Experimental Response and FRC Strengthening of Existing RC Members

Brian Stratman – Business Development Leader **- MAPEI**
Giulio Morandini, Alberto Balsamo, Ciro Del Vecchio, Marco Di Ludovico, Andrea Prota

MAPEI
Milano, Italy

University of Naples "Federico II"
Dept. of Structures for Engineering and Architecture

INTRODUCTION

Recent seismic events outlined the main structural weaknesses of existing RC buildings:

- **Brittle failure** of structural members due to lack of proper seismic details

- **Joint panel shear failure** due to the lack of stirrups in the joint panel

- **Buckling of longitudinal reinforcement** due to the high spacing of stirrups (200-300 mm)

OBJECTIVES

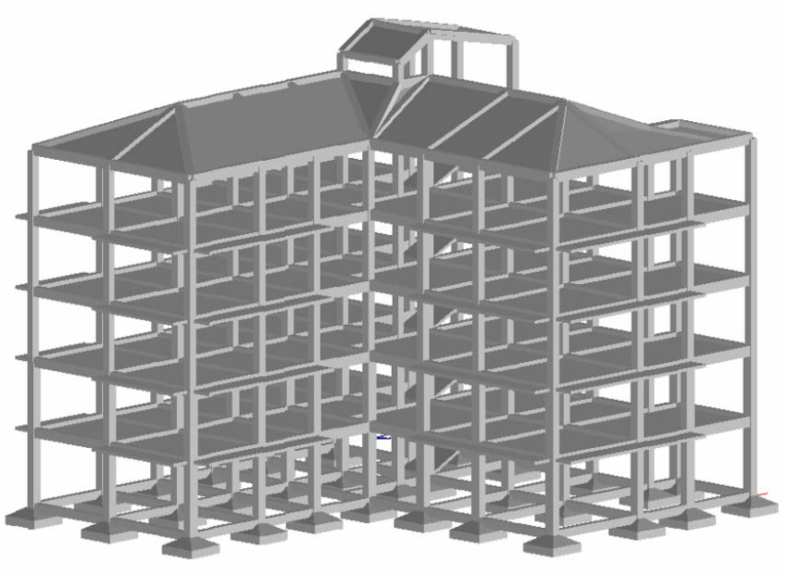
- Sampling of the specimens from **real building damaged by the L' Aquila 2009 earthquake** and demolished

- Identify the **main structural weaknesses** of the case study building via experimental tests

- Design and testing of a proper seismic retrofit solution (HPC material) for **shear strengthening of beam-column joints**

- Design and testing of a proper retrofit solution (HPC material) to improve the **confinement of columns**

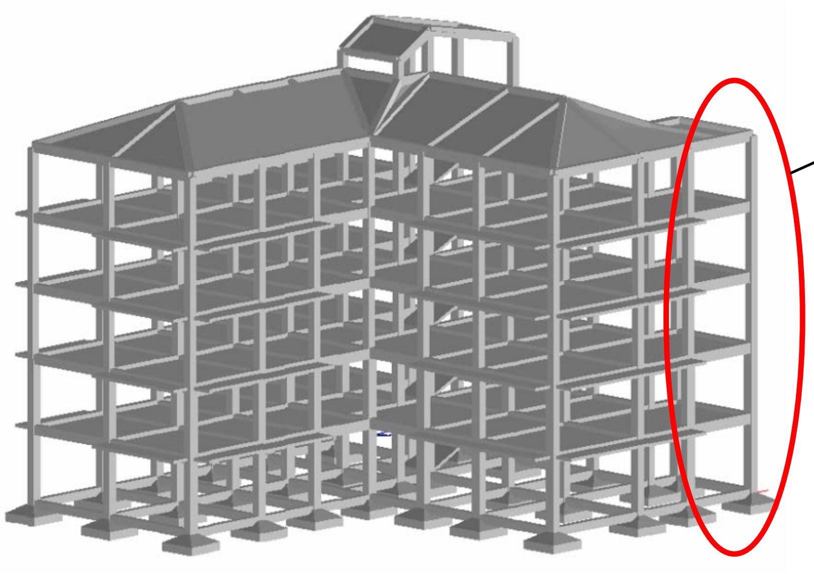
CASE STUDY BUILDING



Case Study 5 storey RC building built in 1963

severely damaged by the L'Aquila earthquake (2009)

BUILDING DEMOLITION

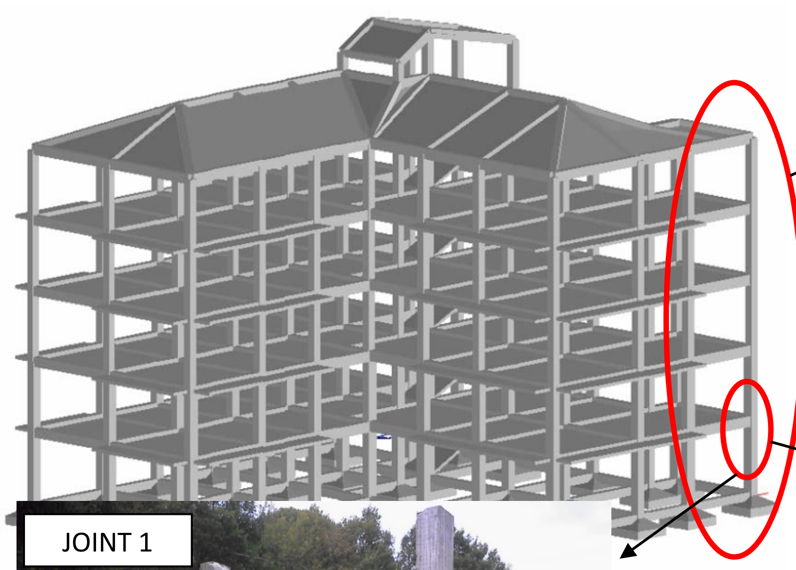


Perimetral frame with corner joints

The building was demolished due to:

- Economic inconvenience of structural retrofitting (after a detailed seimic assessment)
- Poor-quality concrete (fc < 8 MPa in some portion of the building)

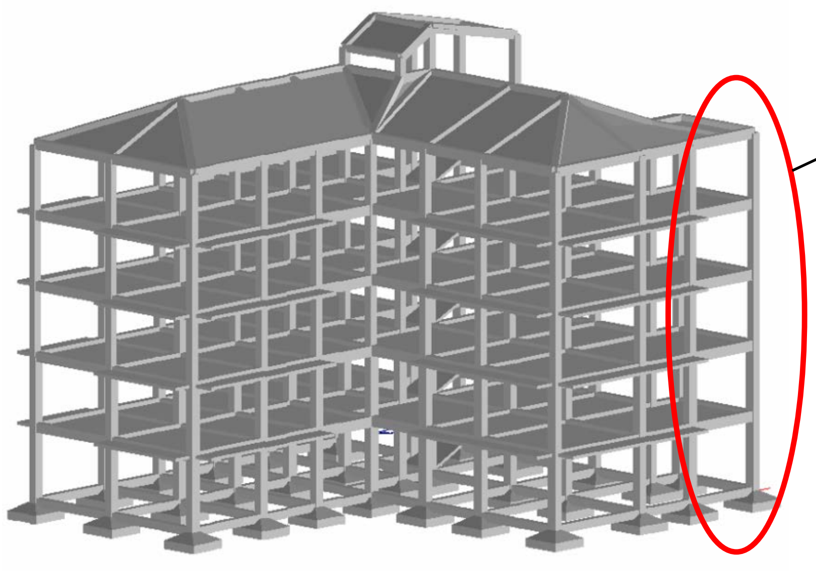
SPECIMEN SAMPLING



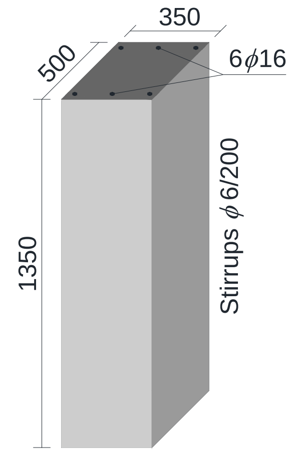
Perimetral frame with corner joints

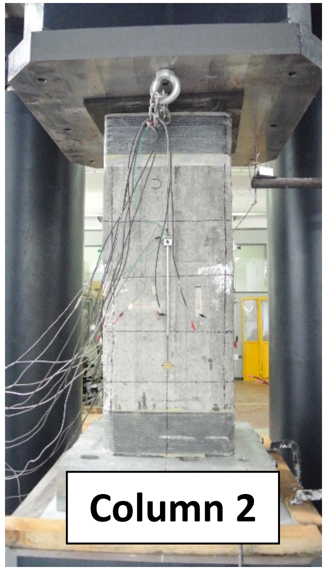
Two beam column joints were extracted at the first floor

SPECIMEN SAMPLING



Two Columns were extracted at the second floor of the same frame





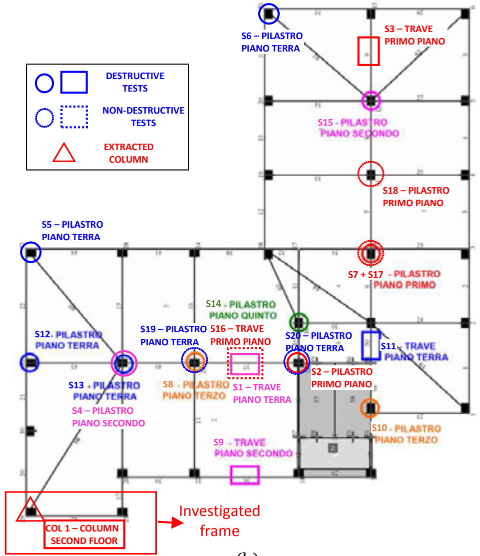
MATERIAL PROPERTIES

Destructive and non-destructive material characterization tests were conducted on the entire building and on the extracted portions

Reinforcing steel

	diameter [mm]	f_y [MPa]	ε_{sy} [mm/mm]	E_s [MPa]	ε_{sh} [mm/mm]	f_u [MPa]	ε_{su} [mm/mm]
Longit. reinforc.	16	400.4	0.0020	203579	0.020	586.6	0.128
	16	395.4	0.0022	178424	0.021	587.6	0.137
	16	374.1	0.0019	196000	0.024	548.3	0.135
	Mean (16)	**390.0**	**0.0020**	**192667**	**0.022**	**574.2**	**0.133**
	12	360.4	0.0019	192217	0.024	504.4	0.236
	12	357.5	0.0020	181415	0.022	501.9	0.148
	12	362.5	0.0024	149463	0.014	506.3	0.010
	14	364.2	0.0021	171254	0.019	526.2	0.213
	Mean (12/14)	**361.1**	**0.0021**	**173587**	**0.020**	**509.7**	**0.152**
Stirrups	6	447.0	0.0025	181691	0.016	574.0	0.070
	6	433.2	0.0027	160459	0.013	548.0	0.060
	6	392.0	0.0018	213043	0.011	550.0	0.150
	6	400.0	0.0026	153846	0.010	549.0	0.110
	Mean (6)	**418.1**	**0.0024**	**177260**	**0.013**	**555.3**	**0.098**

smooth internal reinforcements

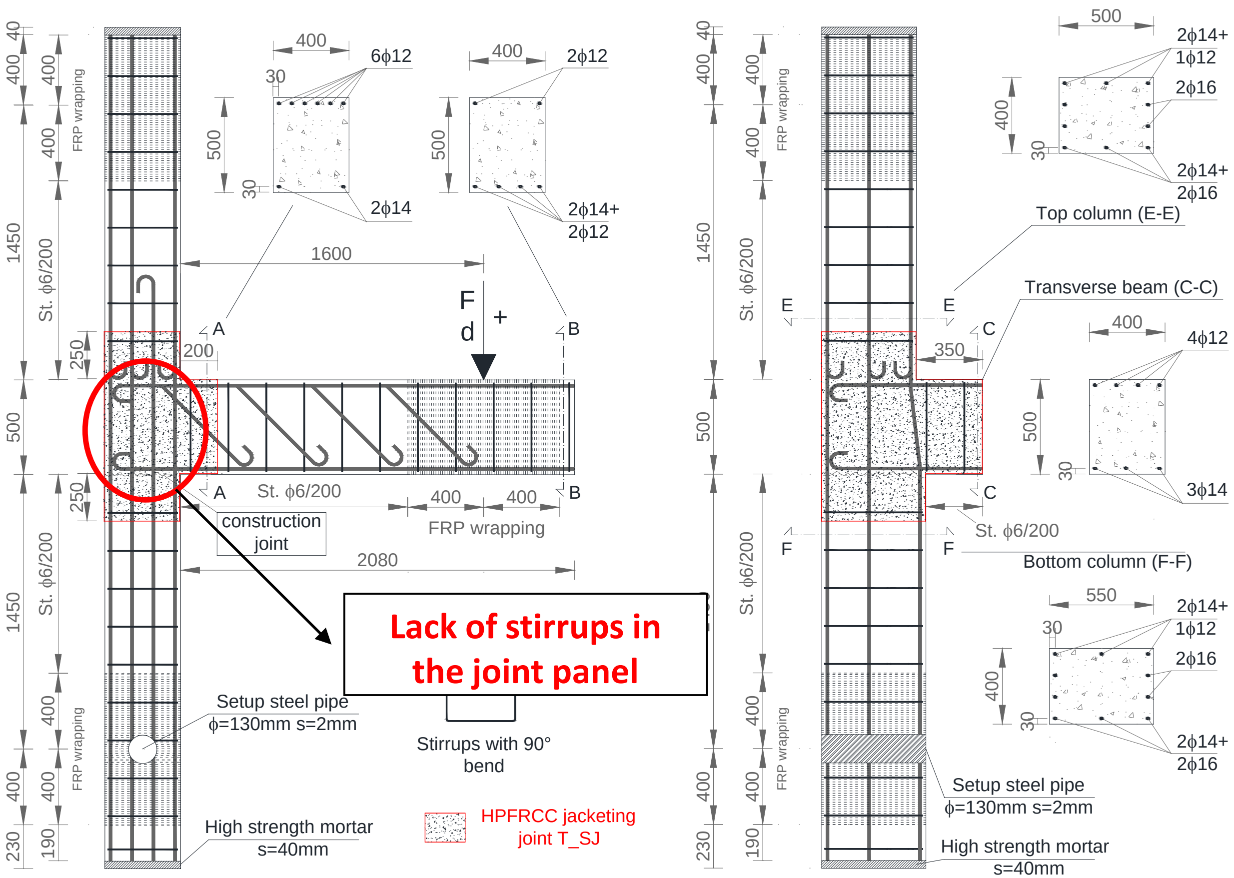


(b)

Concrete

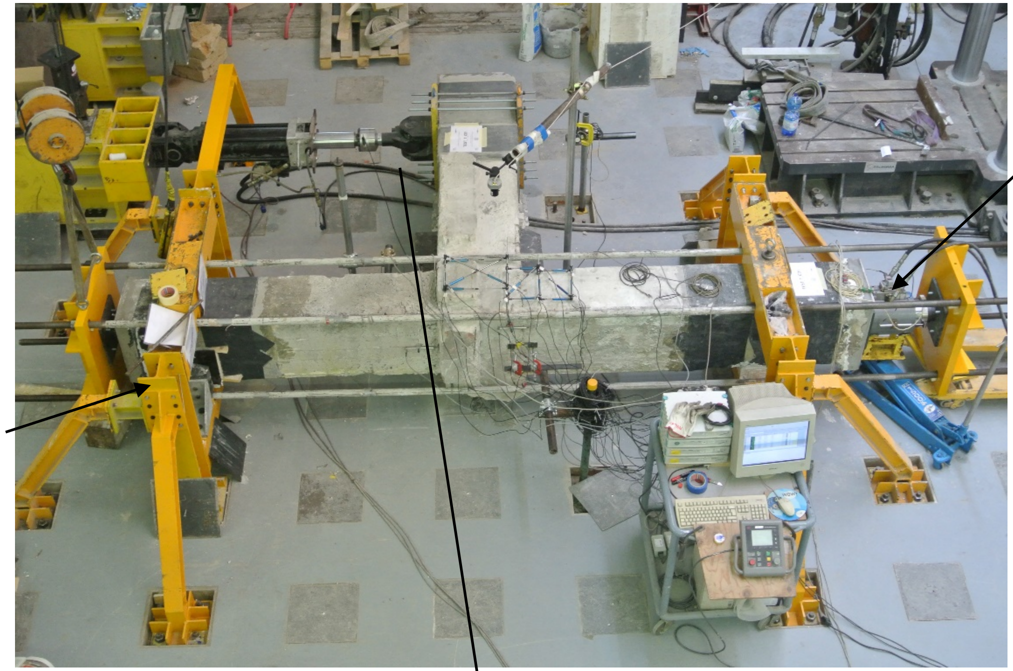
f_c =12 MPa

STRUCTURAL DETAILS



- Smooth internal reinforcements
- Lack of transverse reinforcements (ϕ6 /200mm)
- No stirrups in the joint panel
- Bad quality construction joint

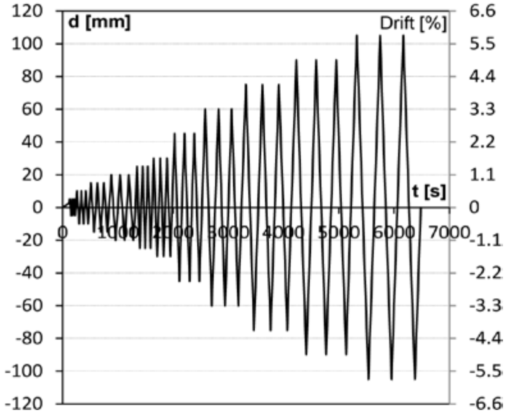
TEST SETUP

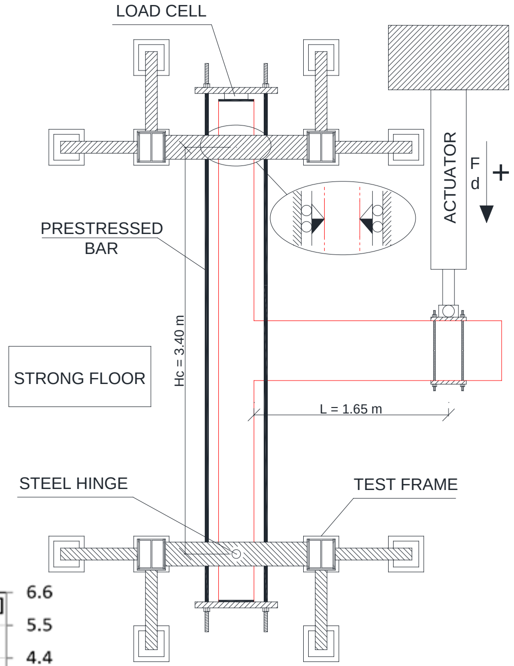


Stiff steel frames

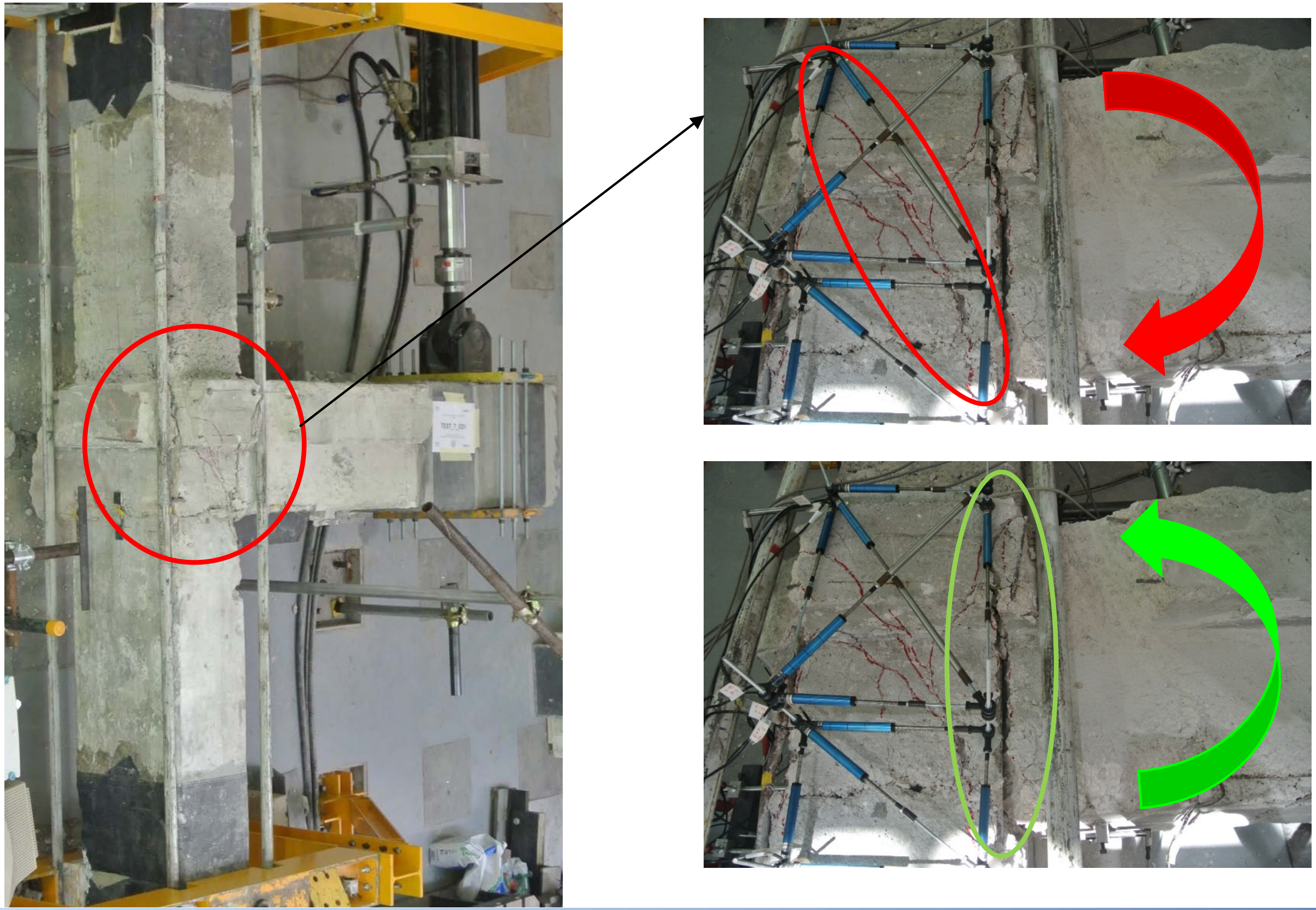
Constant axial load on the column

Cyclic displacement at the beam end





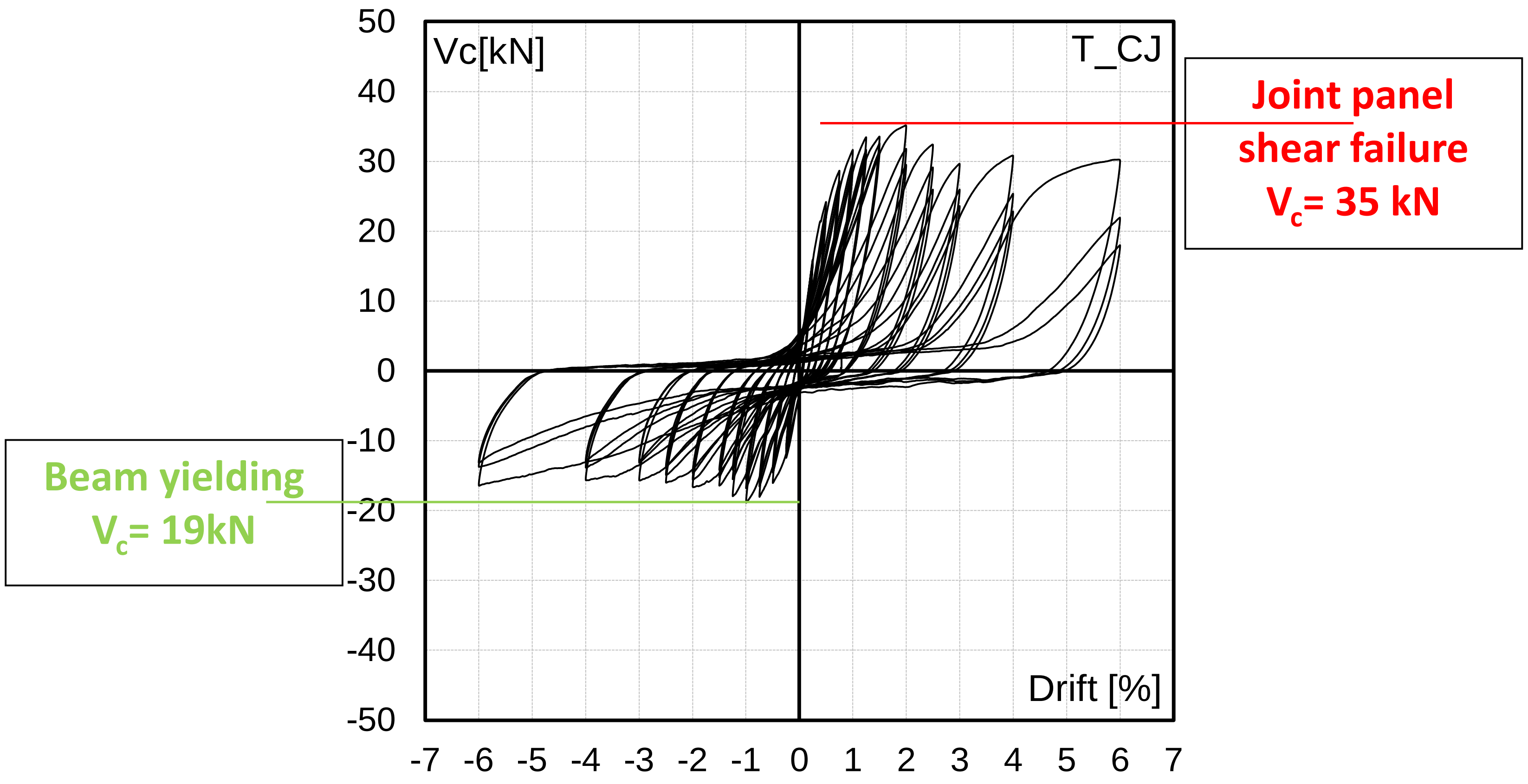
TEST RESULTS – AS-BUILT JOINT



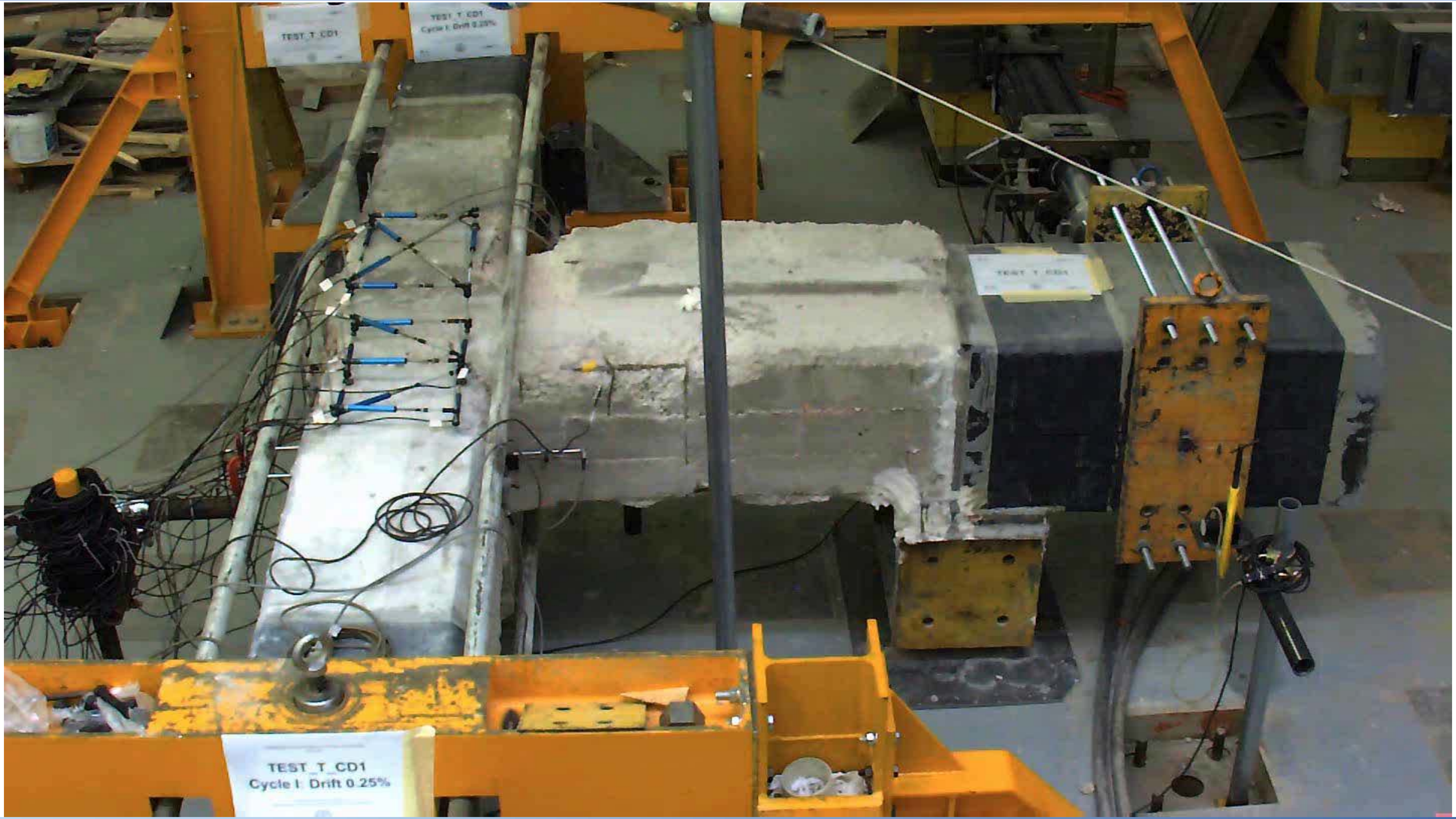
Poor seismic performance due to the joint panel shear failure (in the positive load direction)

Beam yielding (in the negative load direction)

TEST RESULTS – AS-BUILT JOINT



TEST RESULTS – AS-BUILT JOINT



TEST RESULTS – AS-BUILT JOINT

Close-up on the joint panel

HPC STRENGTHENING

Concrete cover removal (40 mm by using a jackhammer to have a rough surface)

Stiff and hydraulic sealed formwork

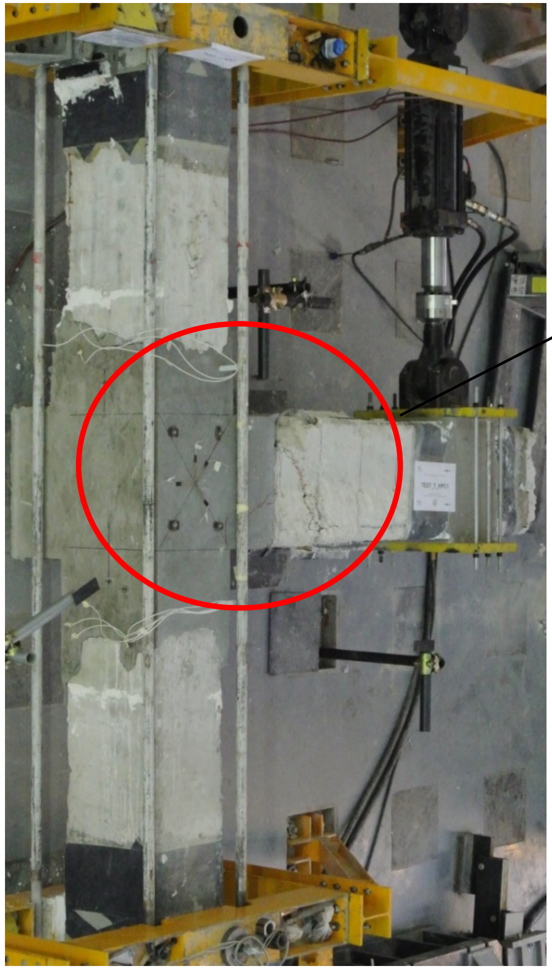
Anti-corrosion cementitious mortar

Cast of the HPC strengthening

HPC STRENGTHENING

View of the
strengthened specimen

TEST RESULTS- HPC JOINT

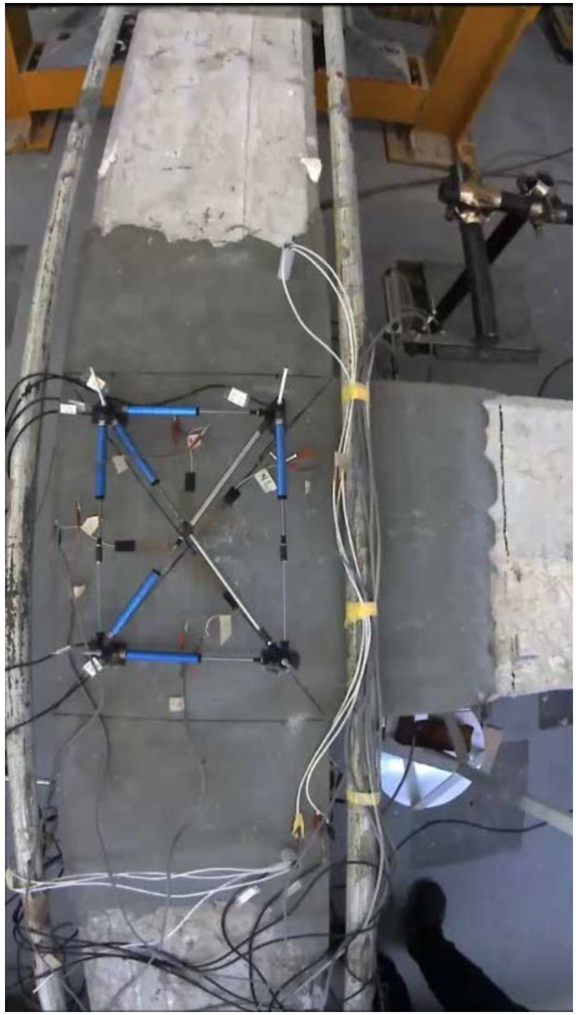


High effectiveness of the HPC strengthening which avoided the joint panel shear failure promoting a more ductile failure mode

Beam hinge in both the directions

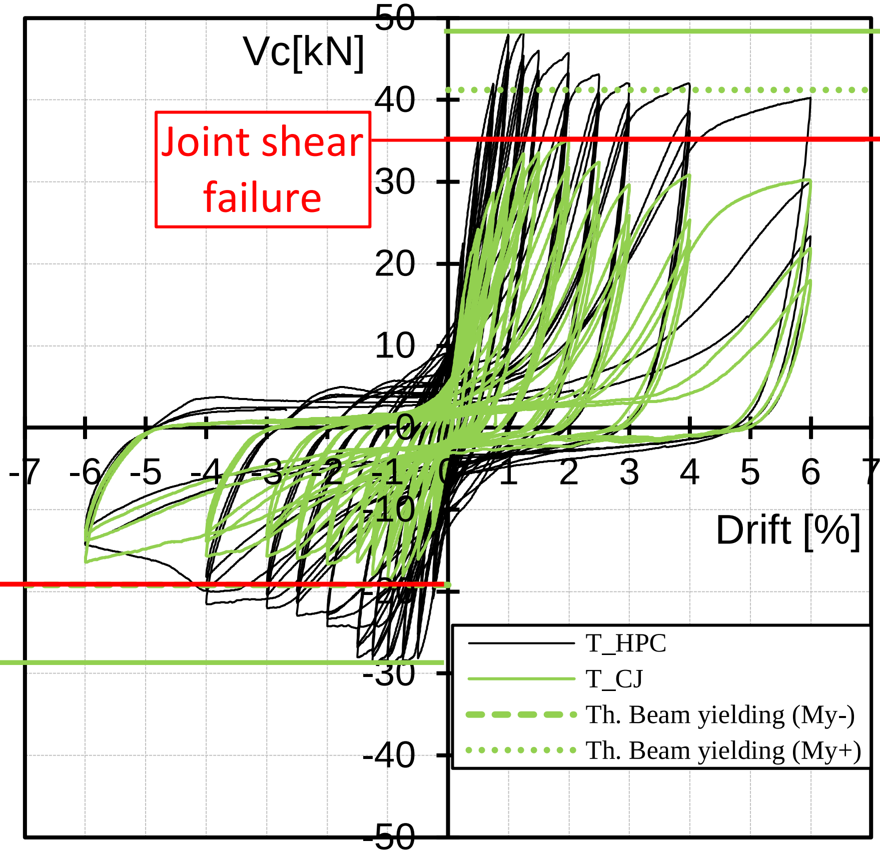
TEST RESULTS- HPC JOINT

TEST RESULTS- HPC JOINT



Close-up on the joint panel

COMPARISON



+85% Dissipated energy

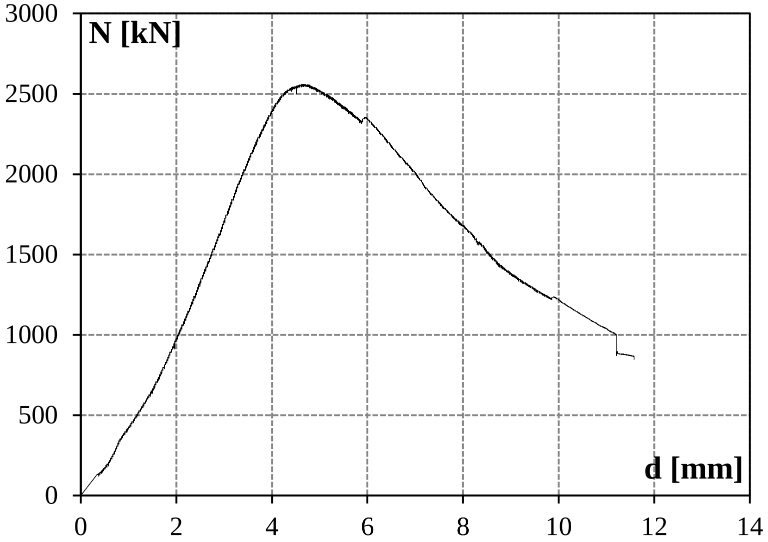
More details can be found in:

Del Vecchio C., Di Ludovico M., Balsamo A., Prota A. (2018) Seismic Retrofit of Real Beam-Column Joints Using Fiber-Reinforced Cement Composites. ASCE Journal of Structural Engineering. Vol. 144(5), https://doi.org/10.1061/(ASCE)ST.1943-541X.0001999

Experimental performances of sampled columns

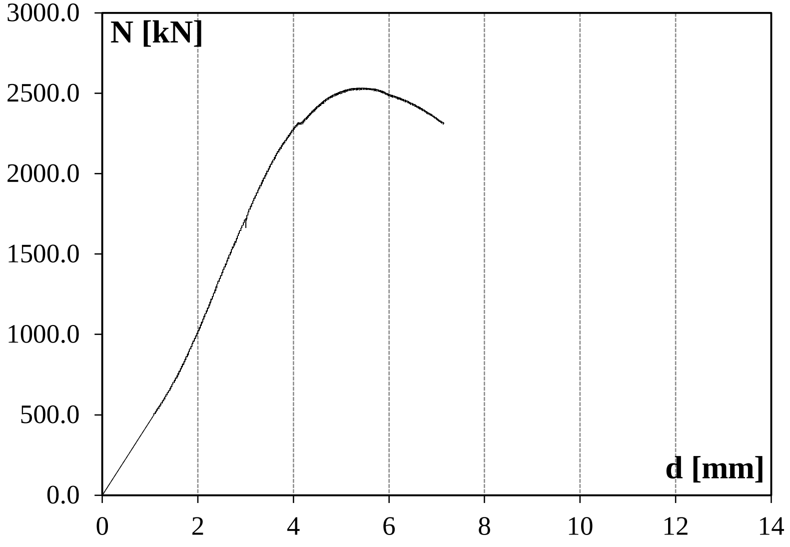
TEST RESULTS-AS-BUILT COLUMN

Mega testing machine (30.000 kN, 3000 tons axial capacity)



Concrete crushing and bar buckling limited the axial load capacity

PRE-DAMAGE ON COLUMN 2



Column 2 was pre-damaged until the spalling of concrete cover and then repaired and strengthened

HPC STRENGT. COLUMN 2

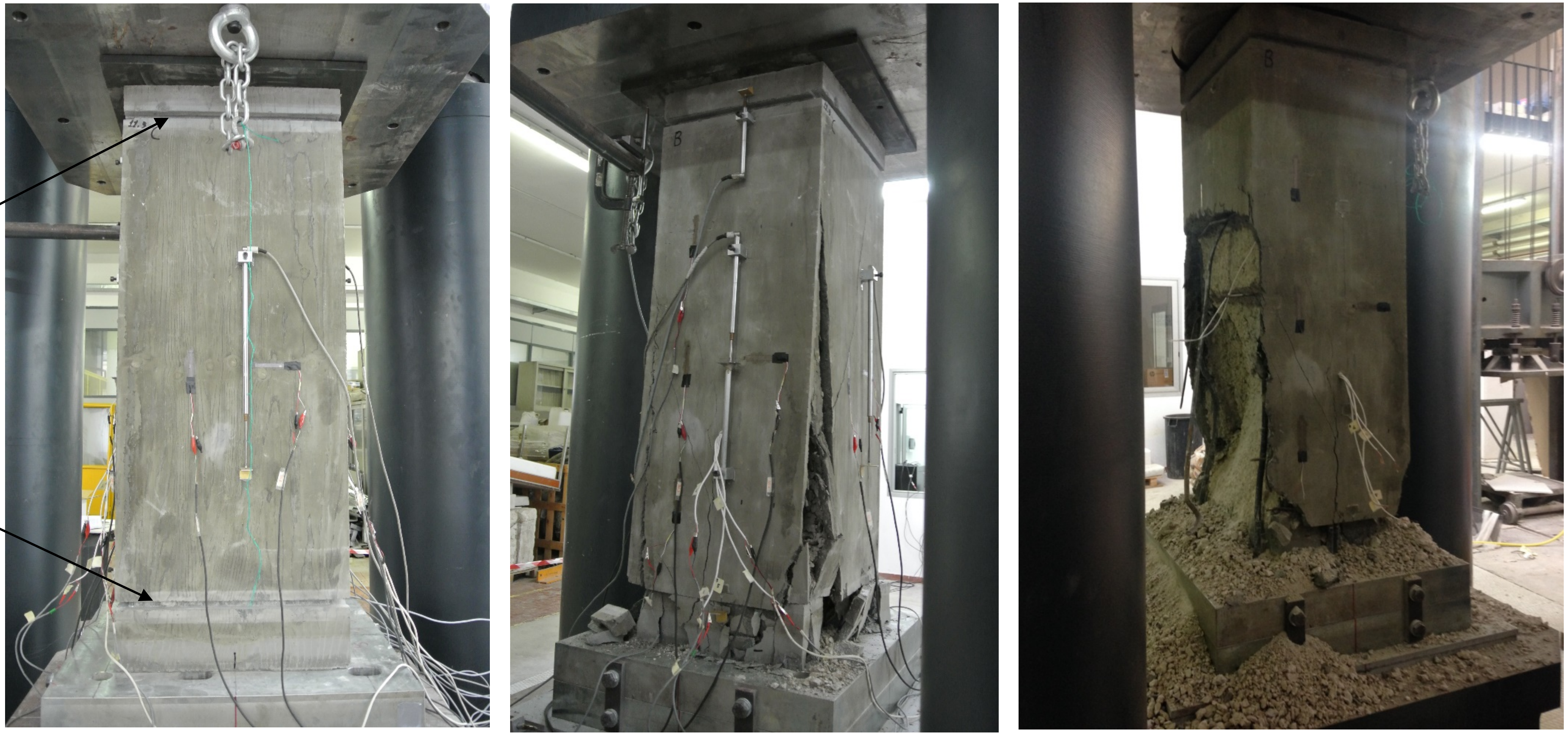
Concrete cover removal (by using a jackhammer to have a rough surface)

Stiff and hydraulic sealed formwork

Cast of the HPC strengthening

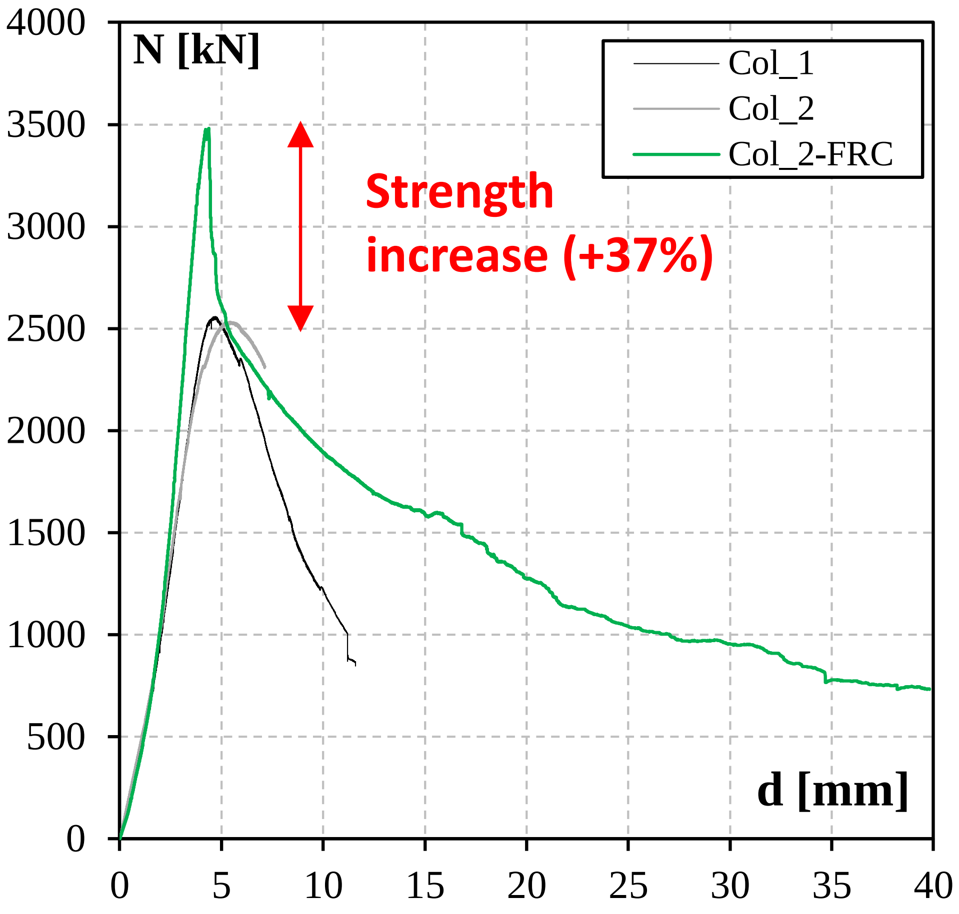
TEST RESULTS - HPC COLUMN

Cut of the HPC jacket before the test
(it is working only in confinement)



Experimental test demonstrated the high effectiveness of the HPC strengthening increasing the axial load capacity and delaying bar buckling

COMPARISON



The confinement by using the HPC strengthening increased the axial load capacity about the 37%

FINAL REMARKS

The experimental results can be summarized as follows:

- The **premature shear failure of poorly detailed beam-column joints** may significantly limit the seismic performance of existing buildings
- An **innovative strengthening solution consisting of a thin FRC jacketing** has been proposed and tested
- The experimental test outlined the **high effectiveness of the proposed strengthening solution** which changed the brittle failure mode in a ductile one (+38 to 54% strength increase, +85% energy dissipation)
- The same strengthening technique has been used also for **column confinement** with satisfactory results (+37% strength increase)

Thank you

Giulio Morandini, Alberto Balsamo, Ciro Del Vecchio,
Marco Di Ludovico, Andrea Prota

MorandiniG@mapei.it

MAPEI

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