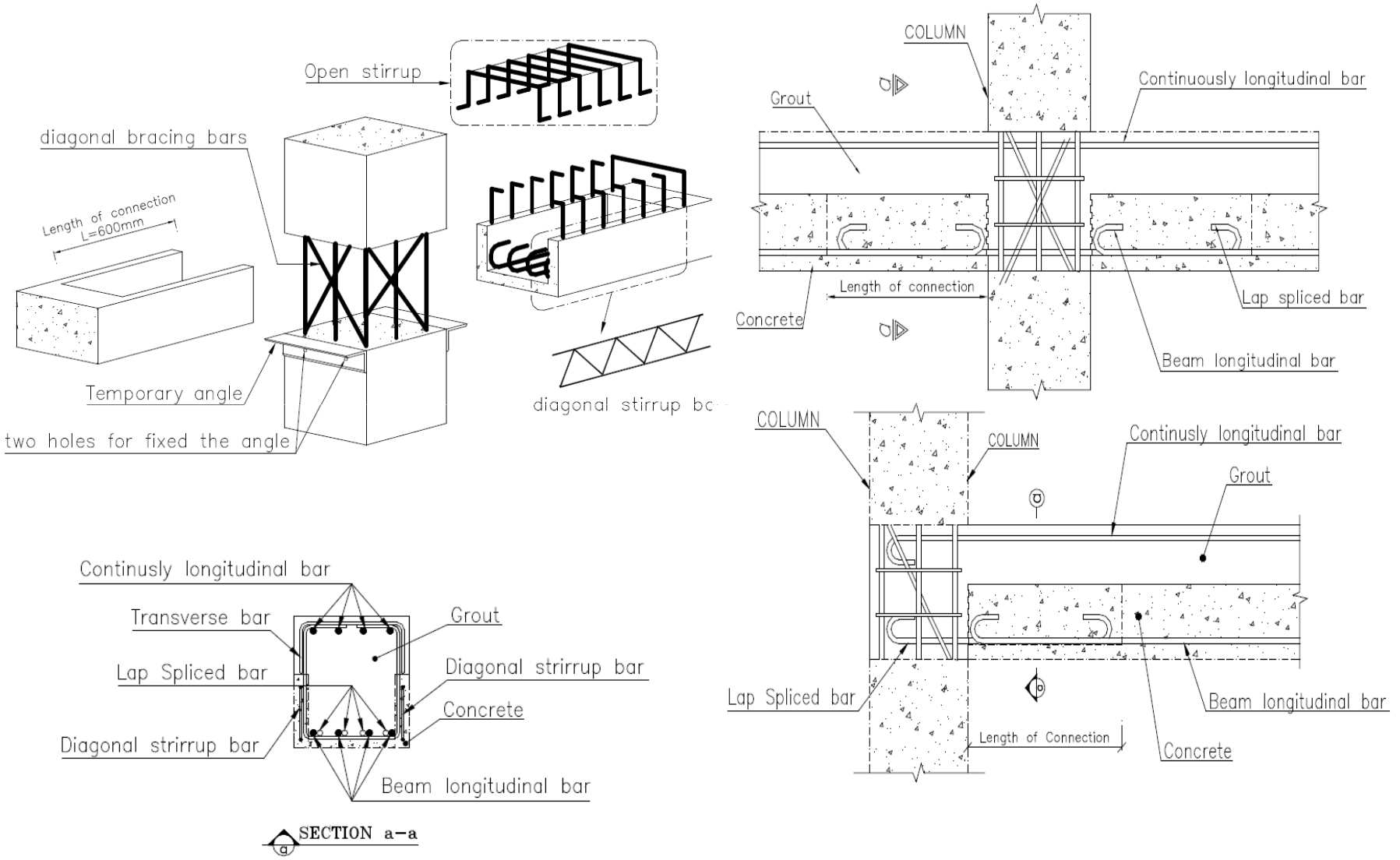




Test Setup and Hysteretic Loop

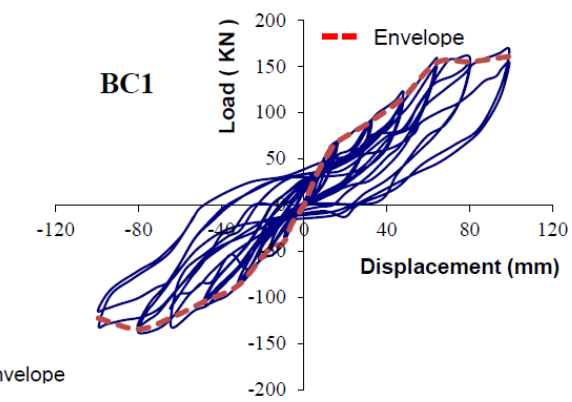
The specimen of precast beam-column exterior joint with corbels was designed in accordance to BS8110, which have considered gravity loading (imposed and dead load) only. Therefore, the specimen studied in this paper experienced severe damage when subjected to quasi-static lateral cyclic loading as shown in experimental work.

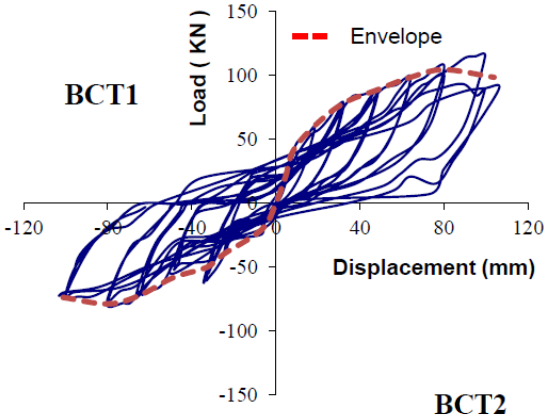
Paratesh *et al.* (2014) developed a ductile moment resisting frame connection for pre-cast frames in seismic region as follows

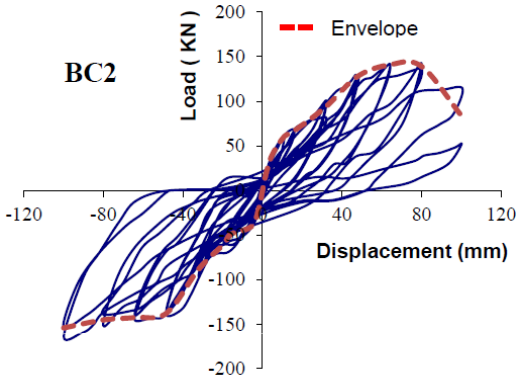


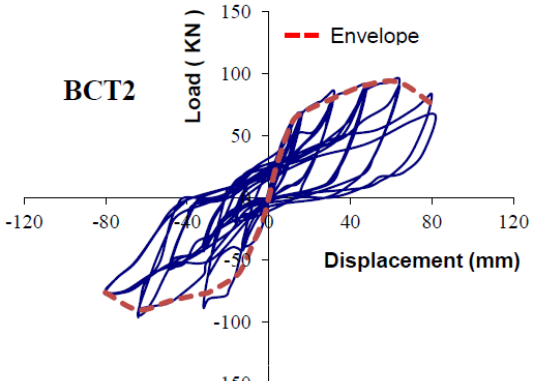
Detailed configuration of different joints

Hysteretic Behavior of Interior

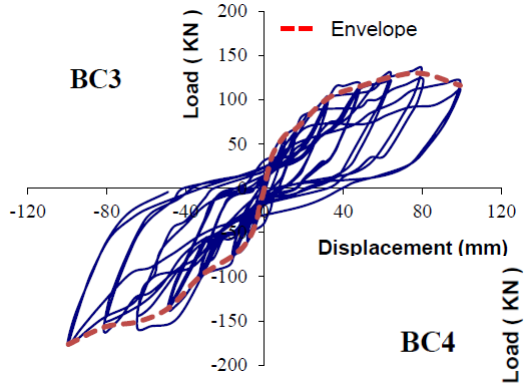


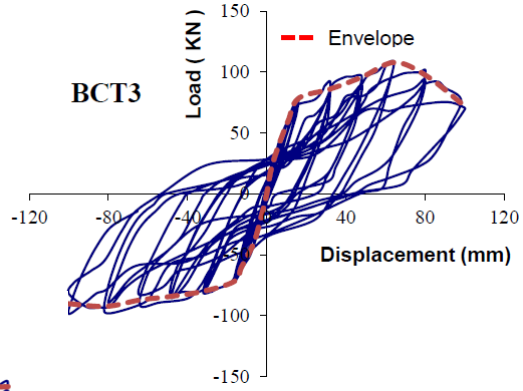


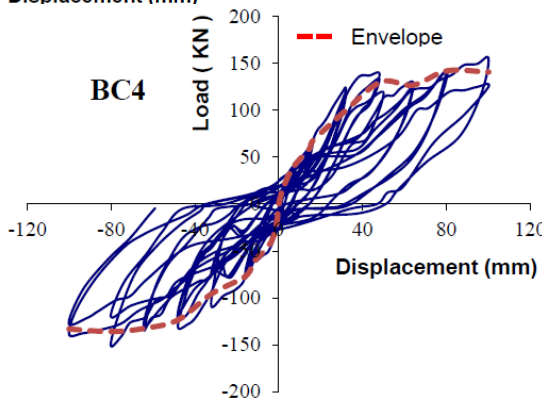


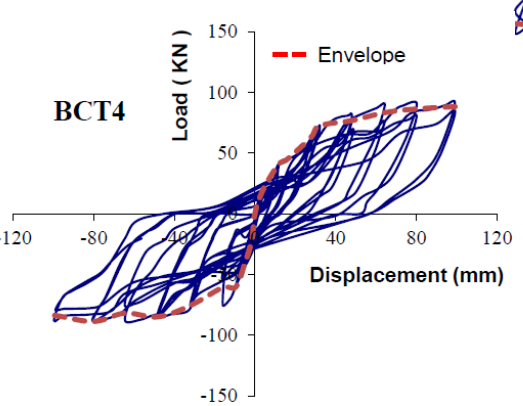


Specimen	Type	Compressive strength of concrete f_c', MPa	Compressive strength of grout, MPa	Specification
BC1	Interior connection	30	-	Monolithic
BC2		25	24	Open stirrup-spacing 100 mm
BC3		27	25	Closed stirrup-spacing 100 mm
BC4		22	23	Closed stirrup-spacing 75 mm
BCT1	Exterior connection	30	-	Monolithic
BCT2		25	27	Open stirrup-spacing 100 mm
BCT3		27	25	Closed stirrup-spacing 100 mm
BCT4		22	28	Closed stirrup-spacing 75 mm



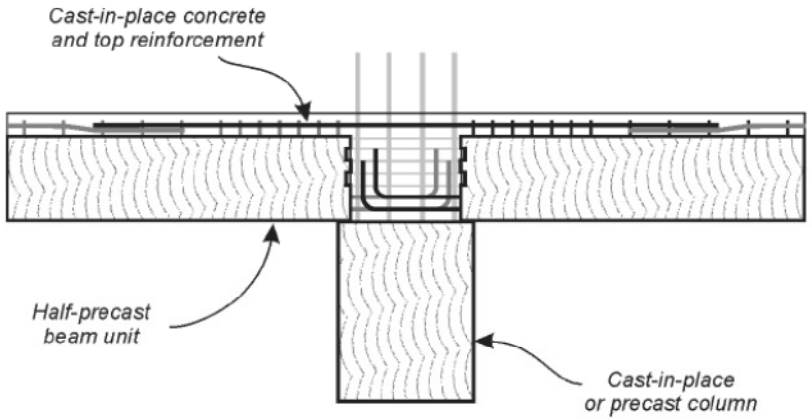




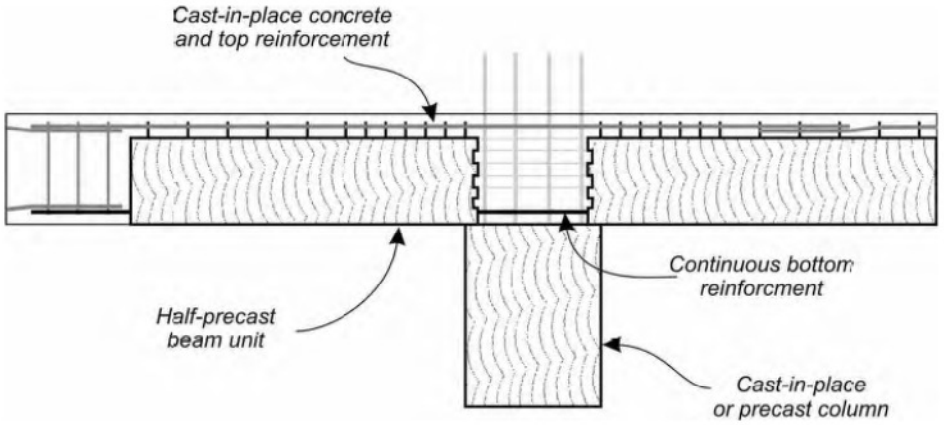


Hysteretic Behavior of Exterior

Pre-cast joints with post tensioned system is alternate to the above mentioned system. In this technique precast beam units are connected with the columns using post tensioned tendons (Fib Bulletin 27).



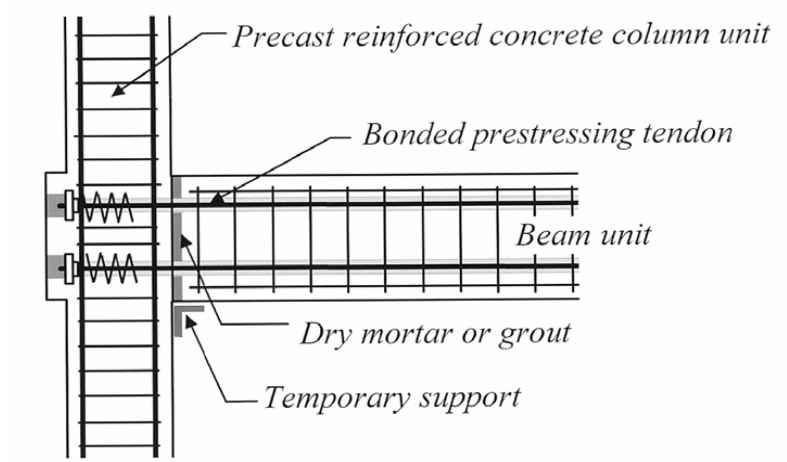
(a) Approach using hooked bar anchorages



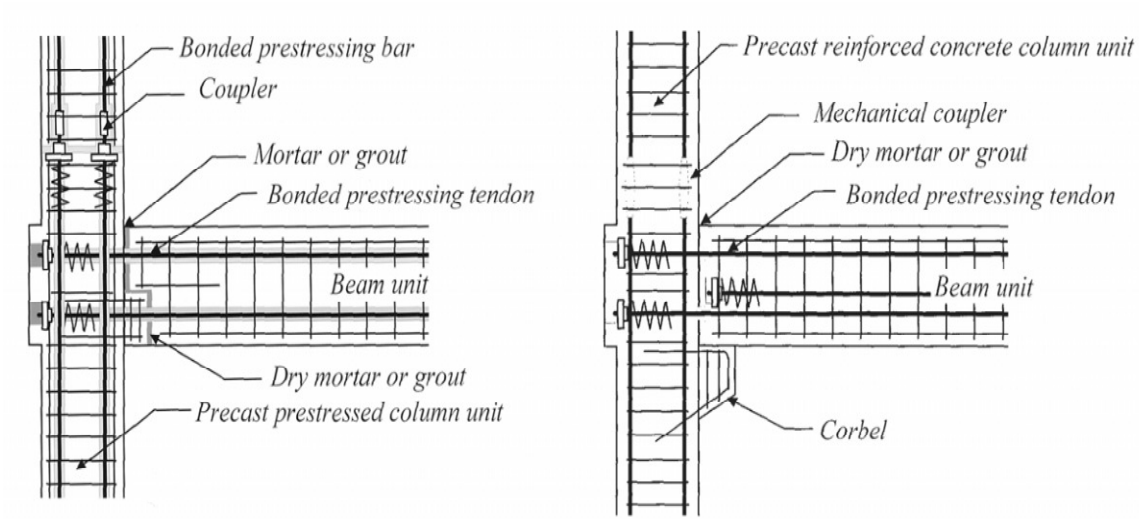
(b) Approach using straight bottom beam bars

Precast beam to column connection mechanism as per *fib*

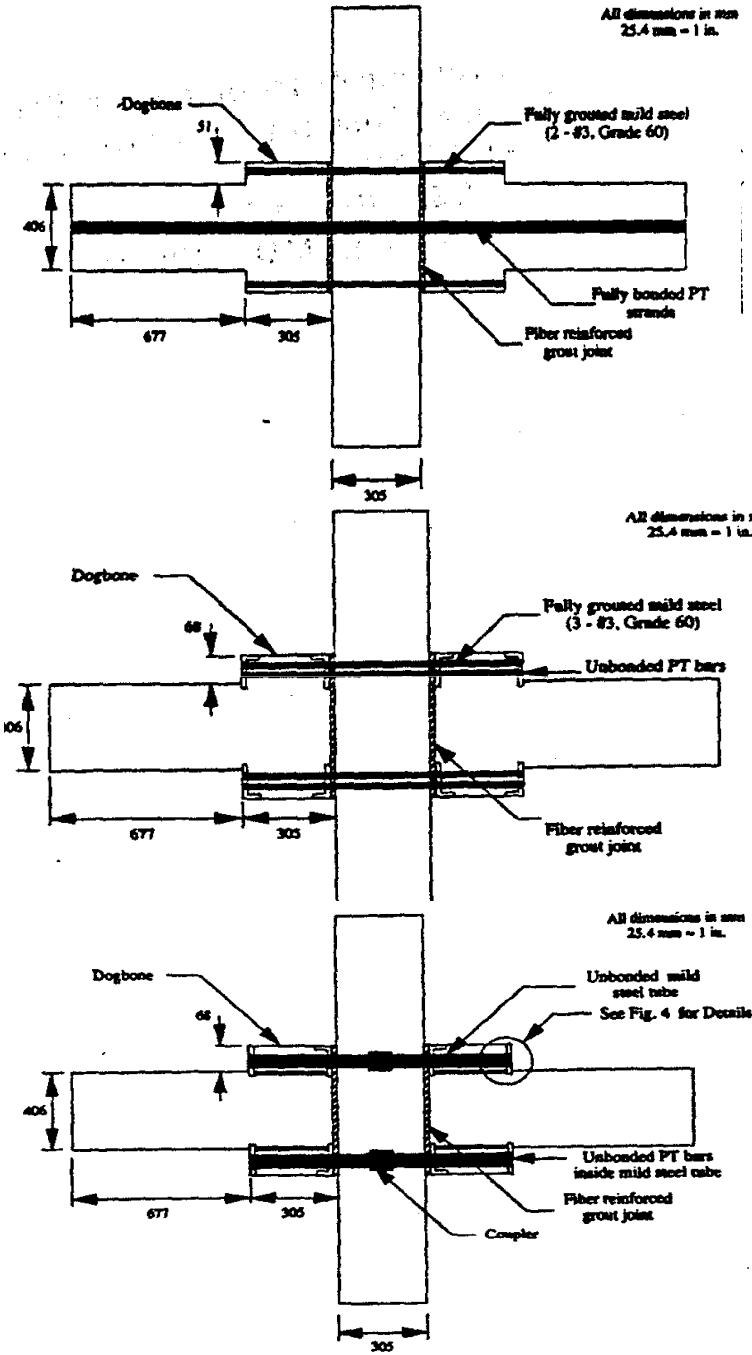
National Institute of Standards and Technology (US) developed this connection mechanism (Stone *et al.*1995; Stanton *et al.*1997).

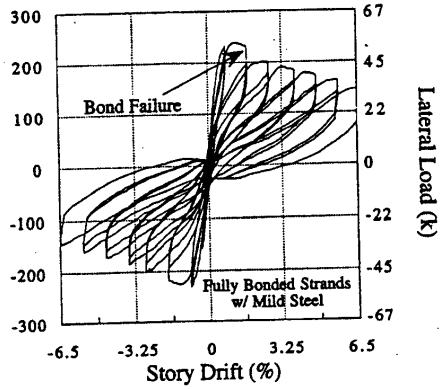


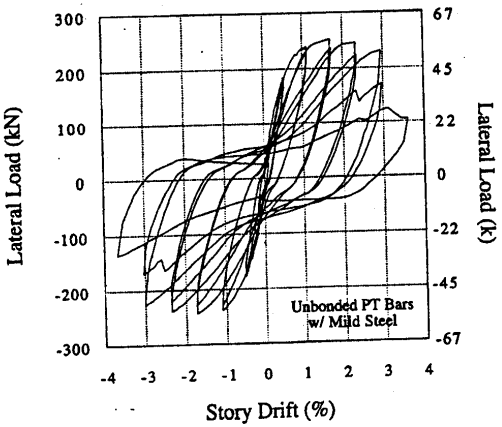
Precast Joints with Pre-stressing tendons

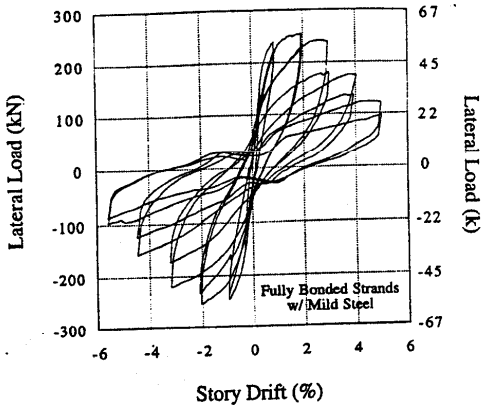


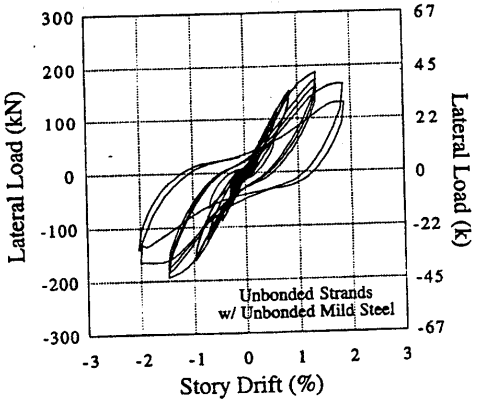
Precast Joints with Pre-stressing tendons with Corbel



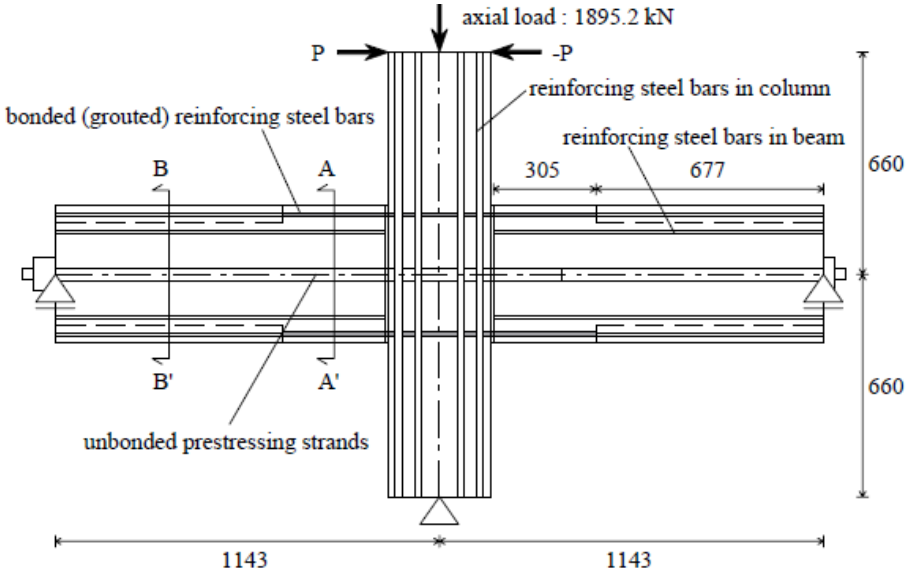




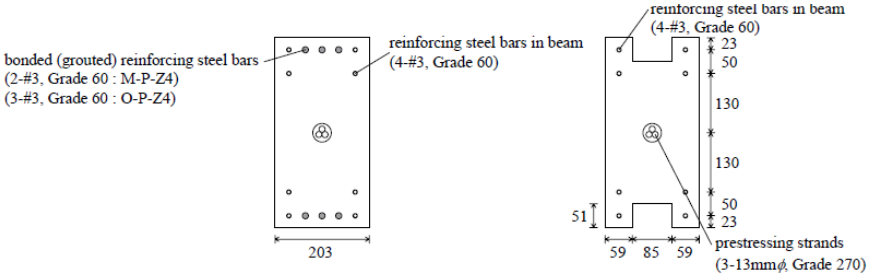




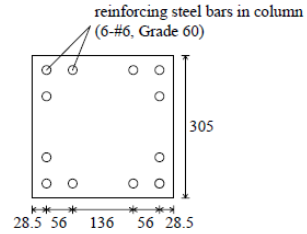
Hysteretic loop of Precast Joints with Pre-stressing tendons (Stone *et al.* (1995)



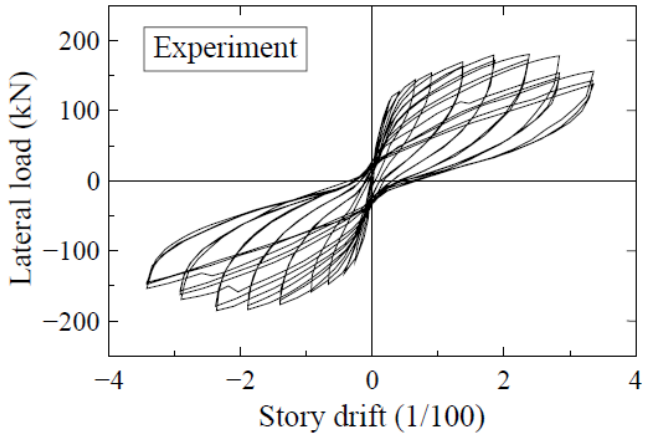
Geometry and loads of specimens



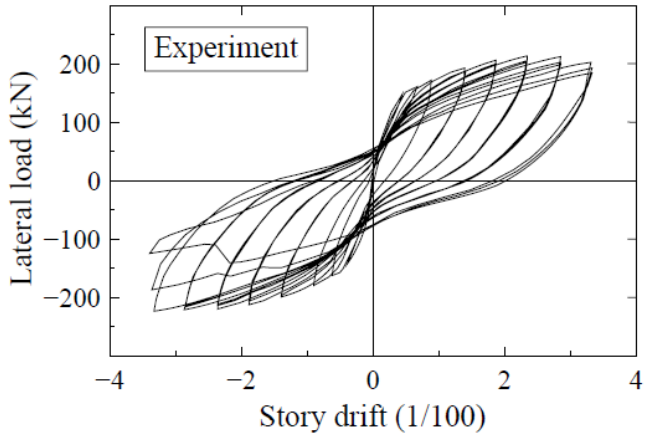
Beam section A-A’ Beam section B-B’



Column section



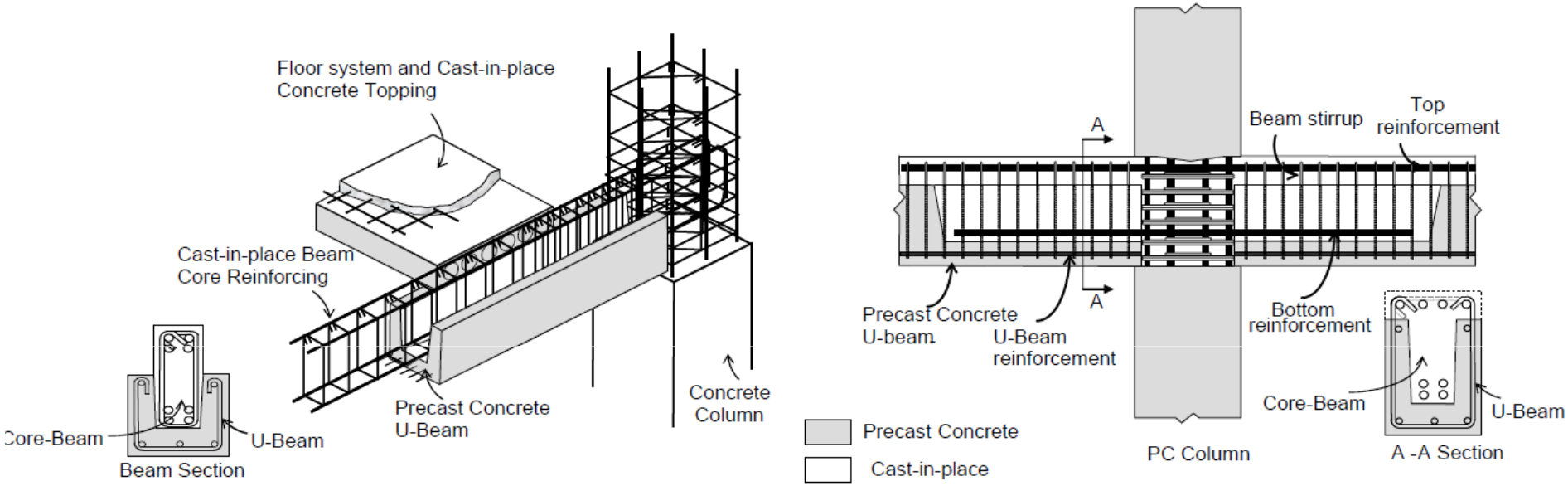
(a) Specimen M-P-Z4



(b) Specimen O-P-Z4

Analytical study of Stone et al. (1995) work by Koshikawa *et al*. (2008)

Precast shell technique is a different mechanism compared to the above discussed joint mechanisms. It use pre-tensioned precast concrete beam shell units as formwork for beams (Park and Bull,1986; Lee,2004; Park *et al*., 2008)



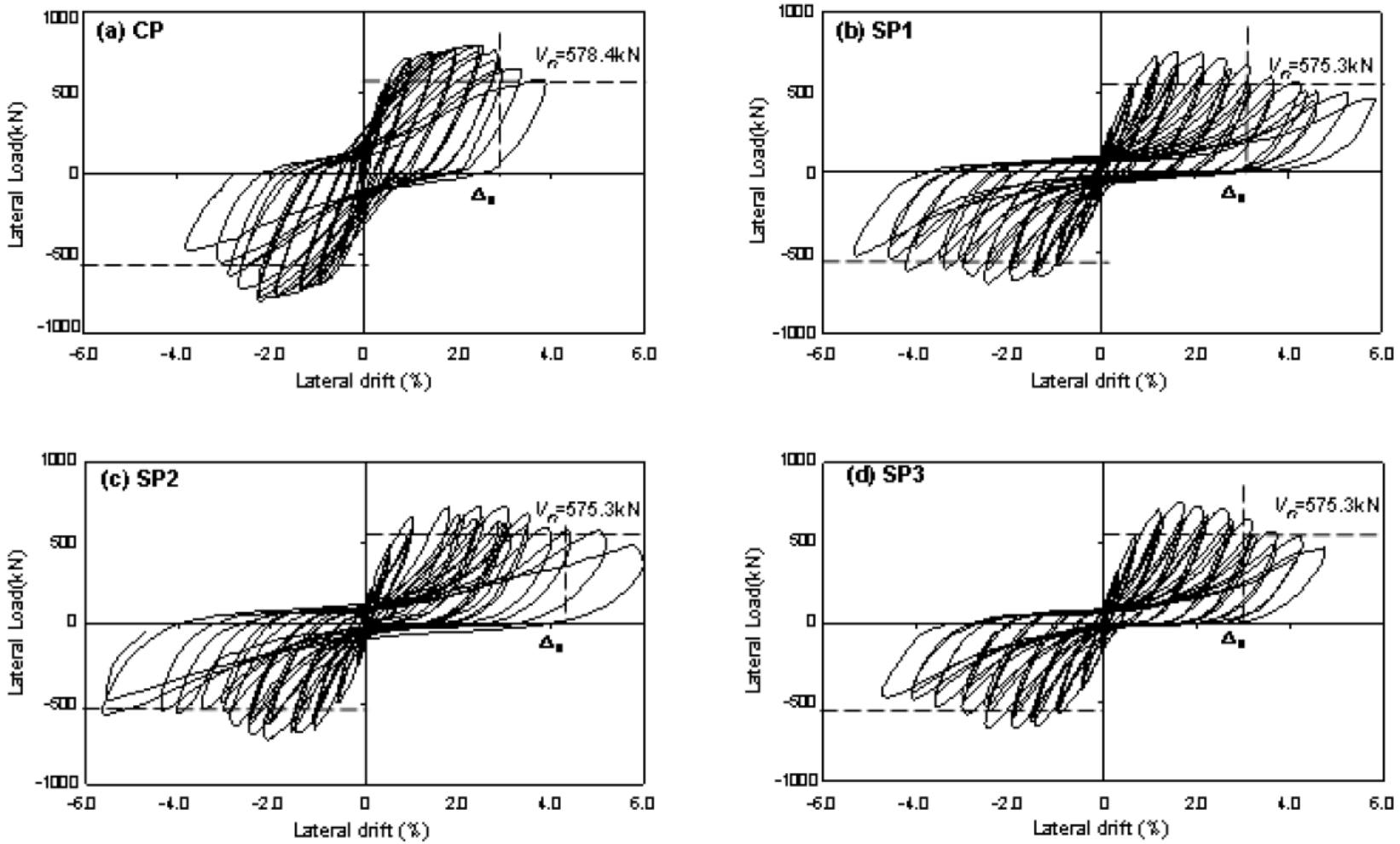
(a) Park & Bull (1986)

(b) LEE (2004)

Precast shell unit construction technique

Specimens	Reinforcement in Beams			Seated length of U-beam shell	Steel Angle-Strengthening for U-beam end
	Top reinforcement (ratio,%)	Bottom reinforcement (ratio,%)	Stirrups		
CP	4-D32(1.23)	2-D25, 2-D29(0.89)	D13@160 (0.22)	-	
SP1	4-D32(1.23)	4-D32(1.66)	D13@120 (0.30)	50mm	
SP2	4-D32(1.23)	4-D32(1.66)	D13@120 (0.30)	50mm	○
SP3	4-D32(1.23)	4-D32(1.66)	D13@160 (0.22)	50mm	○
SP4	4-D32(1.23)	4-D32(1.66)	D13@120 (0.30)	65mm	
SP5	4-D35(1.49)	4-D35(1.99)	D13@120 (0.30)	50mm	○

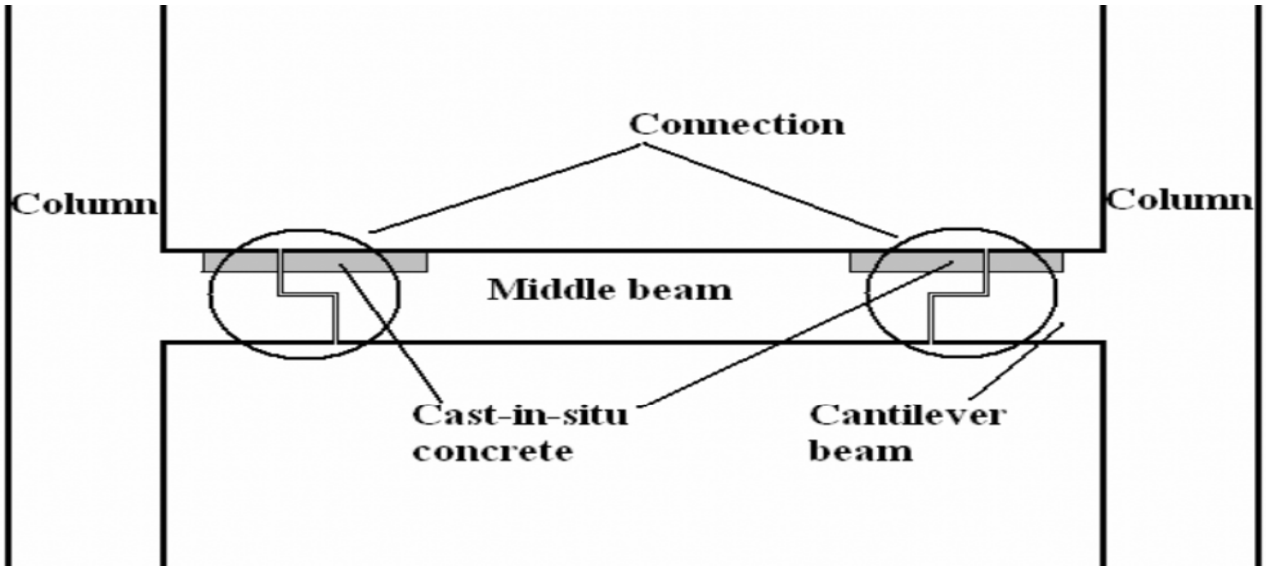
Hysteretic behavior of joint with Precast shell unit technique (Park *et al.* 2008)



I. Enhanced load carrying capacity with reduced stiffness and energy dissipation.

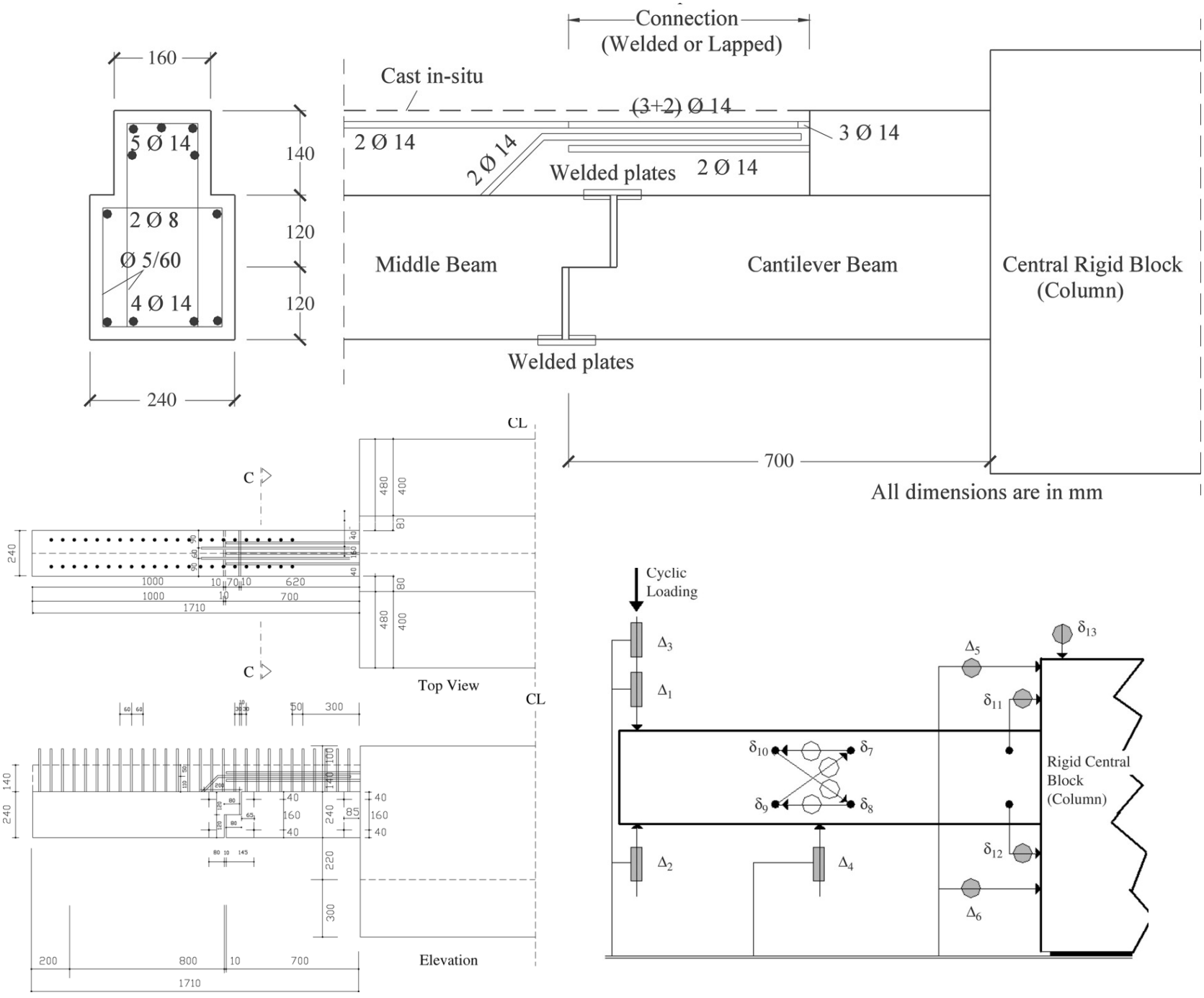
II. The use of higher diameter bar and the reduced shear area due to the fixing of beam in column encourages the shear cracks.

Hasan *et al.*(2005) investigated the cyclic performance of precast concrete beam-to-beam connection using conventional and welding technique and compared with specimen made monolithically.

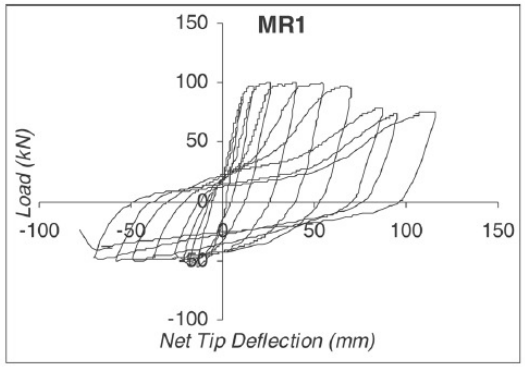


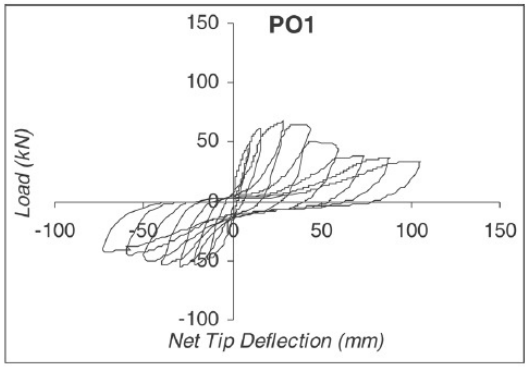
- There are four different configurations that have been employed to connect the middle beam with the column connection.

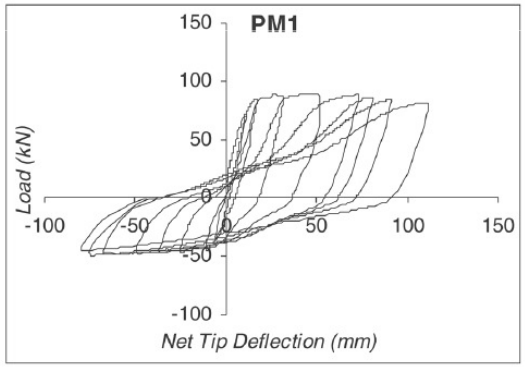
- Increased lap splice length, welding, base plate with higher reinforcement percentage have been used as different configuration in the connection region.

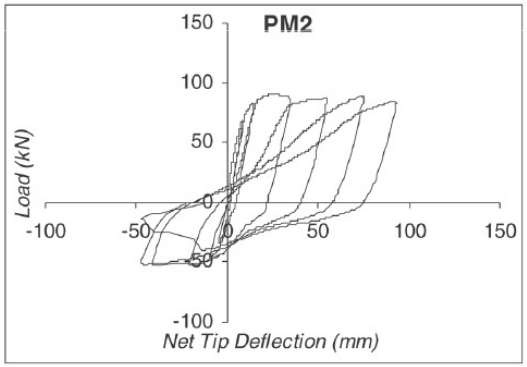

Connection
(Welded or Lapped)
160
Cast in-situ
(3+2) Ø 14
5 Ø 14
2 Ø 14
3 Ø 14
2 Ø 14
Welded plates
2 Ø 14
140
2 Ø 8
120
Ø 5/60
Middle Beam
Cantilever Beam
Central Rigid Block
(Column)
4 Ø 14
120
Welded plates
240
700
All dimensions are in mm
CL
C
480
400
80
240
1000
10
70
10
620
1000
10
700
1710
C
Top View
CL
60
60
50
300
140
240
40
160
40
85
40
160
40
220
300
200
800
10
700
1710
Elevation
Cyclic
Loading
Δ3
Δ1
Δ2
Δ4
δ10
δ7
δ9
δ8
δ13
Δ5
δ11
δ12
Δ6
Rigid Central
Block
(Column)

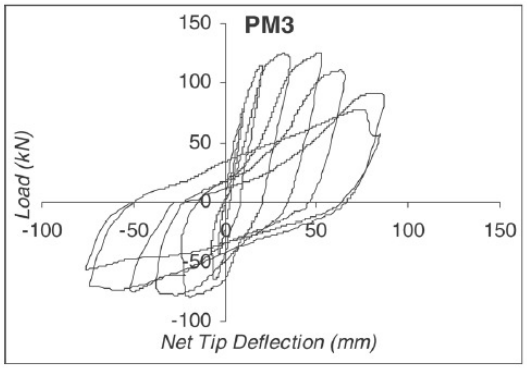
Specimen	Longitudinal steel		Top steel connection		Bottom steel connection		
	Top	Bottom	Type	Length	Bars	Weld length	Weld plate anchorage
MR1	$4\phi14$ ($\rho \cong 0.015$)	$2\phi14$	Continuos				
PO1	$4\phi14$	$2\phi14$	Lapped	390 mm (28ϕ)	$3\phi10$	35 mm	$3 \times 2\phi8$ ($L = 400$ mm)
PM1	$4\phi14$	$2\phi14$	Welded		$3\phi10$	60 mm	$3 \times 2\phi8$ ($L = 400$ mm)
PM2	$4\phi14$	$2\phi14$	Lapped	660 mm (47ϕ)	$3\phi10$	60 mm	$3 \times 2\phi8$ ($L = 400$ mm)
PM3	$4\phi16$ ($\rho \cong 0.020$)	$2\phi16$	Welded		$3\phi16$	60 mm	$3 \times 2\phi12$ ($L = 500$ mm)
PM4	$4\phi14$	$2\phi14$	Lapped	660 mm (47ϕ)	$3\phi14$	60 mm	$3 \times 2\phi10$ ($L = 400$ mm)

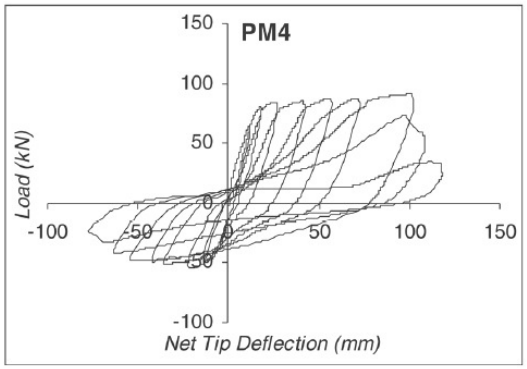








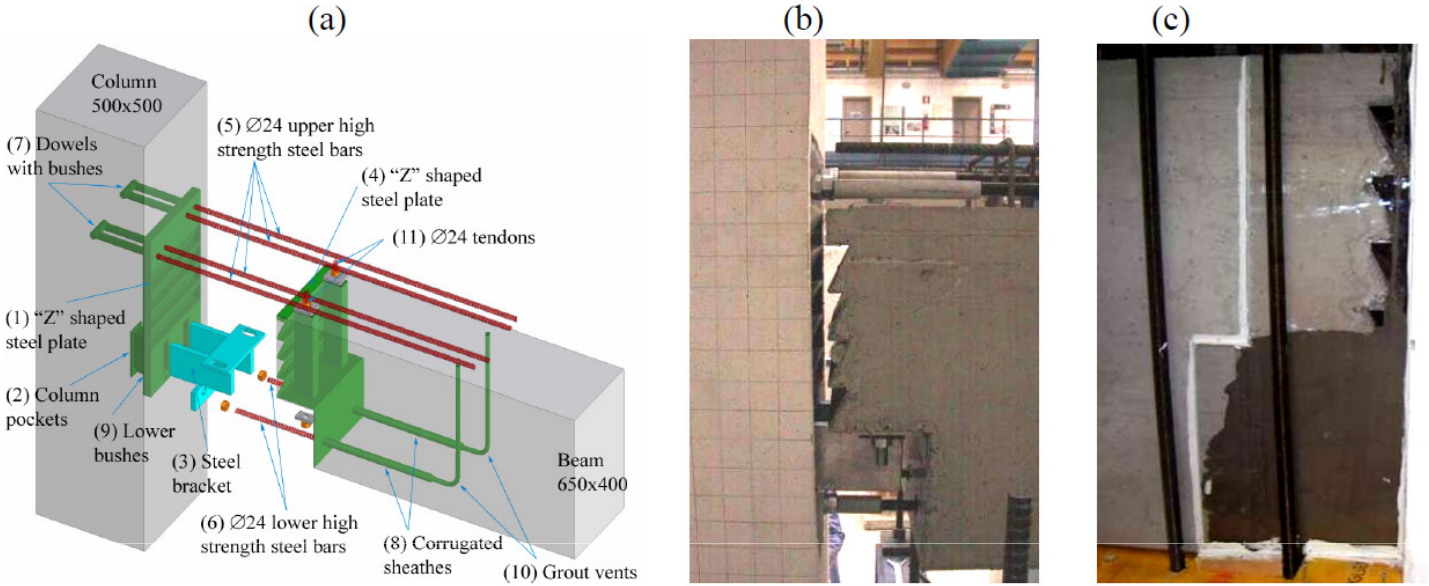




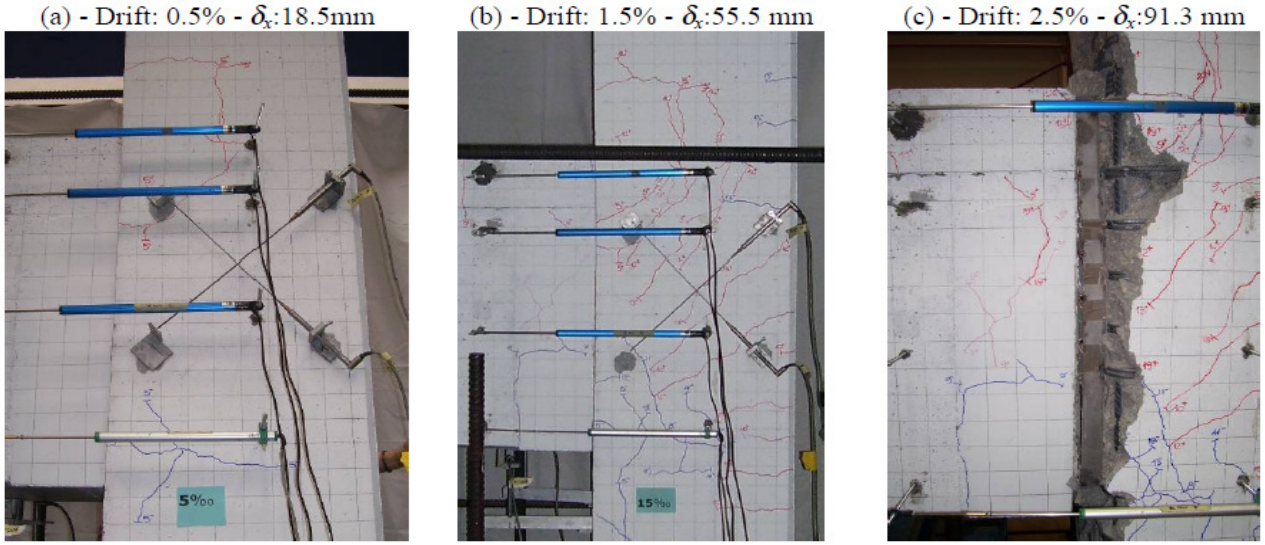
I. The welding techniques reduces the anchorage problem and offers better resistance to force and successfully transferred the forces.

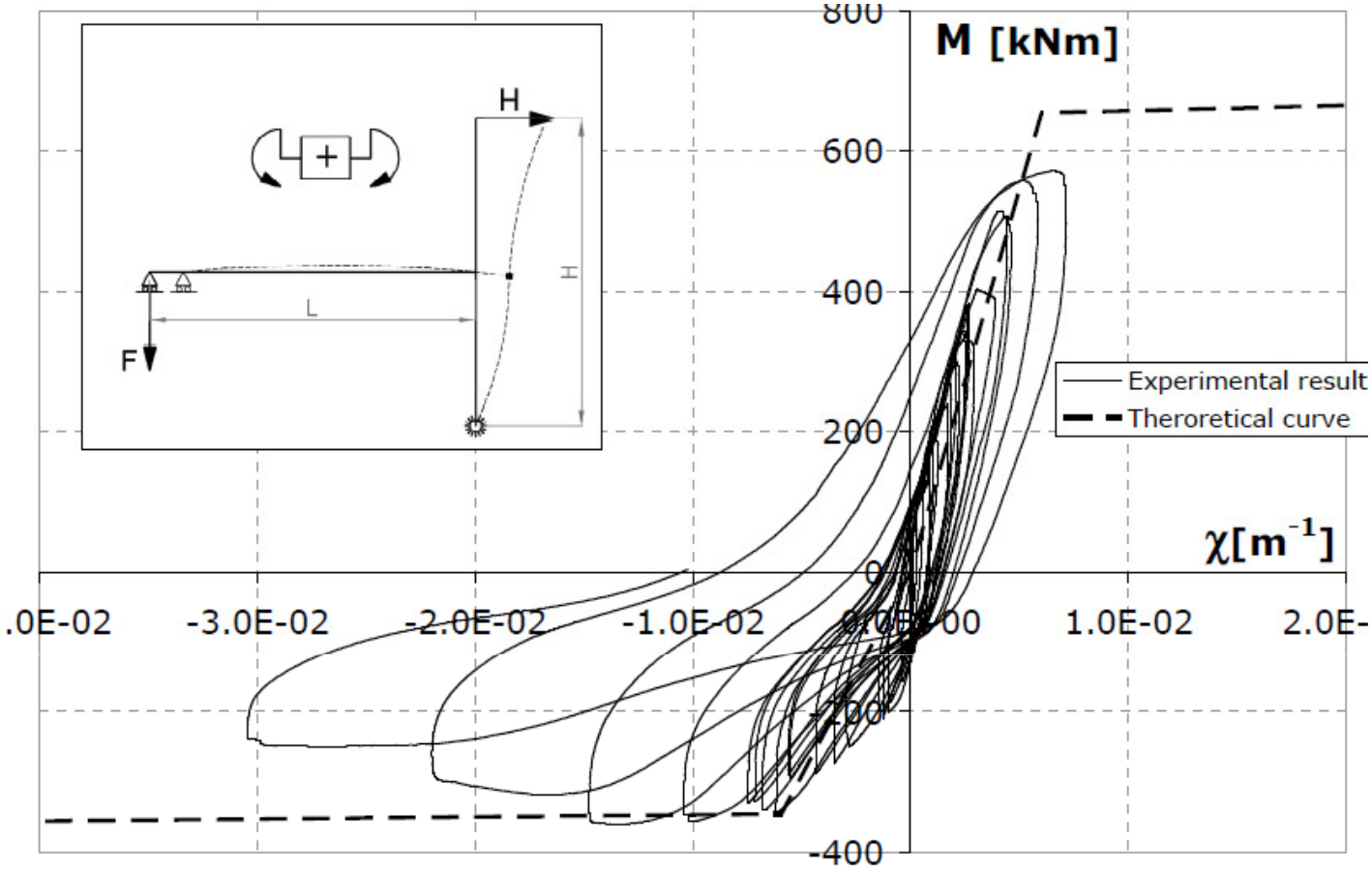
II. The higher lap splice enabled specimen is also exhibits better performance than the conventional precast technique.

Meteli et al. (2008) developed a beam to column “dry” joint for precast concrete elements and tested under cyclic loading. The joint system consists of a “Z” shaped steel plate with four upper and two lower bushes to connect the threaded bars to the column. The plate, which is embedded in the column, is equipped with two pockets .



Edilmatic system components for beam-column joints in pre-cast structures

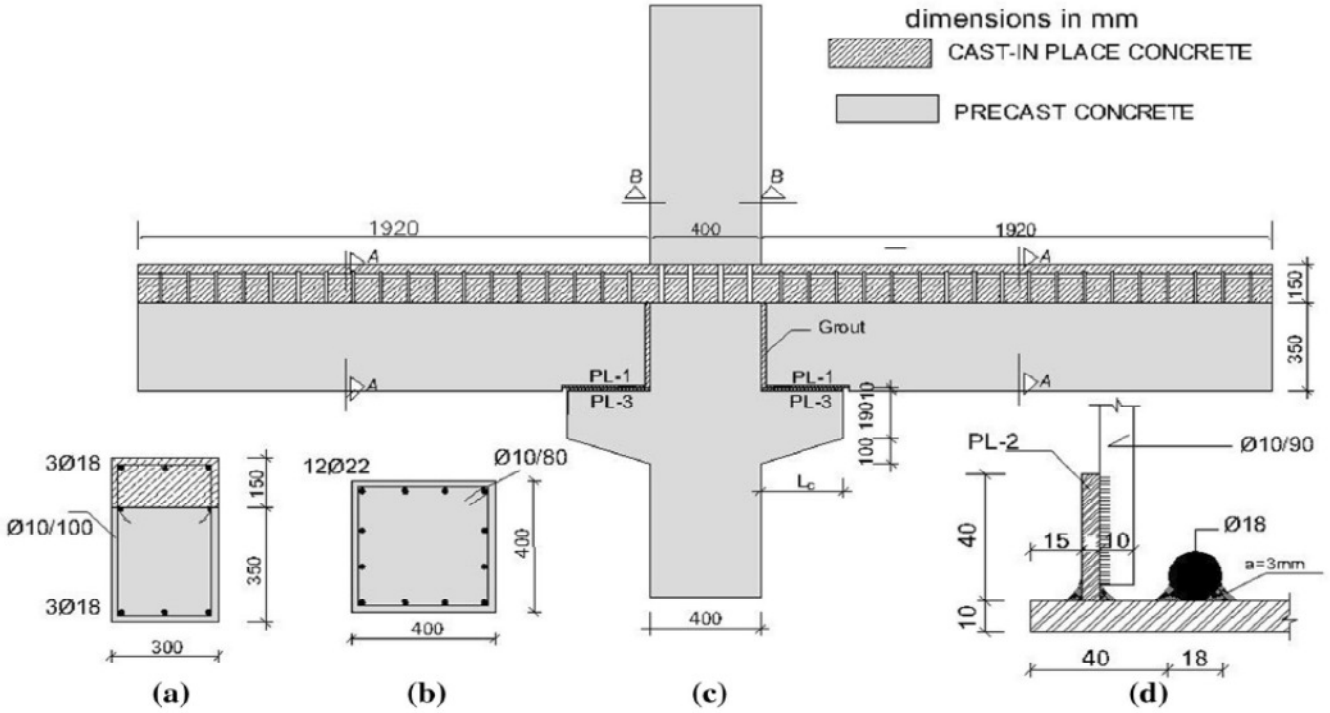




➢Stable rotational behaviour up to 2.0% drift.

➢Limited dissipative capacity because of the early collapsed due to the brittle failure of the connection on the column side.

Sadik *et al* (2017) investigated the behavior of precast hybrid (emulative-welded) beam-column connections with welded components under cyclic loading. Figure shows the detailed mechanism of this emulative welding technique. Strength, stiffness and energy dissipation capacities of test specimens were investigated with respect to welding coefficient and unbonded length of rebar connected with the plate as the main test variables. However, the precast specimens with lesser welding coefficient showed gradual strength degradation up to 3.5% drift ratio. Also the damage indices are close to monolithic specimens.



Precast joint with emulative-welding technique.

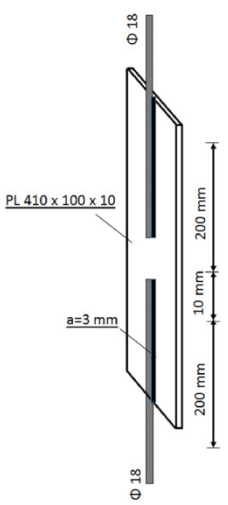
(a)

(b)

Emulative-welding technique.

(c)

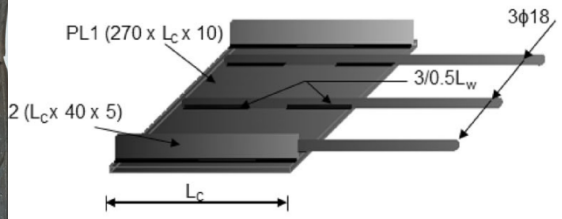
(d)

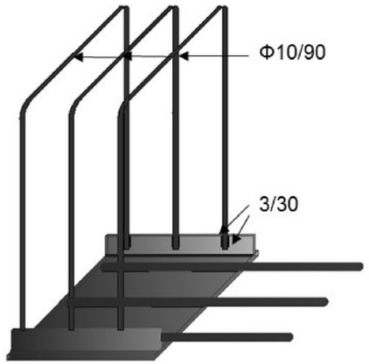


(a)

(b)

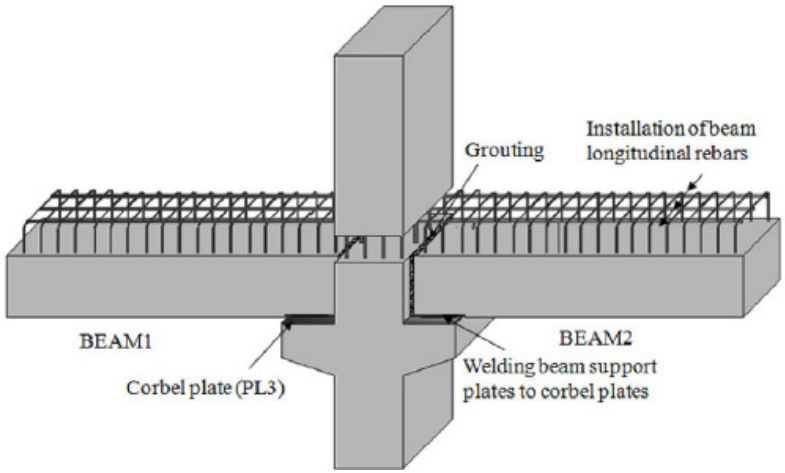
(c)

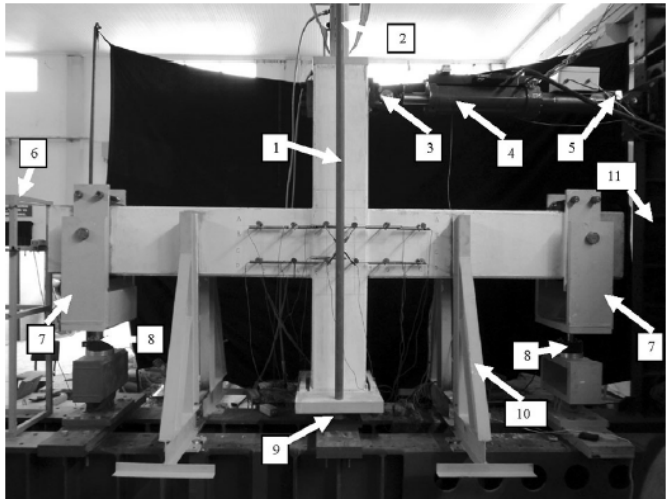


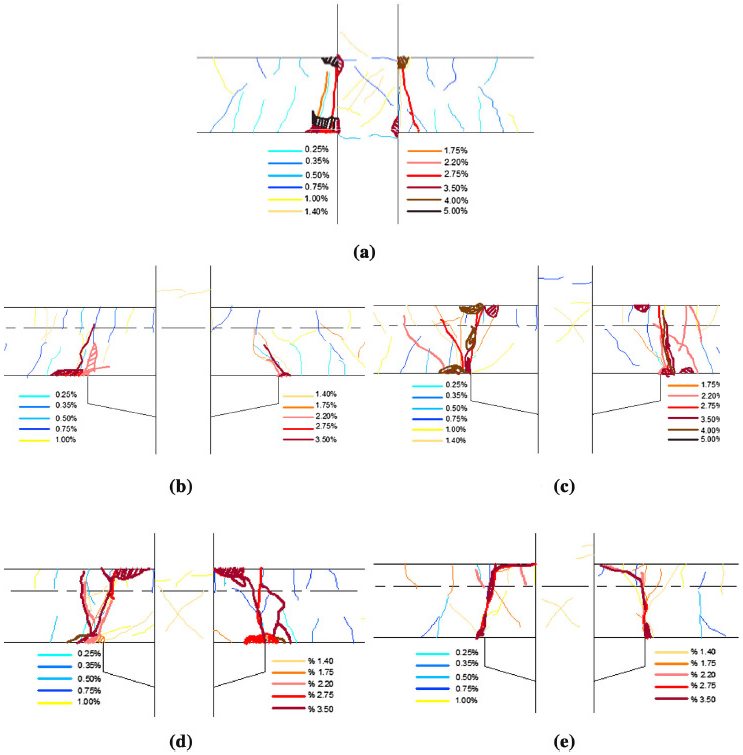


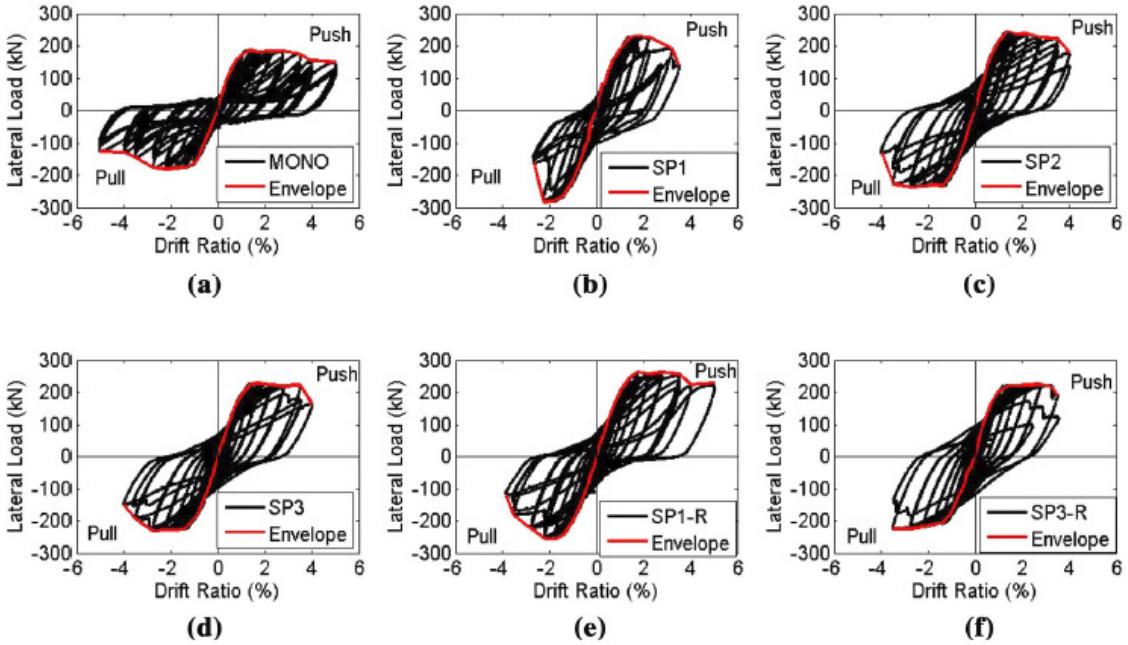
Emulative-welding technique enabled specimen

Specimen	α	L_c (mm)	L_w (mm)	ρ_w (%)	s_h/d_b	L_u (mm)	C (%)	CE (%)
SP1	2.0	450	340	0.52	5.6	N.A.	0.31	0.49
SP2	1.5	350	250	0.52	5.6	N.A	0.19	0.35
SP3	1.2	300	200	0.52	5.6	N.A	0.196	0.37
SP1-R	2.0	450	340	0.52	5.6	5 d_b	0.19	0.35
SP3-R	1.2	300	200	1.0	4.2	10 d_b	0.196	0.34





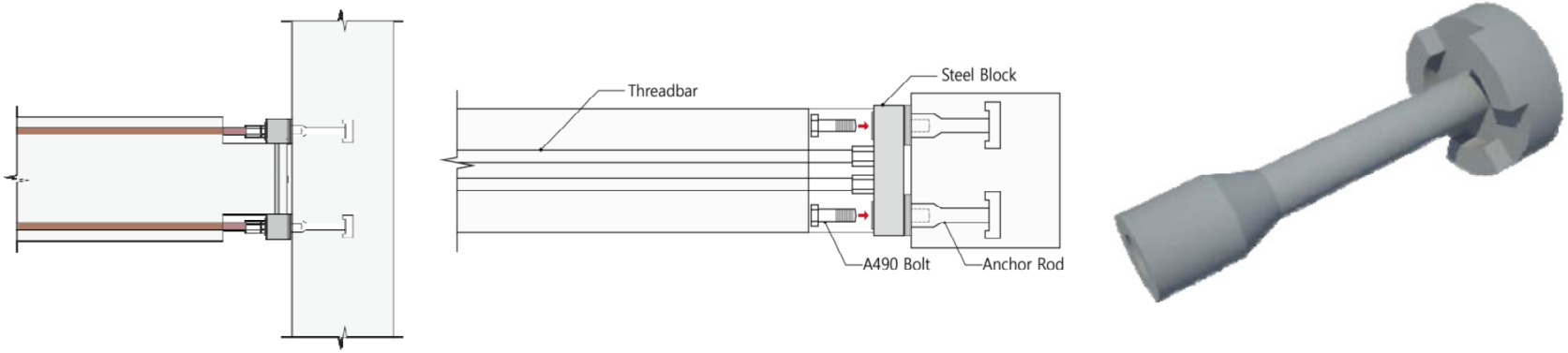




The specimen unbounded length showed a higher ductility than monolithic specimen, but showed severe pinching due to shear failures.

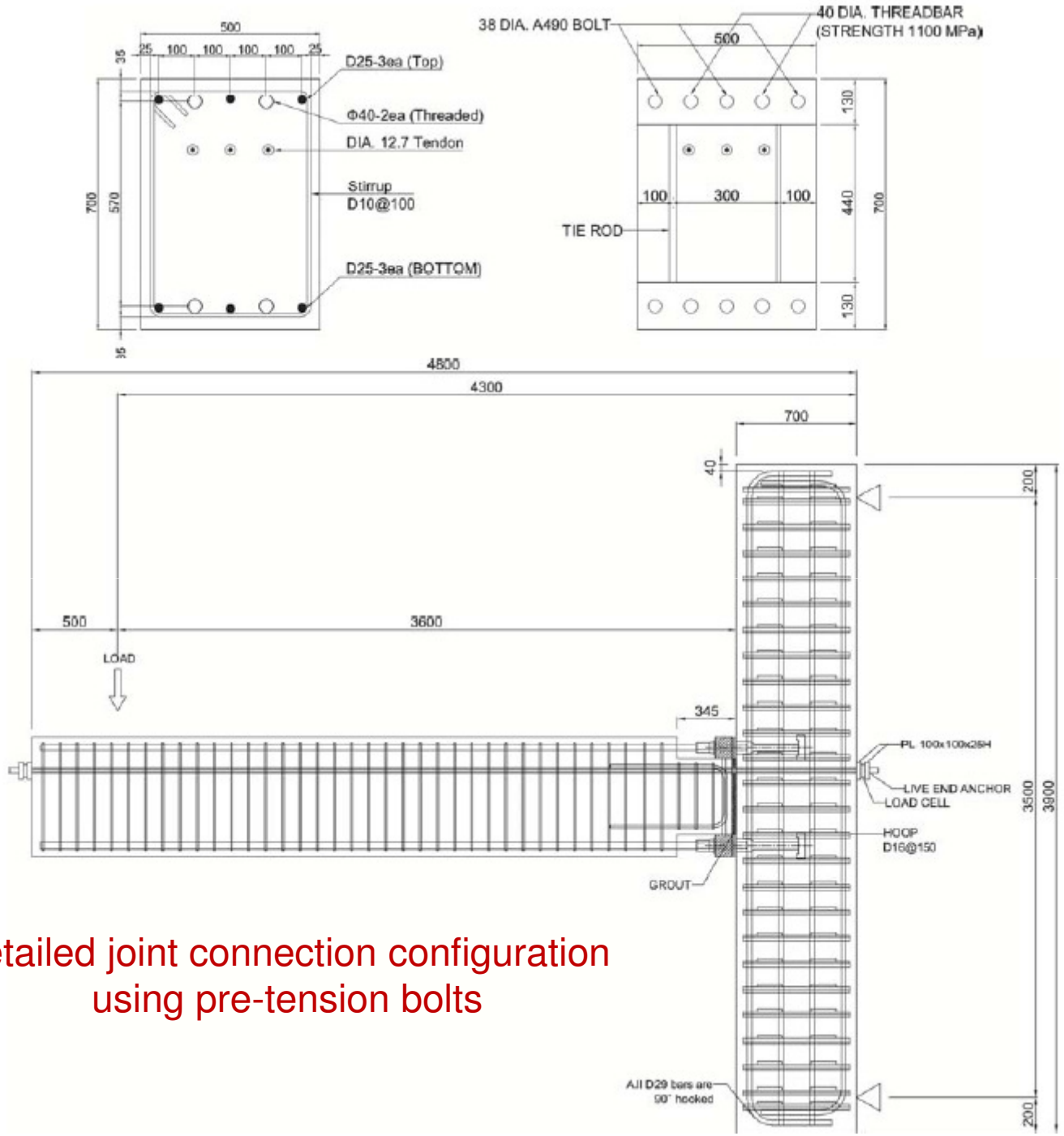
The specimens with higher unbounded length showed an improved seismic behavior and the additional ties to prevent early buckling of longitudinal bars .

Thomas *et al.* (2013) proposed a new precast beam-column connection using pure dry cast method. Fig. 10 shows the pre-tension bolting connection. Pre-tensioning bolt, steel block and threaded bar are the main elements used in the concepts. An anchor bolt is embedded in the column has a provision for bolting.

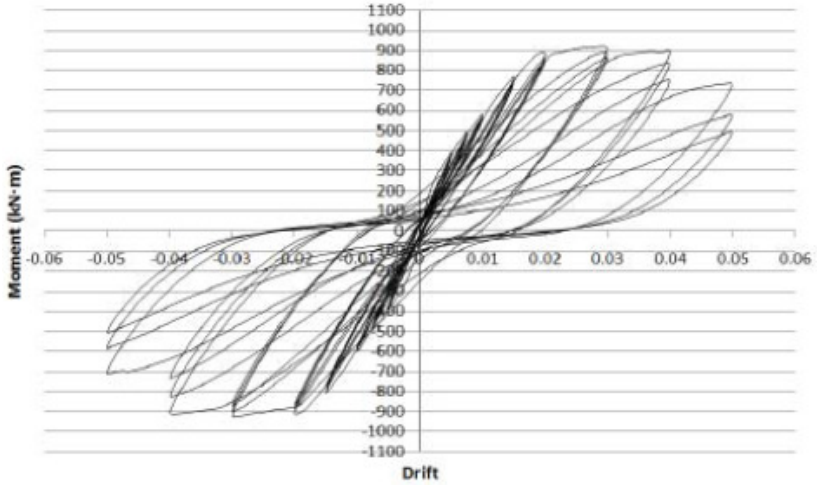


Pure dry cast method; beam connection using pre-tension bolts

	Column		Beam		Connection
Specimen	Dimension (mm)	Longitudinal Steel (mm)	Dimension (mm)	Longitudinal Steel (mm)	Embedded Nut with Anchor
RC1	500×500	12-D25	400×650	10-D29	-
PC1	500×500	12-D25	400×650	Ø40 threaded bars	2-Ø45 (300 mm long)
PC1-T	500×500	12-D25	400×650	Ø40 threaded bars & 3-Ø12.7 PT tendons	2-Ø45 (300 mm long)



Detailed joint connection configuration using pre-tension bolts



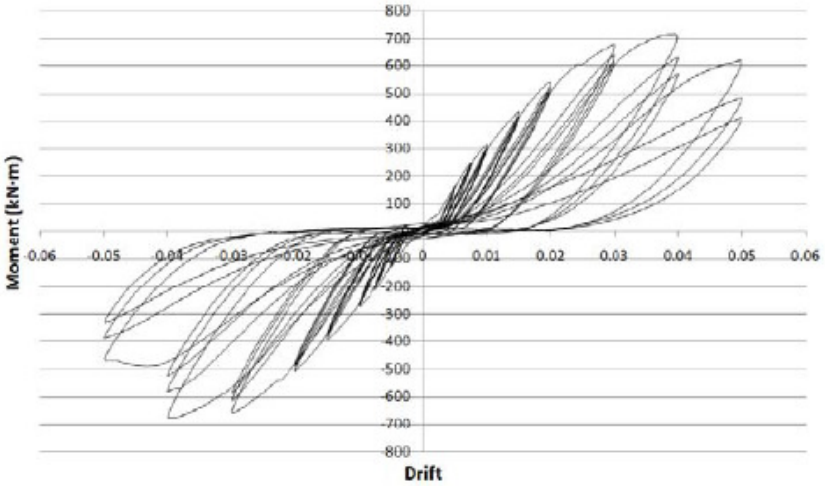


Fig. 6 Beam moment-story drift ratio relationship for PC1

Test results of pure dry casting technique

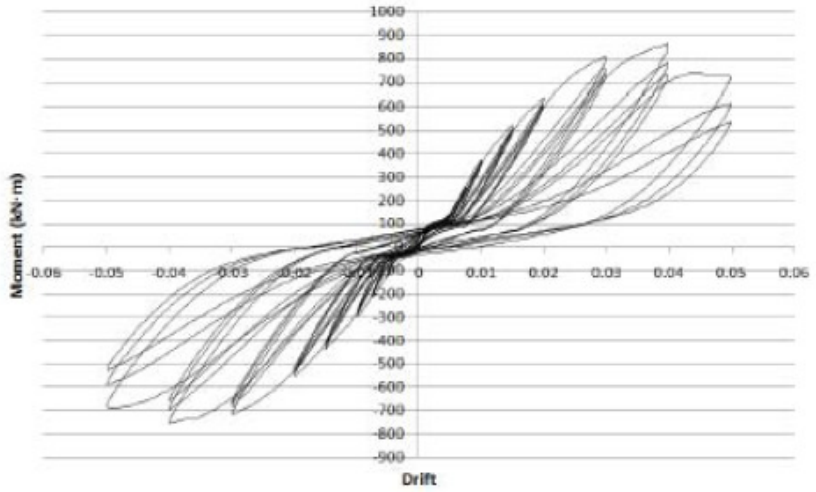
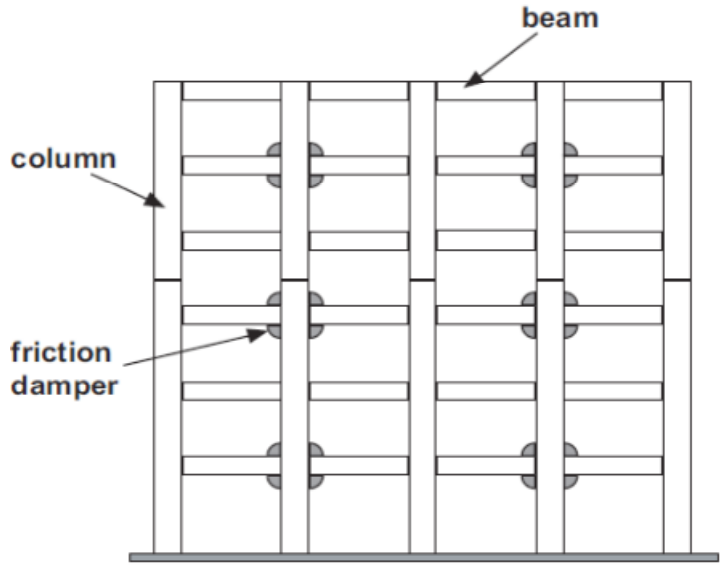
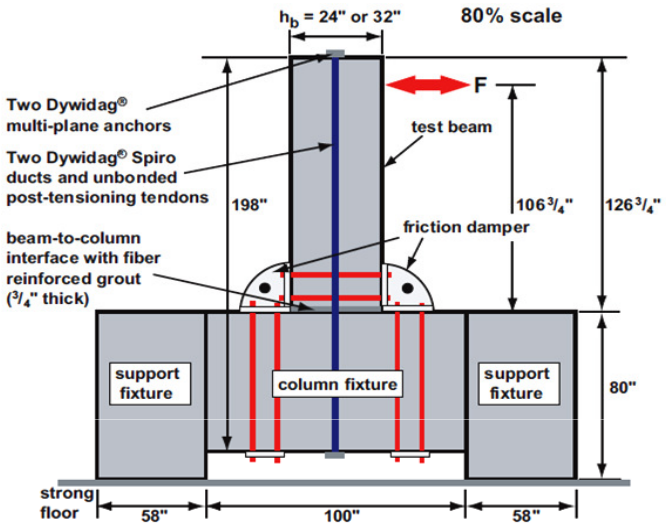


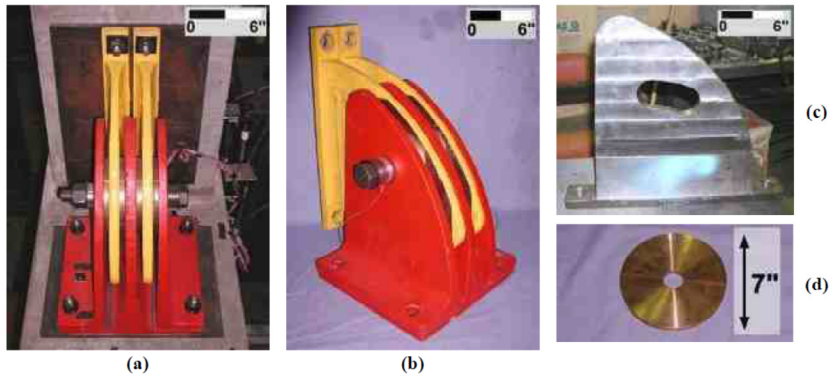
Fig. 7 Beam moment-story drift ratio relationship for PC1-T

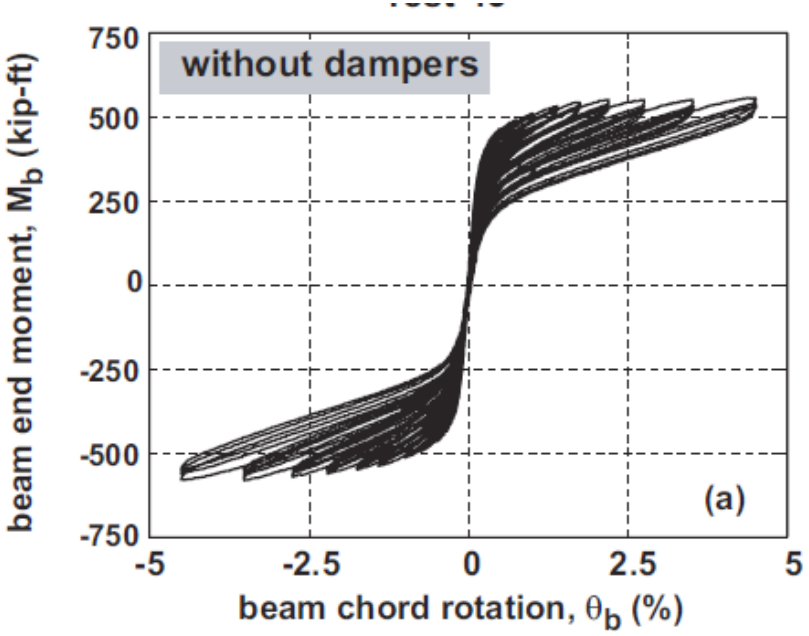
Brian *et al.* (2004) developed a friction damper for post-tensioned precast concrete beam-to-column joints. This dampers are placed at the connection region through which the energy dissipation during earthquake will take place

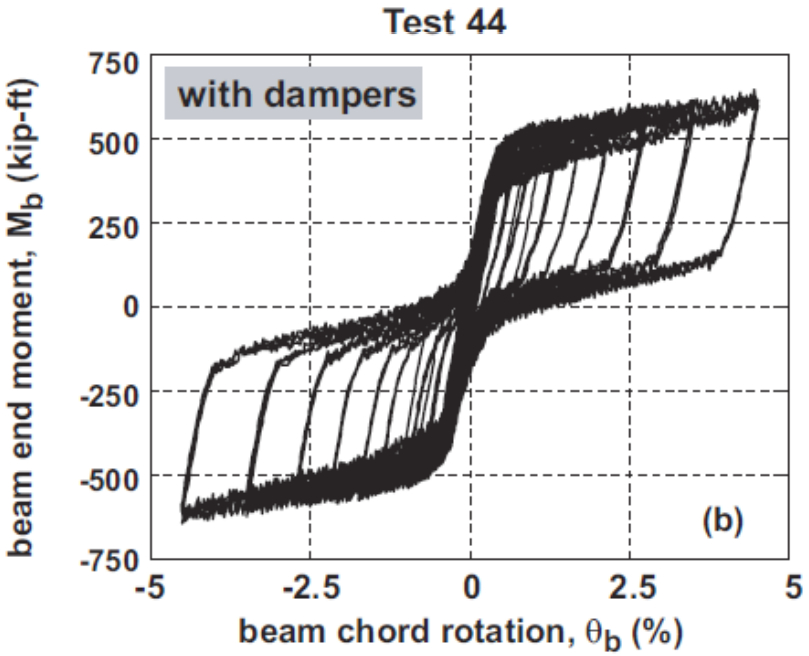




Pre-cast frame with proposed dampers and the detailed configuration







Hysteretic test results and conclusions

In terms of beam-column subassembly behavior:

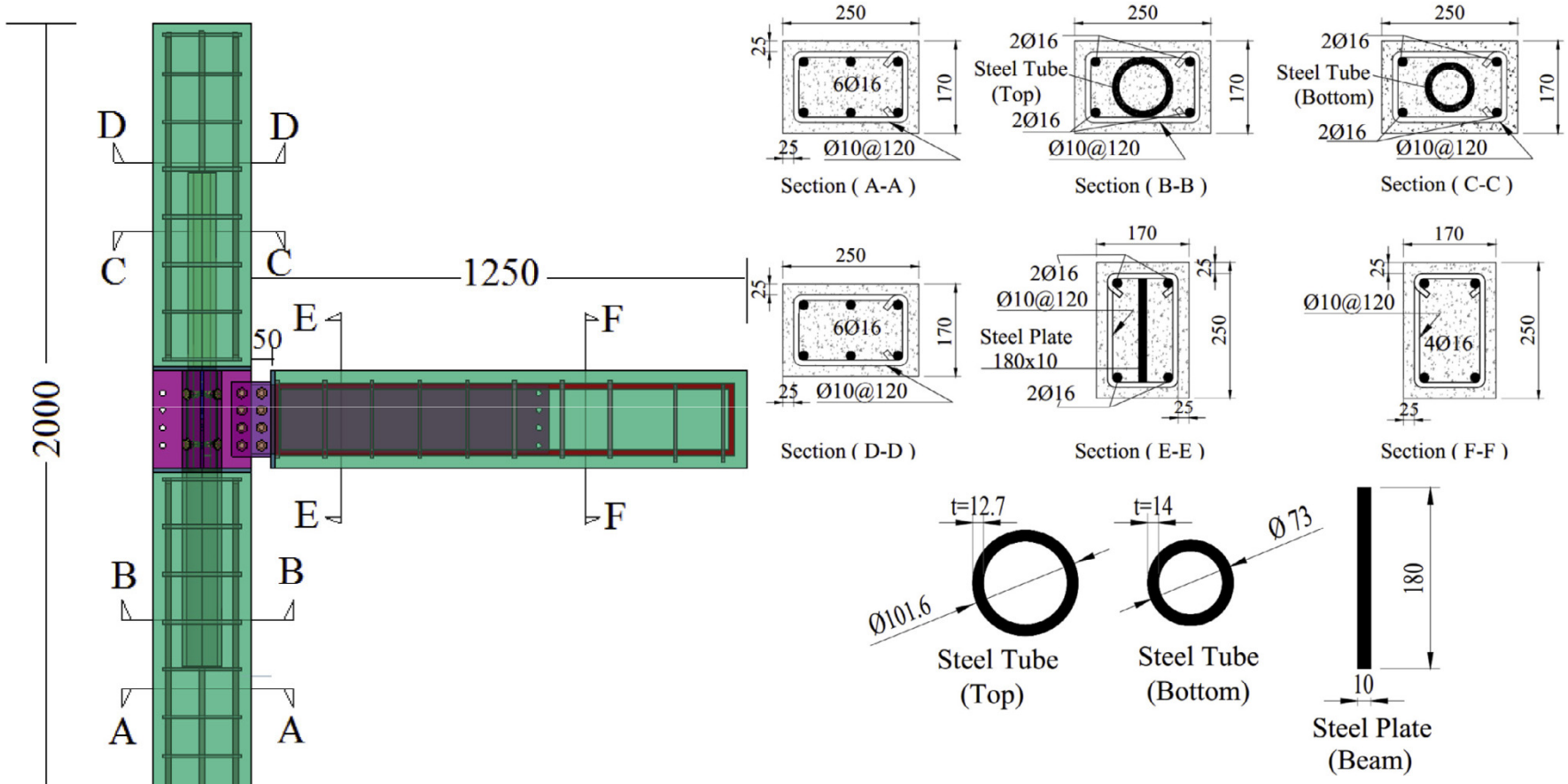
I. Dampers transfers the shear forces at the beam-to-column interfaces;

II. Smaller depth beams with dampers can have the same resistance as larger depth beams without dampers;

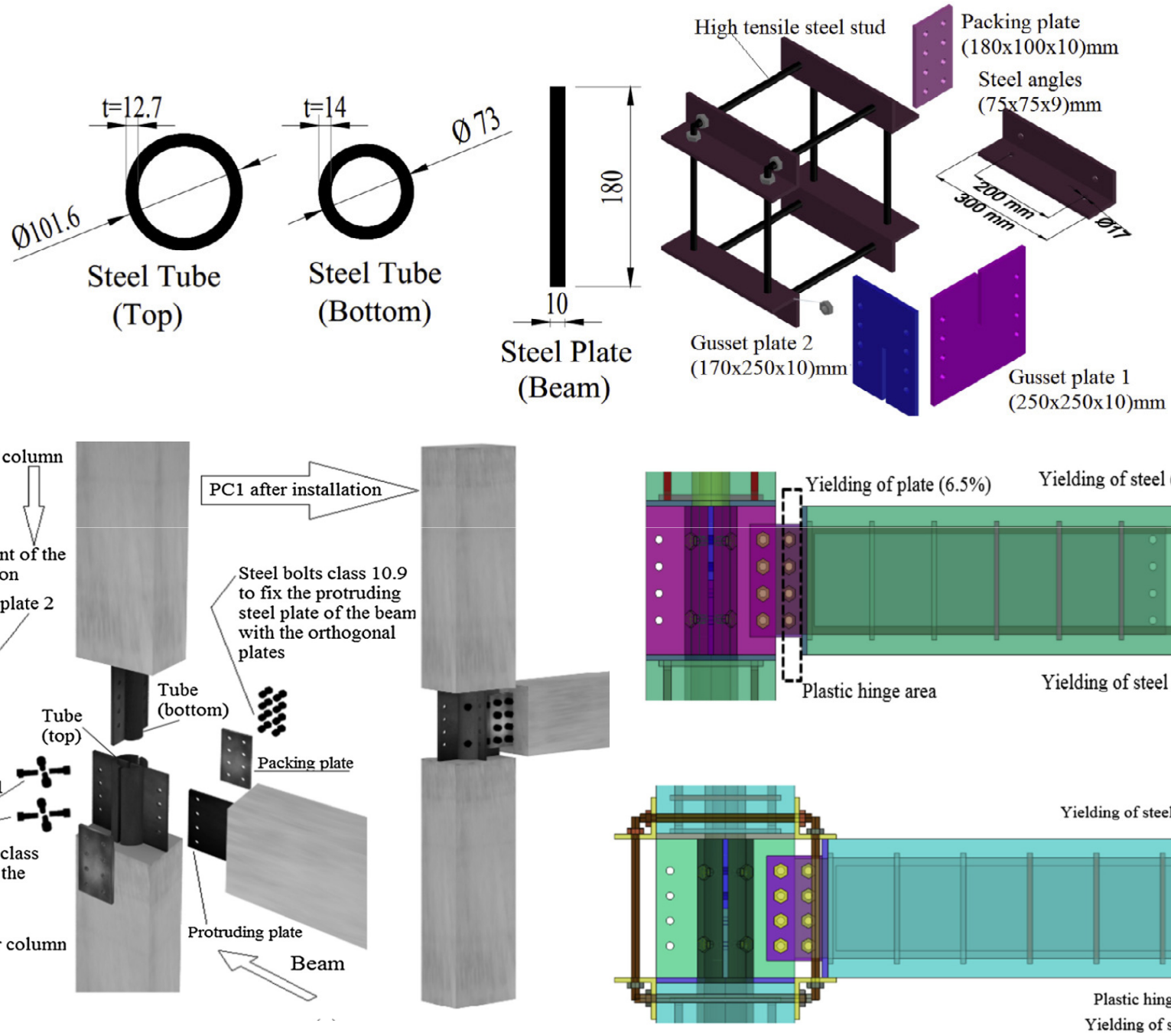
III. Dampers increases the energy dissipation;

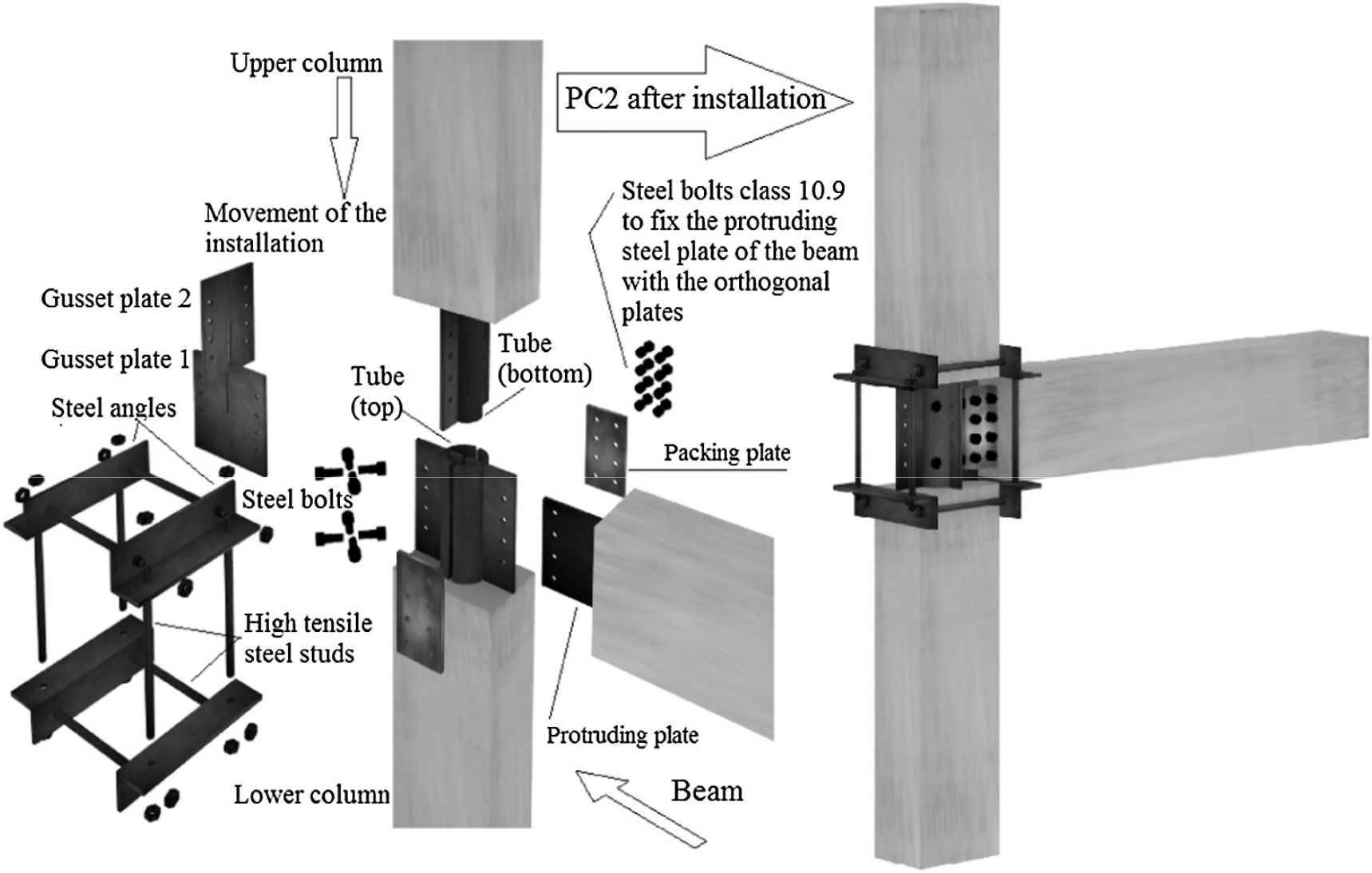
IV. Damper connection plates act to confine the concrete and significantly reduces the deterioration at the beam ends.

Haider*et al*.(2017) developed a hybrid precast concrete beam-to-column connections using encased steel section under cyclic loading. Figure shows the mechanism involved in this technique.

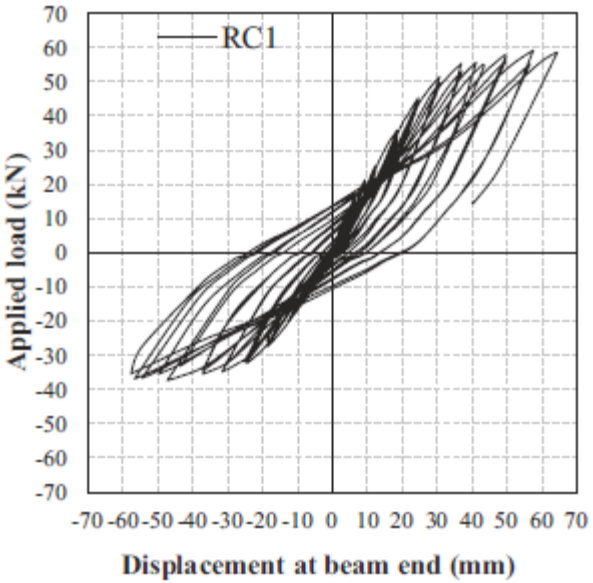


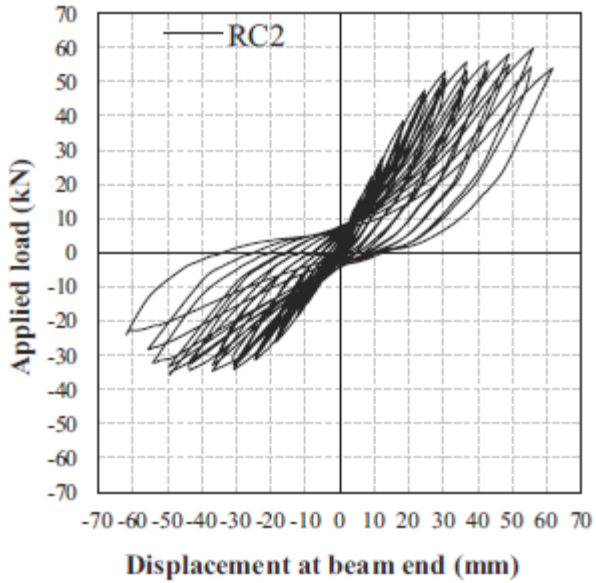
Precast beam-to-column connections using encased steel section

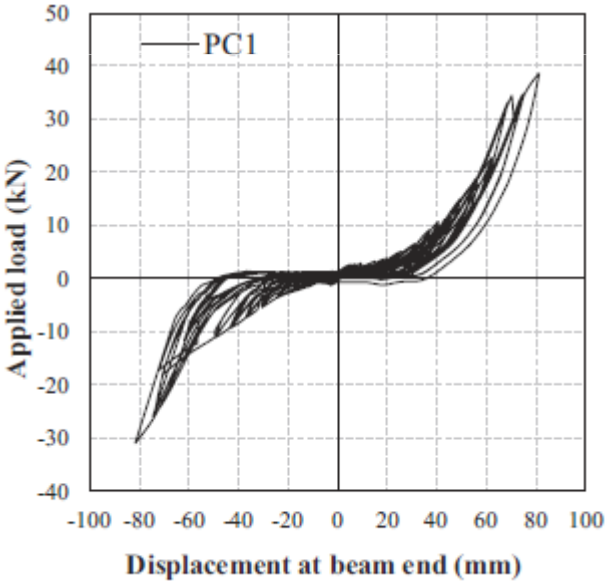

t=12.7
t=14
Ø 73
Ø101.6
Steel Tube
(Top)
Steel Tube
(Bottom)
180
10
Steel Plate
(Beam)
High tensile steel stud
Packing plate
(180x100x10)mm
Steel angles
(75x75x9)mm
200 mm
300 mm
Ø17
Gusset plate 2
(170x250x10)mm
Gusset plate 1
(250x250x10)mm
Upper column
Movement of the
installation
Gusset plate 2
PC1 after installation
Steel bolts class 10.9
to fix the protruding
steel plate of the beam
with the orthogonal
plates
Tube
(bottom)
Tube
(top)
Packing plate
Gusset plate 1
Steel bolts class
10.9 to fix the
steel tubes
Lower column
Protruding plate
Beam
Yielding of plate (6.5%)
Yielding of steel (5.5 %)
Plastic hinge area
Yielding of steel (5.5 %)
Yielding of steel (7.0 %)
Plastic hinge area
Yielding of steel (7.0 %)

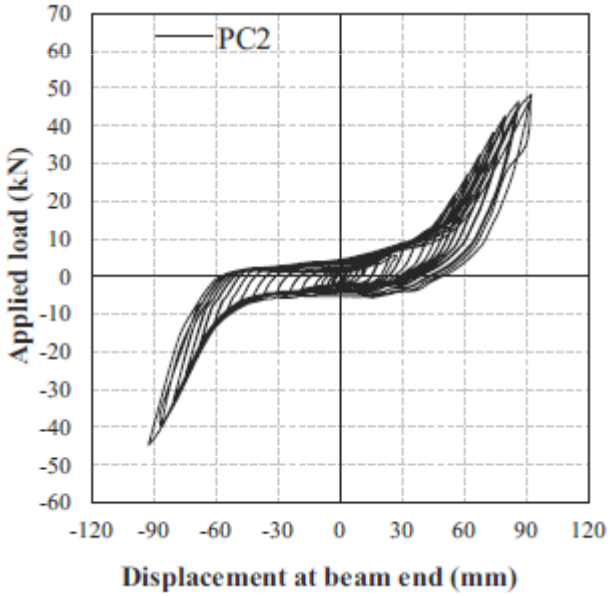


Precast beam-to-column connections using encased steel section external holding connection





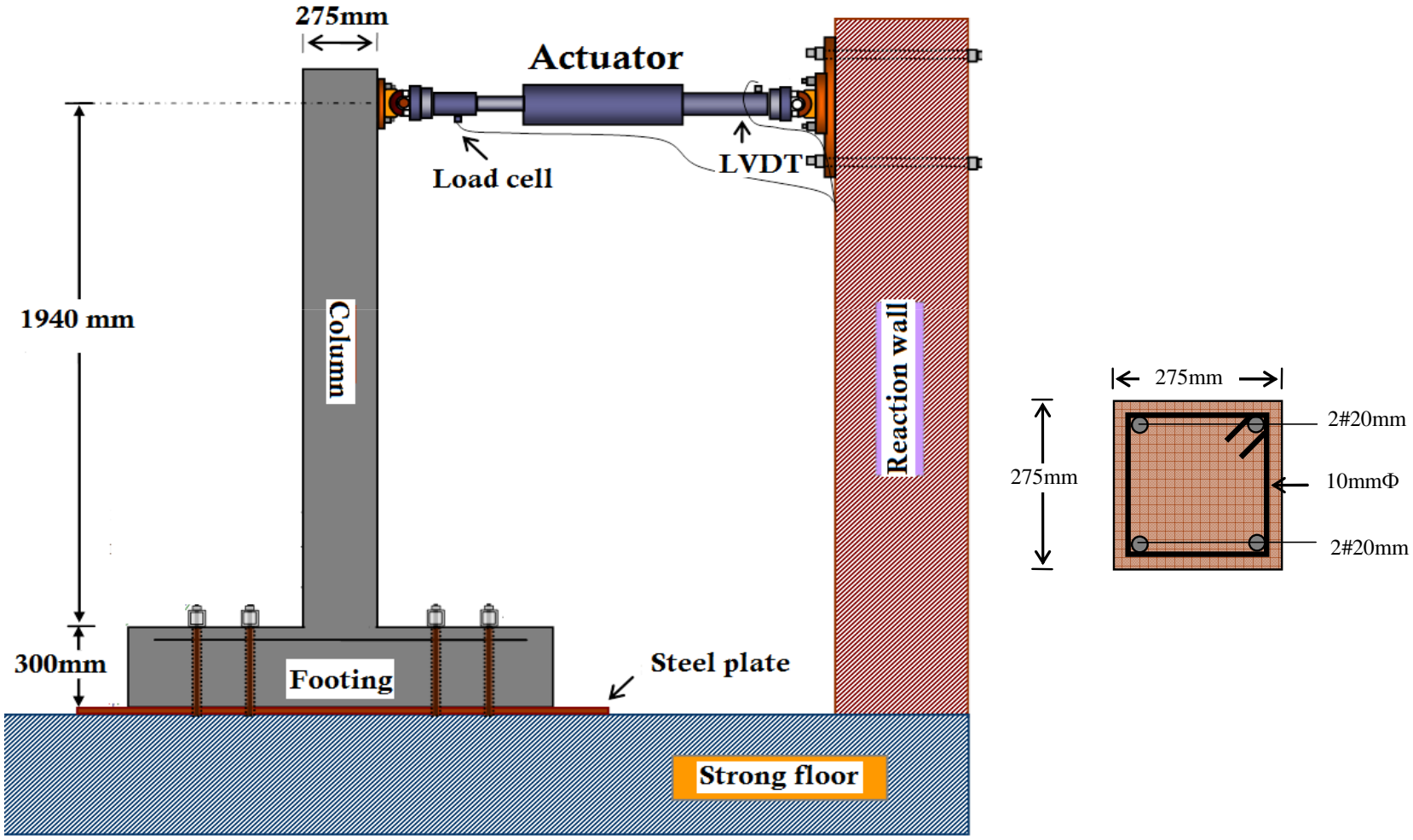




Hysteretic behavior of Precast beam-to-column connections using encased steel section

Cyclic Testing of Column to Foundation with Rebar Coupler – An Experimental Case Study

Detailed configuration of column with foundation

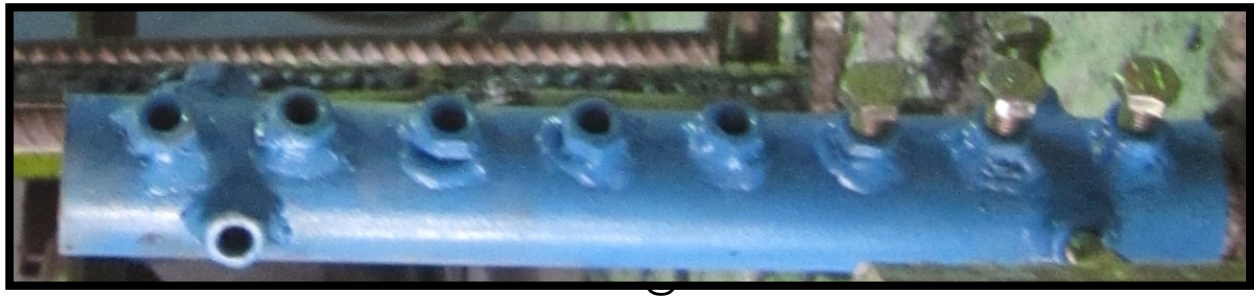


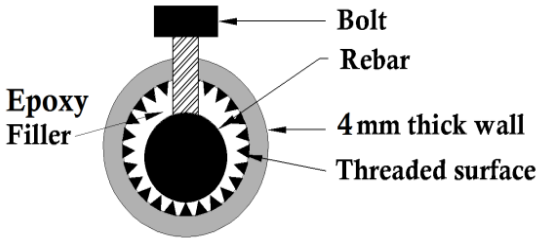
Properties of Coupler

Length : 120 mm
Diameter : Outer - 34 mm Inner – 26 mm
Wall thickness : 4 mm

Two 20mm bar was connected using coupler with 120mm length & 4 bolts and tested under tension to evaluate its tensile strength.

The observed tensile strength : 382 Mpa
Failure Mode : Reinforcement Slip
In retrofitting, Threaded Coupler with 240mm length & 8 bolts was used.





Coupler-cross section

Retrofitting Methodology

Column Removed from Foundation

Column with extended Rebar

Column fixing with Foundation

Coupler fixed with the foundation rebar

Column and Foundation rebar connected

Epoxy filling

Connected foundation and column with confinement

Column Connected with Foundation

Concreting Methodology

In order to address the bonding between old and fresh concrete EPOXY Coating was used

To create proper contact between the top portion of column with bottom portion, Letter Box Shuttering used for concreting

Old Concrete Surface

Epoxy Coated Concrete Surface

Letter Box Shuttering

FRP Wrapping

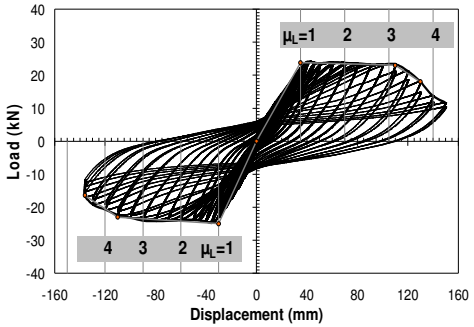
Surface Treatment

Epoxy application
&
CFRP Wrapping

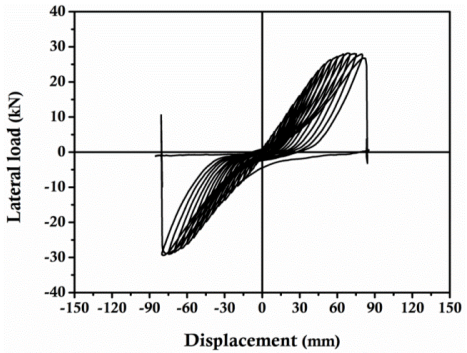
Strengthened
Column

Test Results

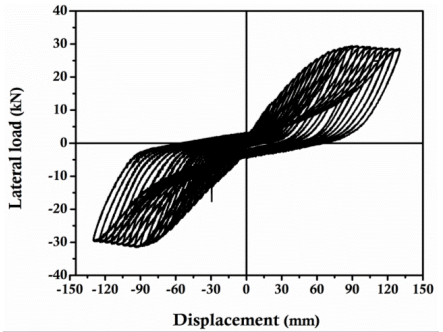
Cyclic Testing In Quasi Static Lab using Actuator



Mono-Conventional specimens

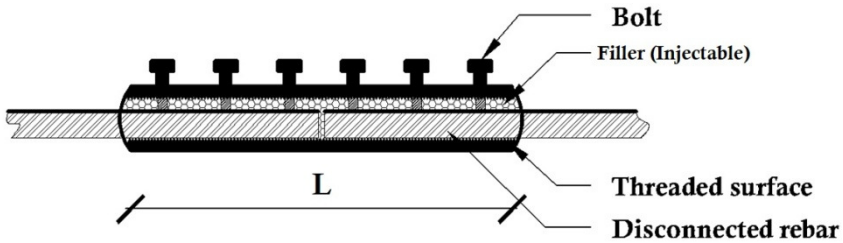


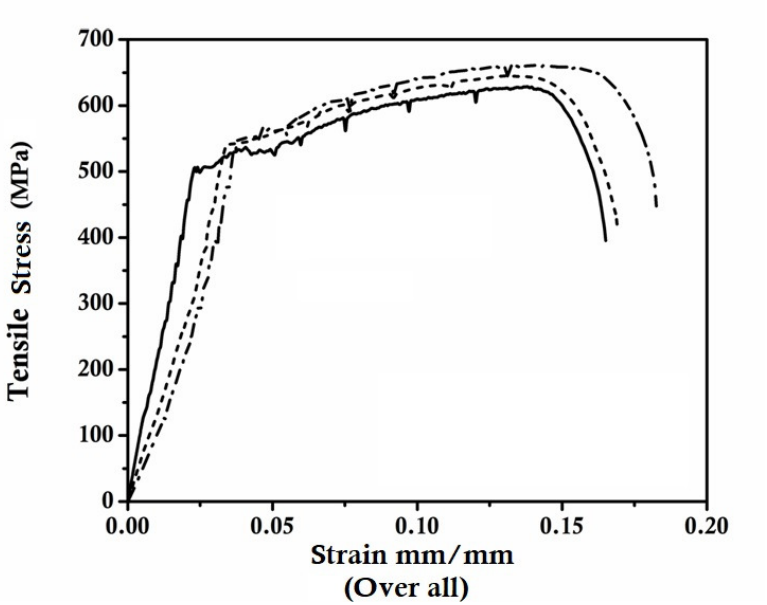
Coupler



Coupler + CFRP

An effective rebar coupler developed @ CSIR-CBRI





Neck Formation in Rebar

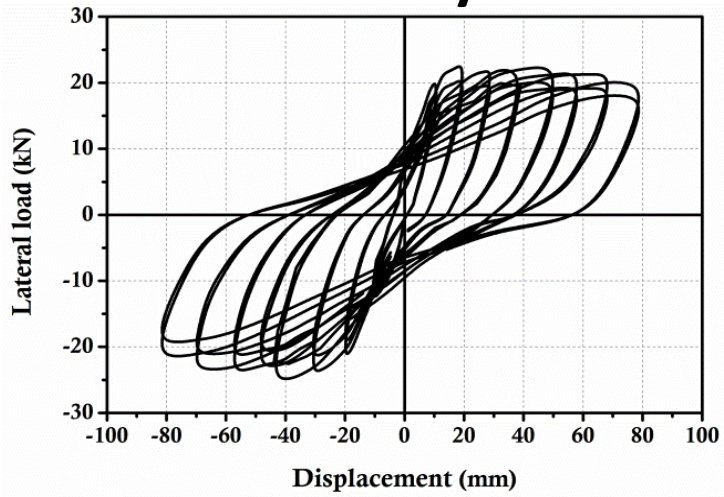
Neck Formation in Rebar connected using Coupler

It can be used to connect any critical element at any critical location of RC frame.

Also it can be used to connect Old to Old and Old to New rebar connection

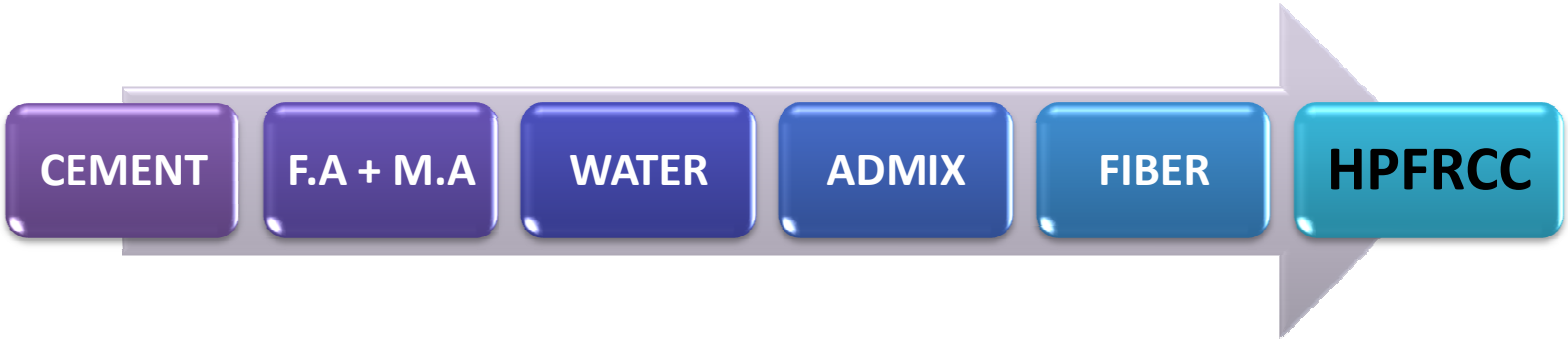
Post failure analysis

Rebar Coupler has been used in the plastic hinge region of the beam column joint and tested under cyclic loading till failure



Hysteretic Loop of Coupler enabled Joint specimen

Ductile Composites for Precast Connections



High Performance Fiber Reinforced Cementitious Composites (HPFRCC) become the alternative option for the replacement of conventional concrete with better strength and ductility.

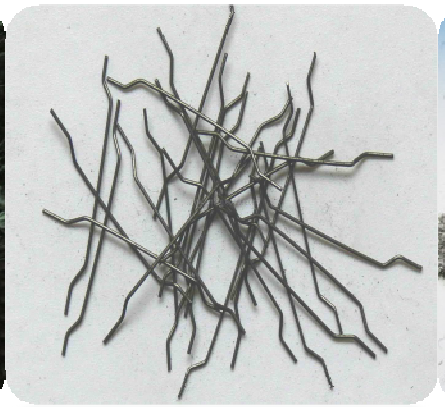
These HPFRCC were prepared using higher volume fibers without coarse aggregates, which provides strain hardening property and considerable amount of tensile strength/strain to the composites.

The application of HPFRCC on structural components eliminates the required special transverse reinforcement with higher energy dissipation .

Types of Composites Employed

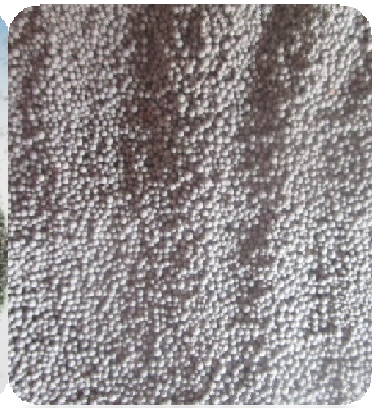
Composites	Fiber	
	Steel	P.P
Conv.	-	-
SFRC	2%	-
ECC	-	3%
SIFCON	8%	-

Polypropylene Fiber



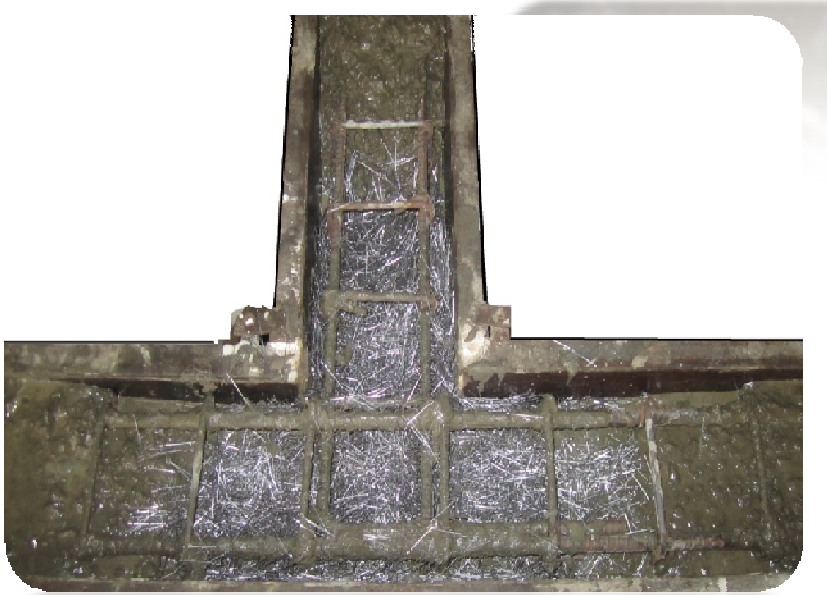
Hooked end Steel Fiber

Steel wool



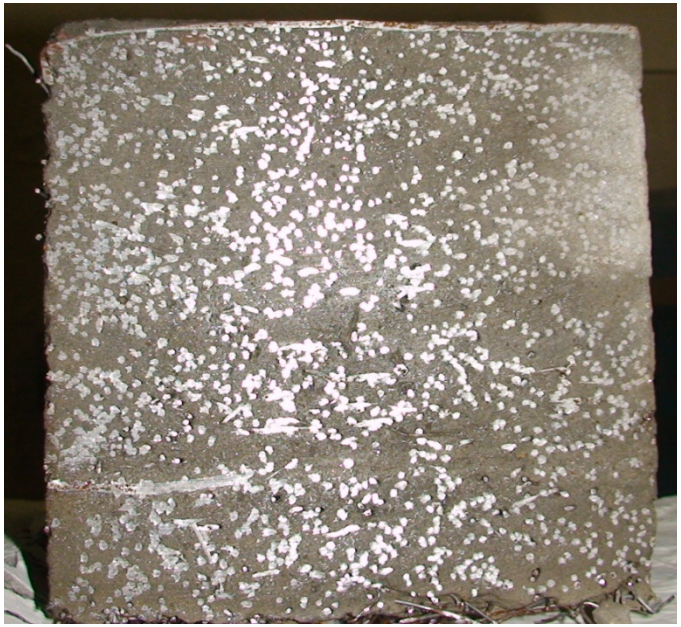
Silica fume

Casting Procedure



SIFCON

ECC

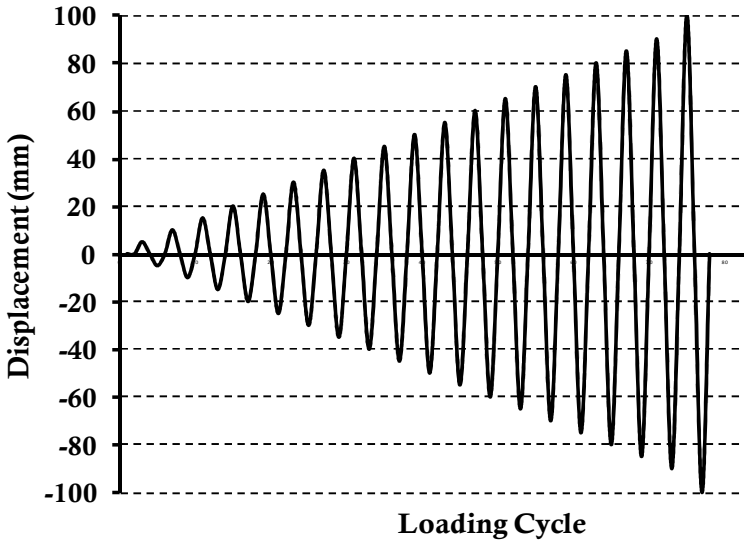


SIFCON Cube (Core sample from Beam)

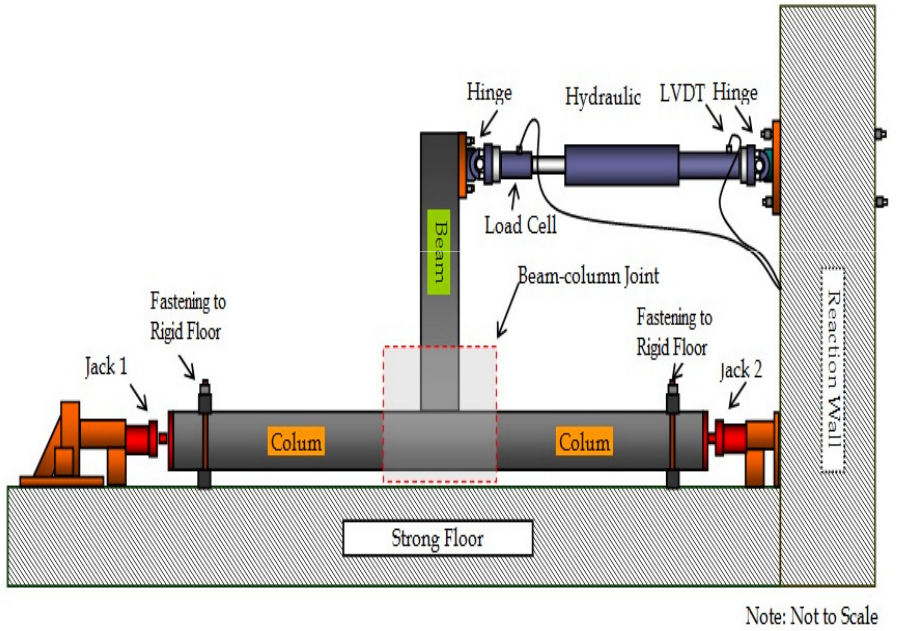
SIFCON Cube before and after failure

Testing Procedure

All specimens are tested under displacement control cyclic loading

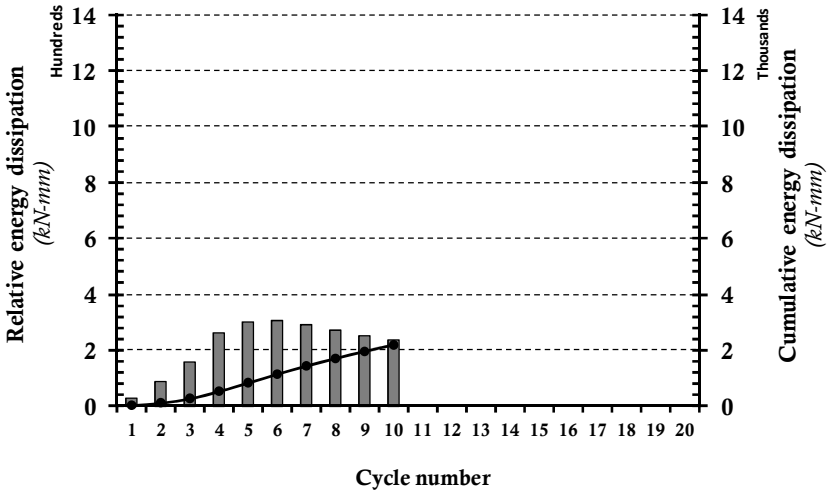


Sinusoidal loading with 5mm increment

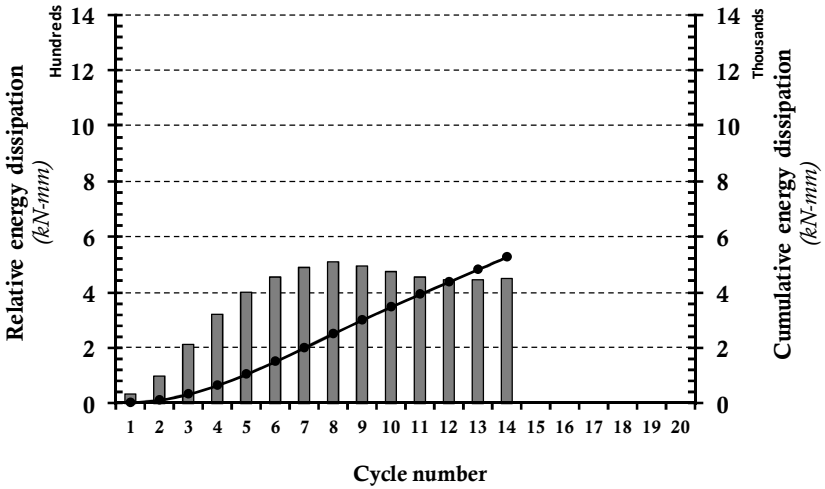


Test setup

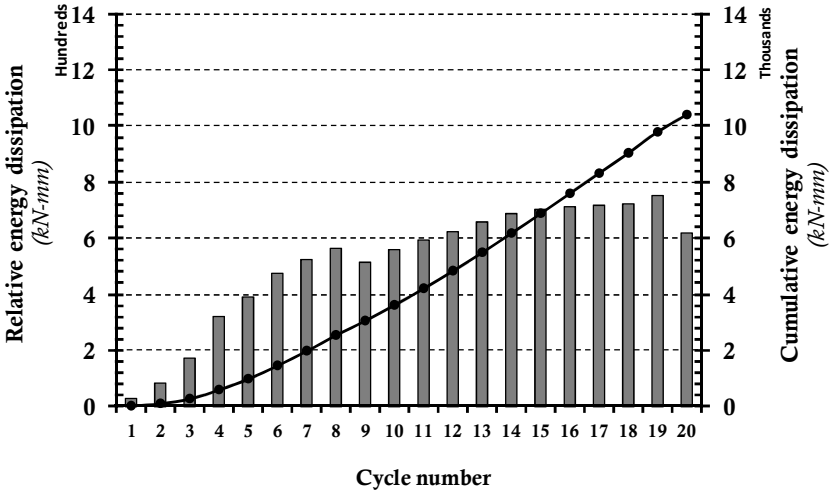
Energy Dissipation



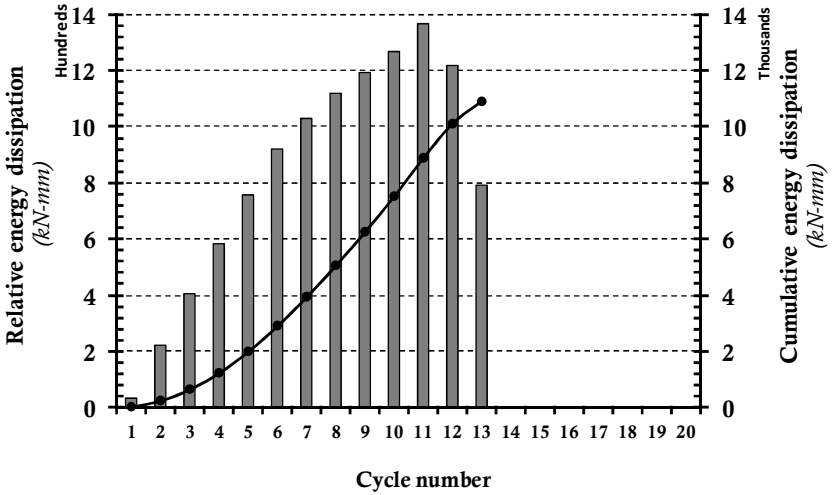
Conventional



SFRC



ECC



SIFCON

Thanks

Dr. K.R.S