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Seismic Retrofitting of RC Frames with RC Infilling

RC Infilling of Existing RC Structures for Seismic Retrofitting

C. Z. Chrysostomou, N. Kyriakides, P. Kotronis, P. Roussis, M. Poljansek, F. Taucer

SERIES Workshop: “Role of research infrastructures in seismic rehabilitation” 8 - 9 February 2012, Istanbul, Turkey

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Partners

Seismic Retrofitting of RC Frames with RC Infilling (SERFIN) Partners

- Cyprus University of Technology
  - C. Z. Chrysostomou (coordinator), N. Kyriakides
- University of Cyprus
  - P. Roussis
- University of Nantes, France
  - P. Kotronis
- DENCO, Greece
  - T. Panagiotakos, A. Kosmopoulos

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Acknowledgments

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- Artur Pinto, Georges Magonette, Francisco Javier Molina, Fabio Taucer, Martin Poljansek and all the personnel of the ELSA laboratory for their contribution in building and testing the structure

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Statement of the problem

- Large number of structures designed without seismic design provisions
- Multi-storey reinforced concrete buildings can be most effectively and economically retrofitted by the construction of new walls

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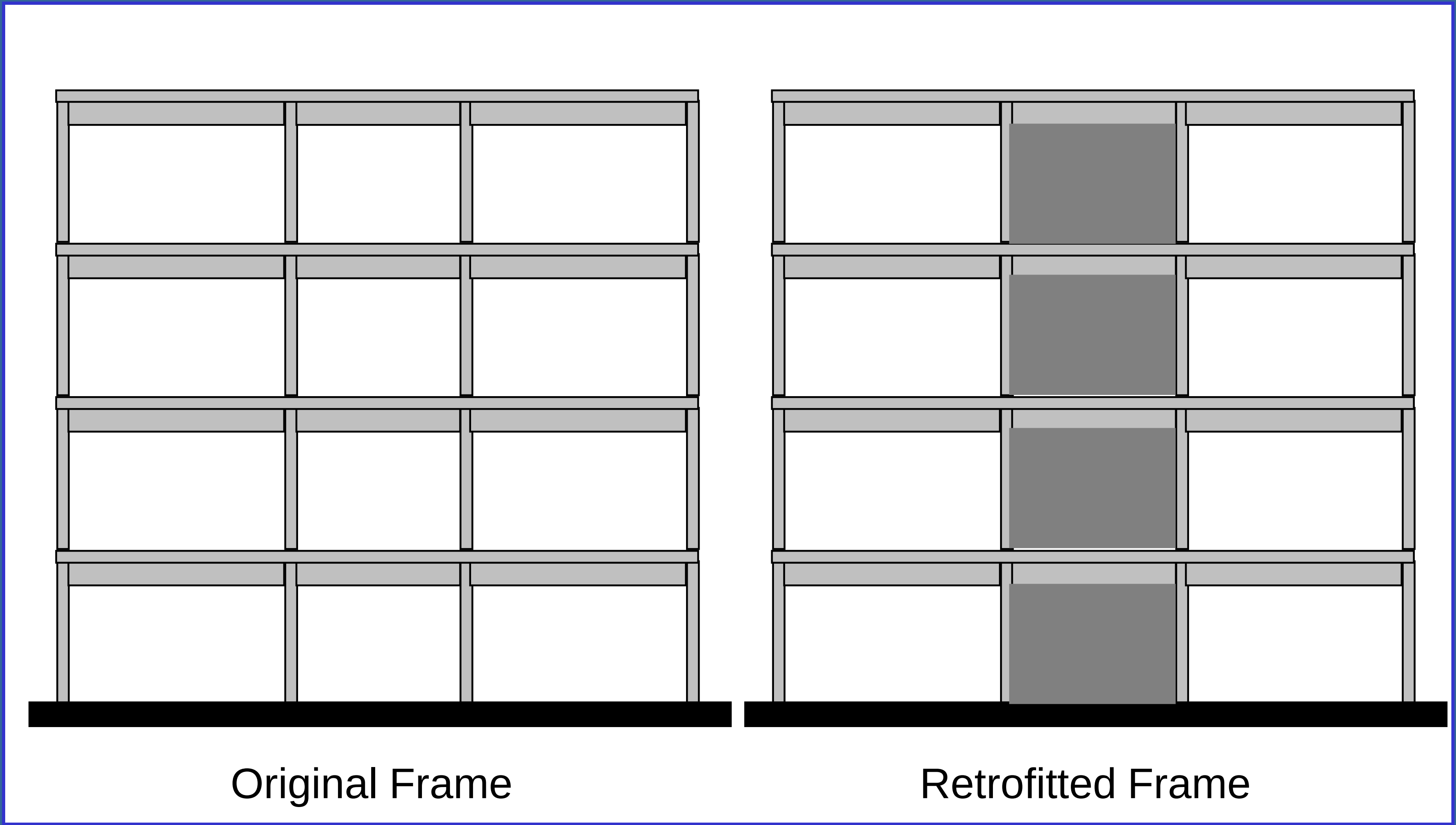
Suggested solution



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Parameters investigated

- Percentage of the reinforcement in the RC infill
  - different percentages of infill wall reinforcement have been studied
- Connection between the RC infill and the surrounding RC frame
  - two types of connection between the infill and the bounding frame (epoxy grouted dowels and/or wall reinforcement starter bars)

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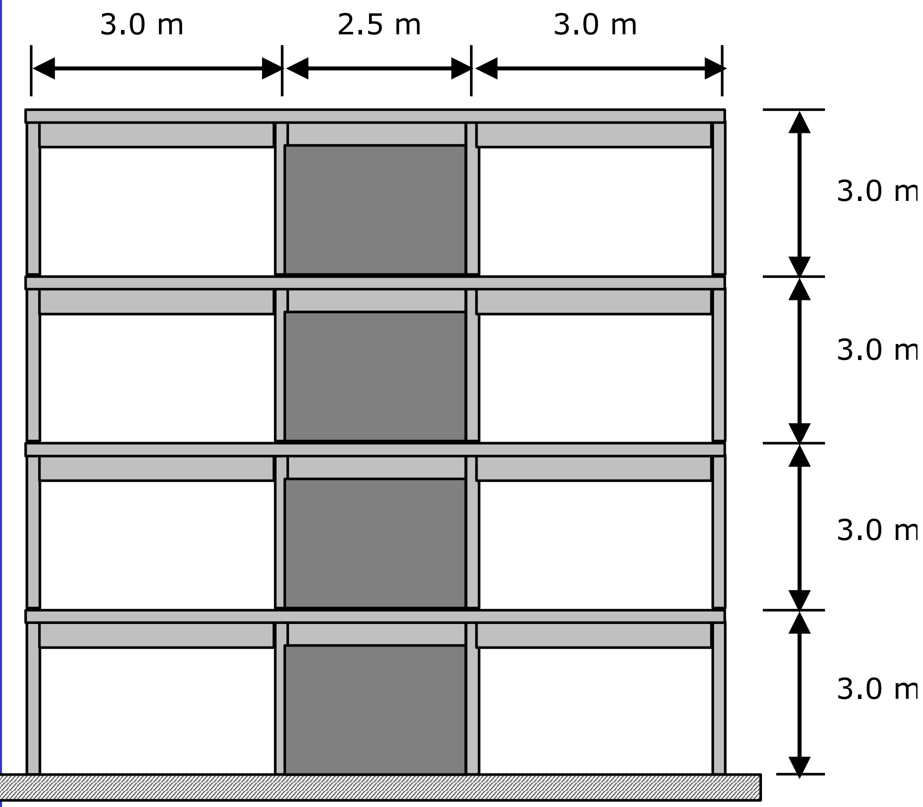
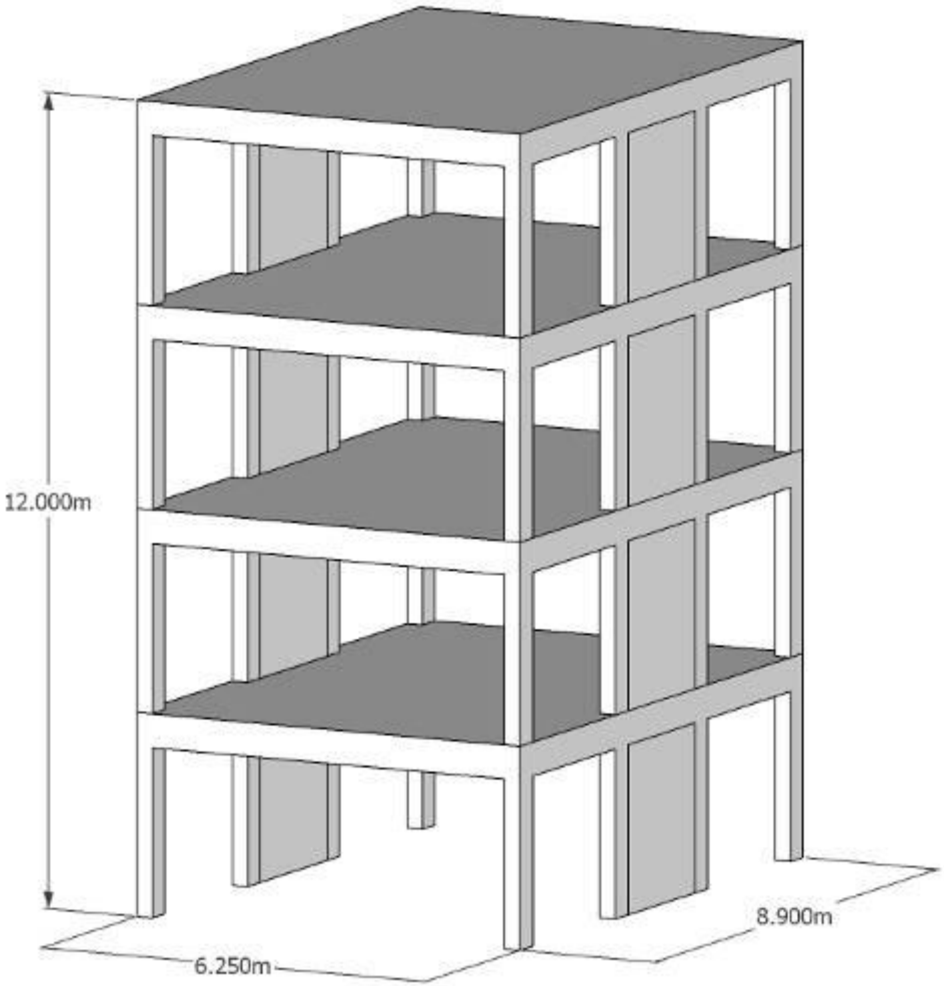
Fulfillment of objectives through a testing campaign

- Test a structure (consisting of two parallel retrofitted RC frames) using the pseudo-dynamic method
- The frame corresponds to frames designed for gravity-loads only in the 1970's

Specimen dimensions



Elevation of test structure



Perspective of mock-up

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Design of frame

- The proposed structure represents typical construction of the late 70’s and beginning of the 80’s in Cyprus
- Structures at that time were designed for gravity loads only, since there were no provisions for earthquake loading
- Use the provisions of BS8110 which is very close to those of CP110 with very minor differences
- Reinforcement details used for the design were according to CP110:1972 and BS8110:1983

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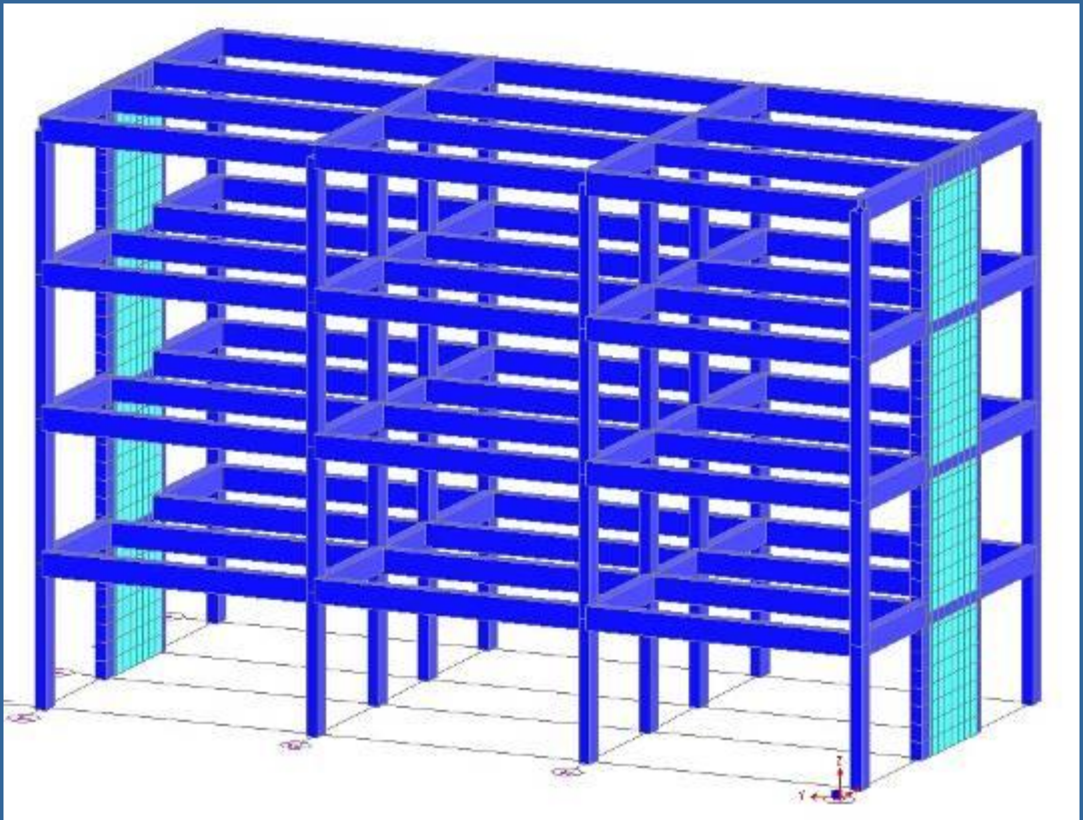
Design of frame: Prototype structure

- 4 frames
- Columns
  - 25cmx40cm
  - Long dim. along plane of loading
- Beams
  - 25cmx50cm
- Slab
  - 15cm thick



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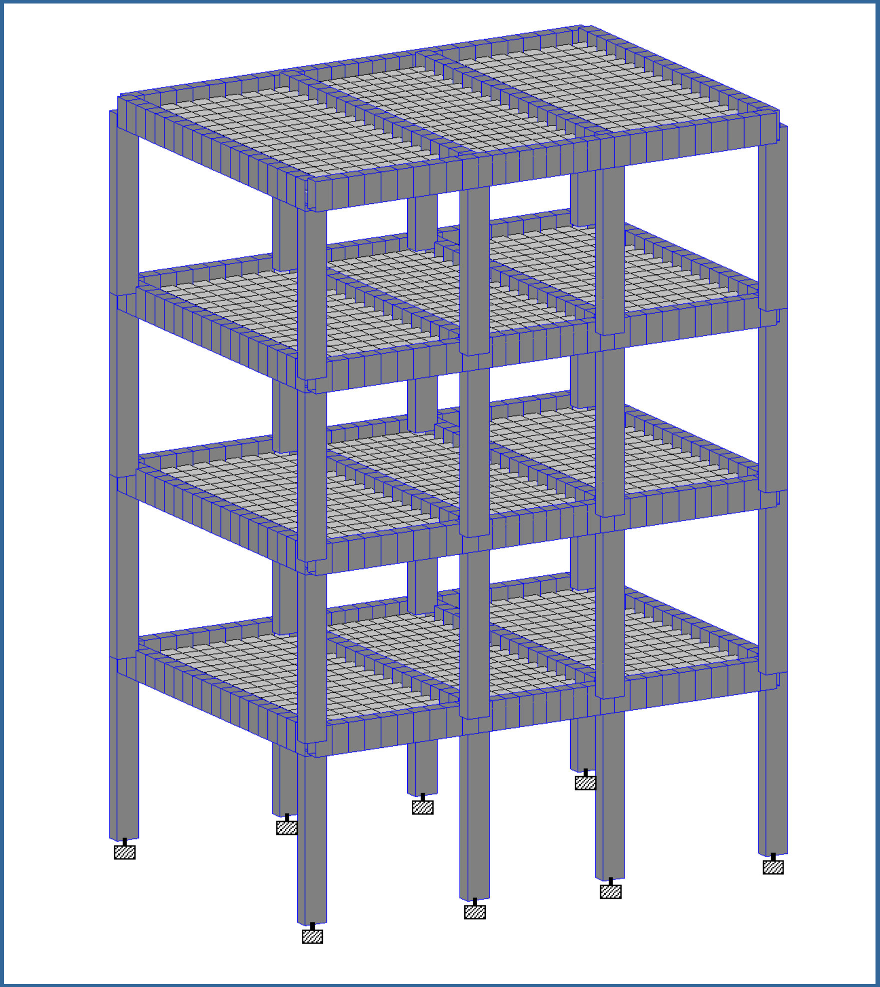
Design of frame: Mock-up without infills

- 2 end-frames of the prototype structure
- Columns
  - 25cmx40cm
  - Long dim. along plane of loading
- Beams
  - 25cmx50cm
- Slab
  - 15cm thick



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Design of frame: Material properties

- Concrete:
  - C20/25 for both the frame and the walls
  - Unit weight 25 kN/m^3
  - E = 30000 MPa
- Reinforcing steel
  - f_{yk}= 400 MPa ribbed bars for both bending and shear reinforcement for the frame (existing structure)
  - f_{yk}= 450 MPa ribbed bars for the RC infill and the dowels to be used for connecting the wall to the bounding frame members

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Design of frame: Loads, Load-combinations, Material factors

- The frame was designed for gravity loads only The loads used were the following:
  - Self-weight: this was calculated using the unit weight of concrete specified above
  - Imposed dead load: 3 kN/m^2 including the load of infills
  - Live load: 1.5 kN/m^2
- Partial factors of safety for loads
  - 1.4 for self-weight and imposed dead-load, and
  - 1.6 for live load.
- Material partial factors
  - 1.5 for concrete and
  - 1.15 for steel

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Design of frame: Resulting reinforcement details

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RC infills

- Made of reinforced concrete
- Connected to the bounding frame by starter bars and/or dowels

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RC infills

- By design the dimensions are such, so as to have high aspect ratio
  - Bending dominated behaviour
  - Higher modes involved after yielding of the wall at the base
- The RC infill wall has the same thickness as the width of the frame members
  - Try to avoid
    - diagonal cracking of the wall
    - failure of the interface connection

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RC infills – Parameters to be investigated

- Percentage of the reinforcement in the RC infill
  - different percentages of infill wall reinforcement was studied

story	N Wall								S Wall							
	web bars	embedment of web starter bars, mm		Dowels					web bars	embedment of web starter bars, mm		dowels				
				Φ mm	embedment, mm							Φ mm	embedment, mm			
		in wall	in frame		bottom & east in:		top&west in:			in wall	In frame		bottom & east in:		top&west , in:	
					wall	frame	wall	frame					wall	frame	wall	frame
1	Φ12@200	600	230	Φ20	160	160	600	190	Φ10@200	500	170	Φ2 0	160	160	500	160
2	Φ10@200	500	170	Φ20	160	160	500	160	Φ 8@200	400	120	Φ18	145	145	400	145
3	Φ8@200			Φ18	400	145	400	145	Φ8@200			Φ16	400	130	400	130
4	Φ8@200			Φ16	400	130	400	130	Φ8@200			Φ16	400	130	400	130

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RC infills – Parameters to be investigated

- Connection between the RC infill and the surrounding RC frame
  - ➢ epoxy grouted dowels and/or wall reinforcement starter bars
  - ➢ two cases are examined
    - Continuity of web reinforcement is provided through lap splices and dowels are provided for shear
    - Web reinforcement is placed at the phase of the bounding members and dowels are provided which double as
      - – dowels
      - – anchorage of the web panel to the surrounding frame but violating the 50mm or 4Φ clear distance requirement for lapping

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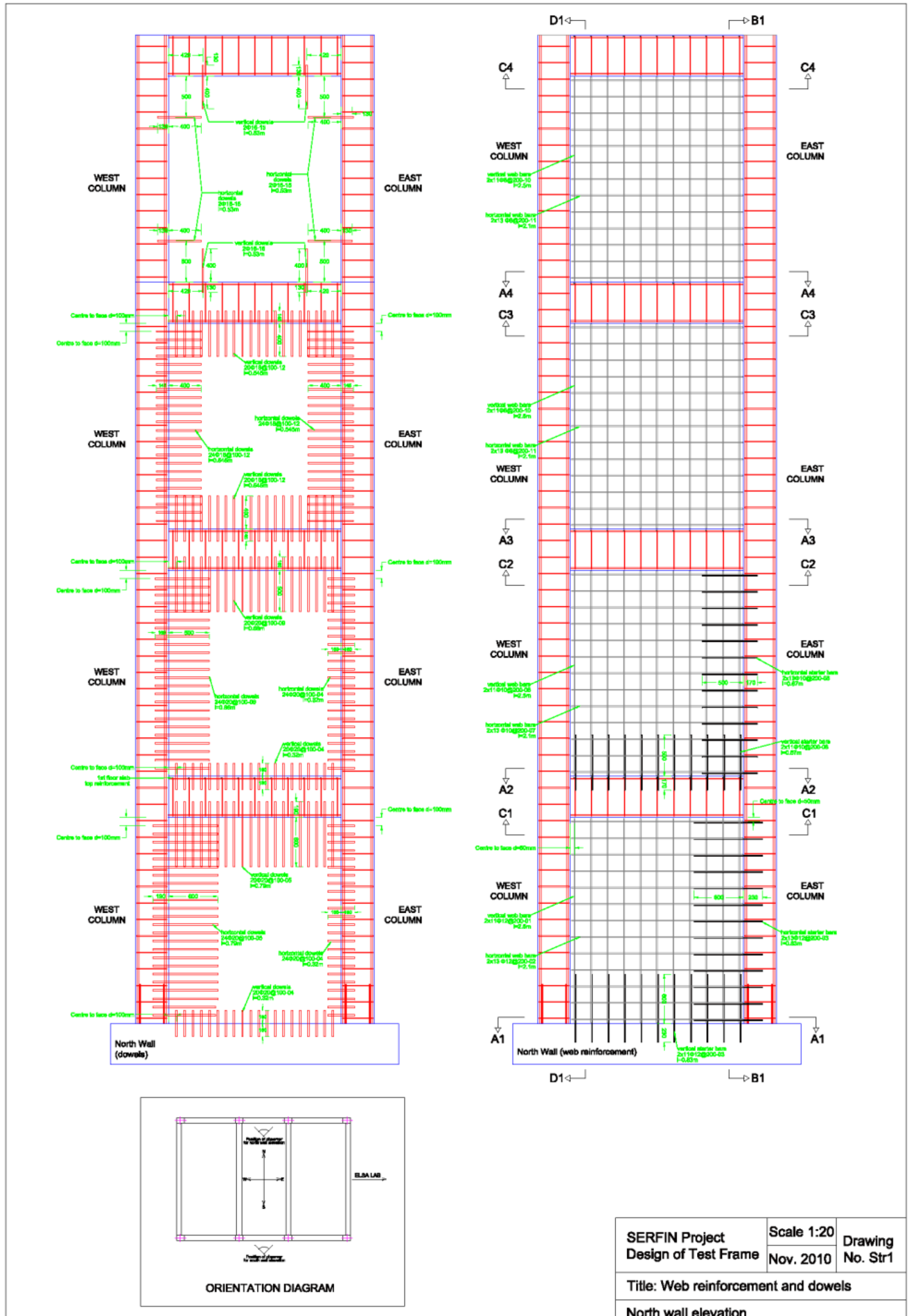
North Wall



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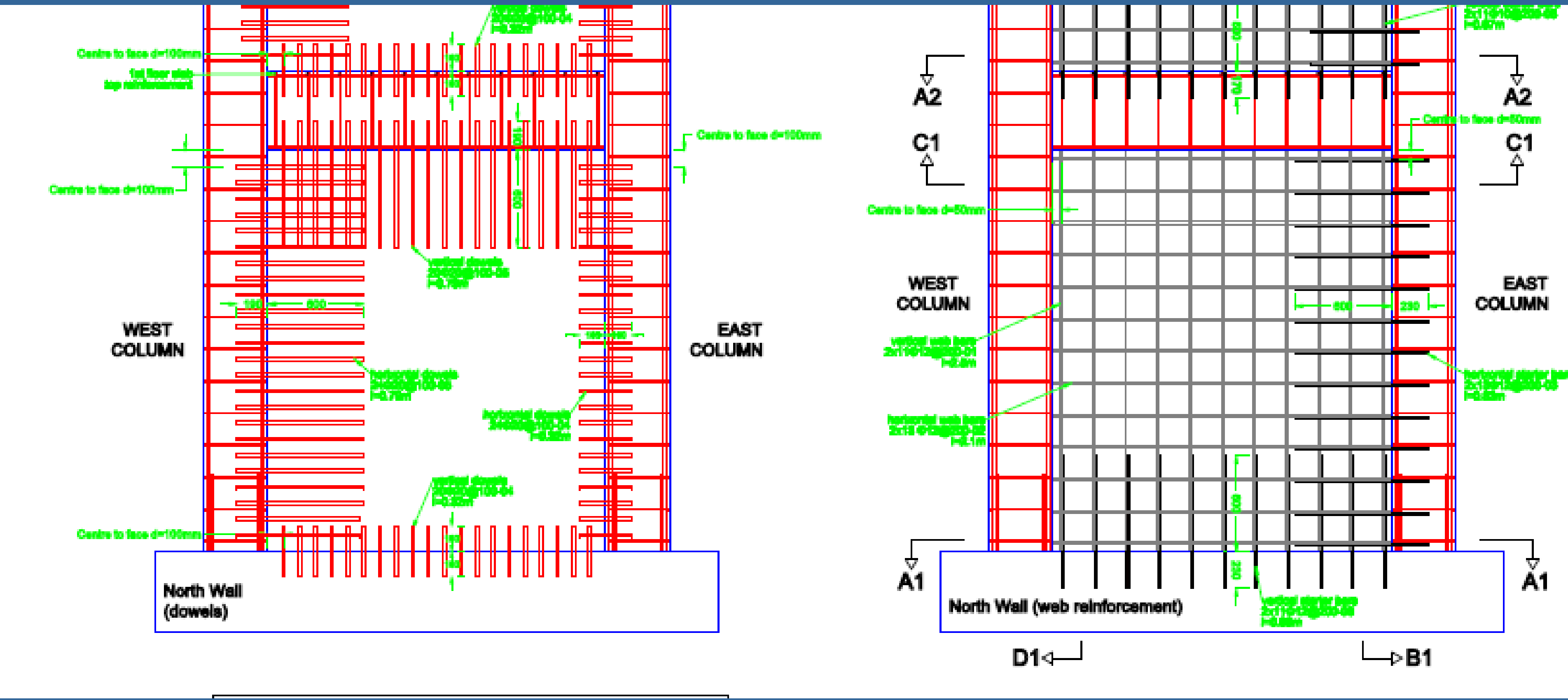
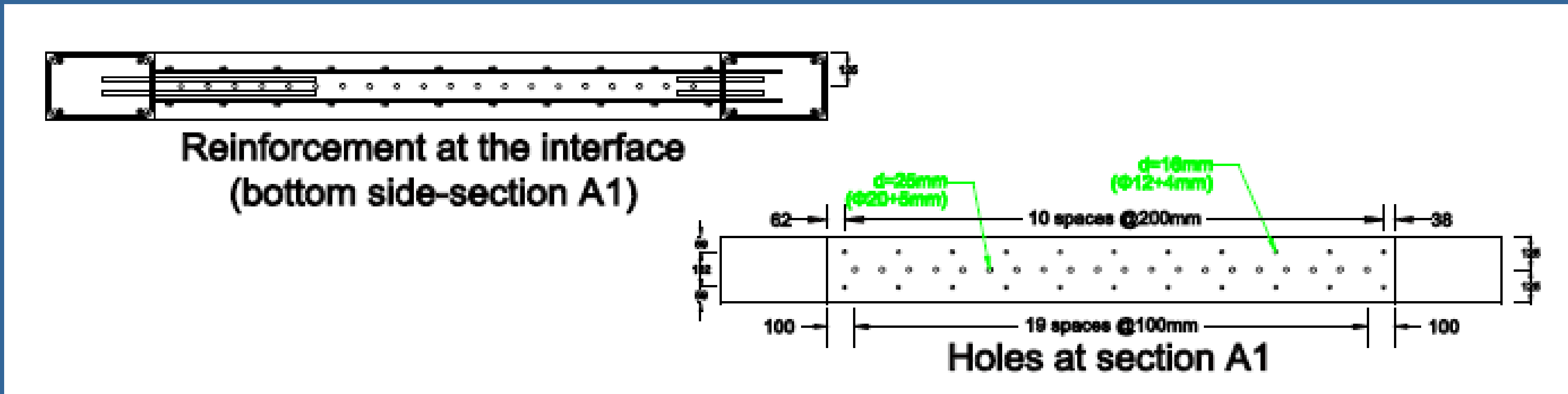
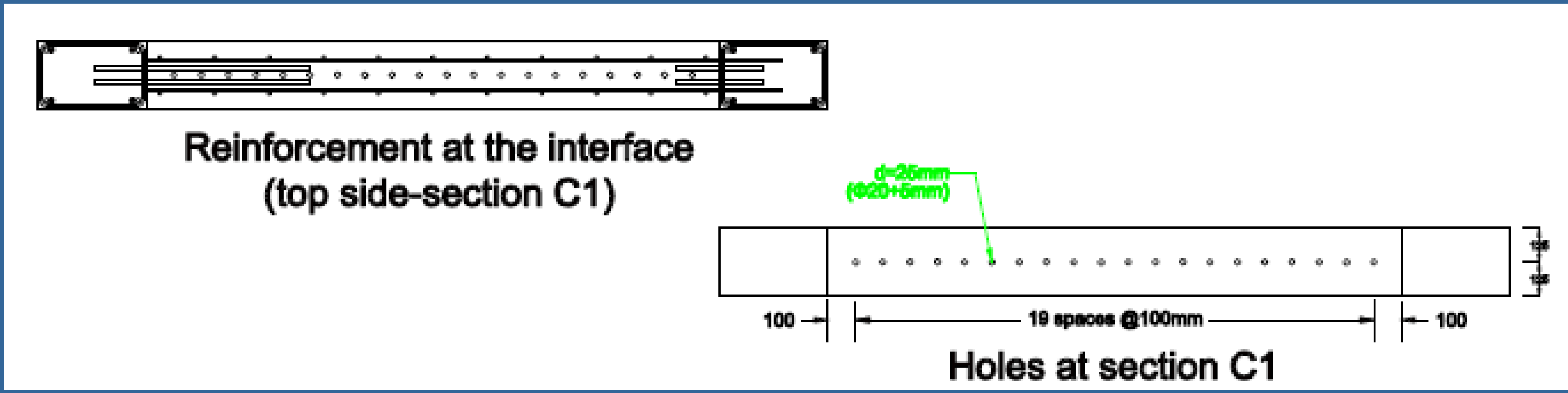
Reinforcement Details



Dowel details



Dowels and starter bars



Dowels only

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Pictures of construction

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Pictures of construction

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Pictures of construction

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Strengthening of ground floor columns

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Strengthening of ground floor columns

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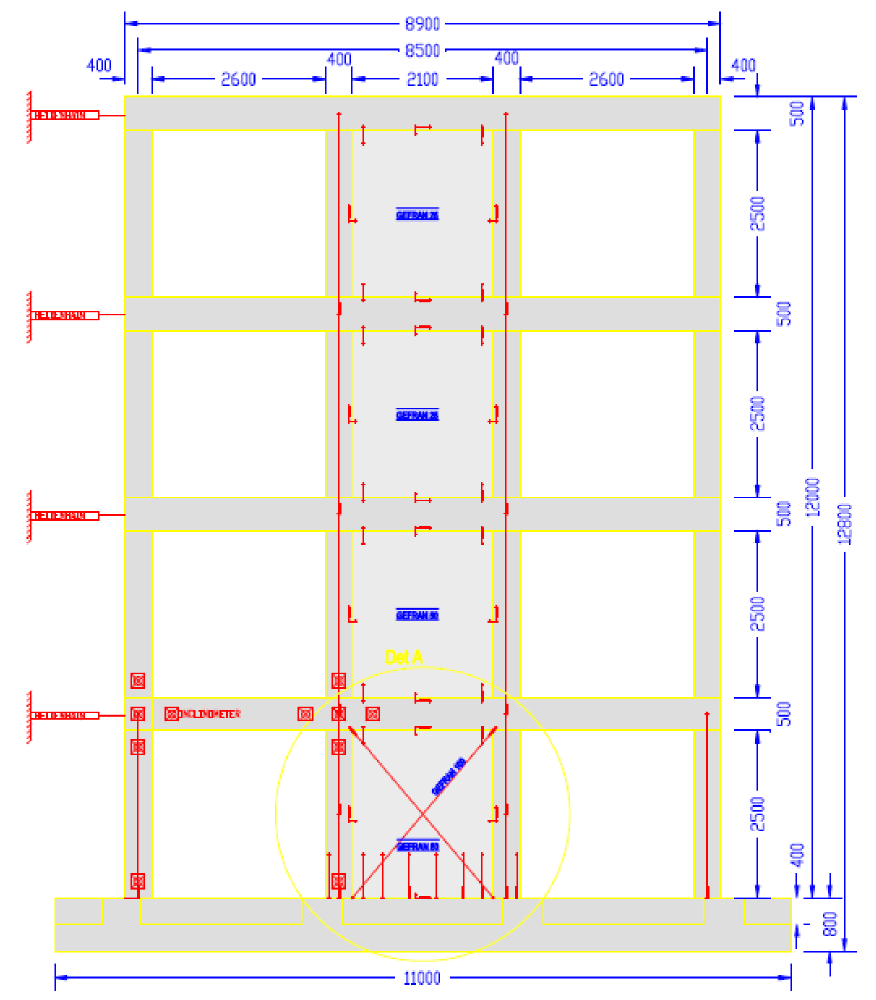
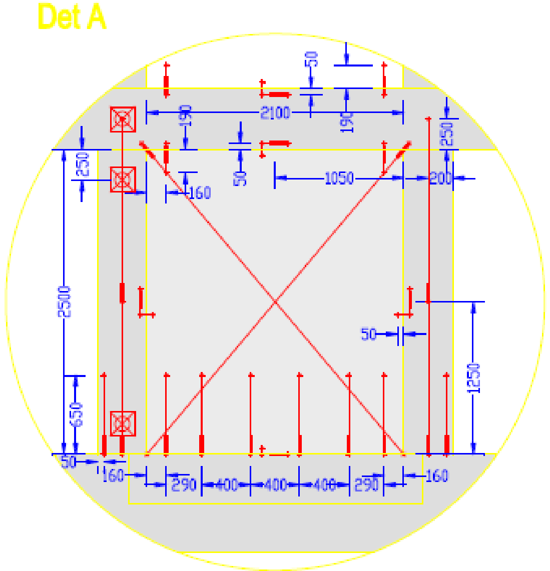
Instrumentation





Displacement	Gefran PZ12 100	4
	Gefran PZ12 50	68
	Gefran PZ12 25	32
	Heidenhein	8
Inclination	Schaewitz AccuStar	22
Force	Piston Load Cell	8

128 channels

SERFIN INSTRUMENTATION
06/04/2011

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Testing

- 3 tests were performed
  - Pseudo-dynamic testing
    - 0.10g
    - 0.25g
  - Cyclic testing
    - Displacement controlled triangular distribution
  - Actuators
    - 2 x 1000 kN at the top two floors
    - 2 x 500 kN at the bottom two floors

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0.25g Pseudo-dynamic

- The Hercegnovi transverse accelerogram was used, scaled to 0.25g

South frame

(with less reinforcement)

N E
W S

North frame

(with more reinforcement)

S W
E N


Ready
00:02


Ready
00:01

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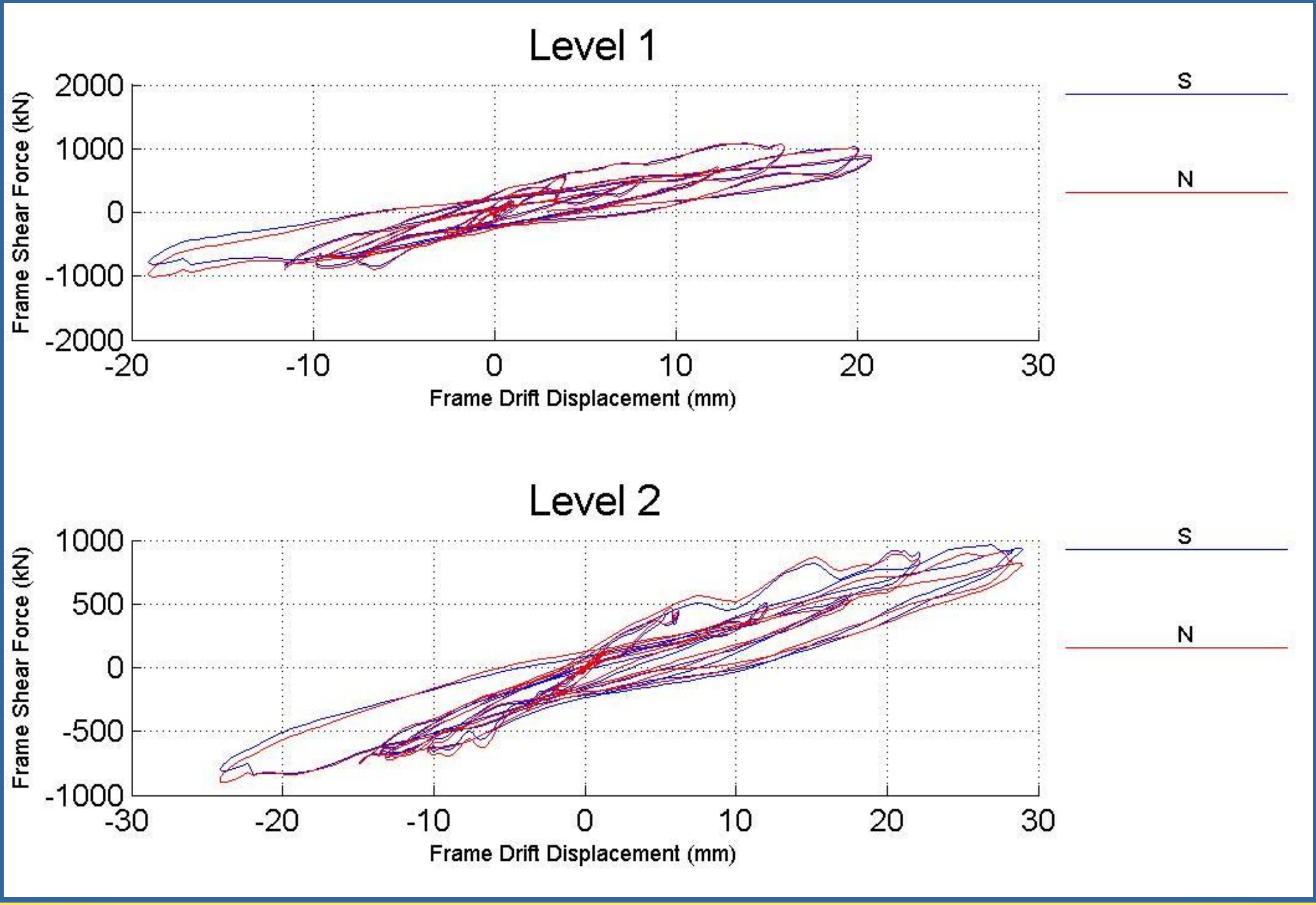
Storey-shears vs. i-d for 0.25 g



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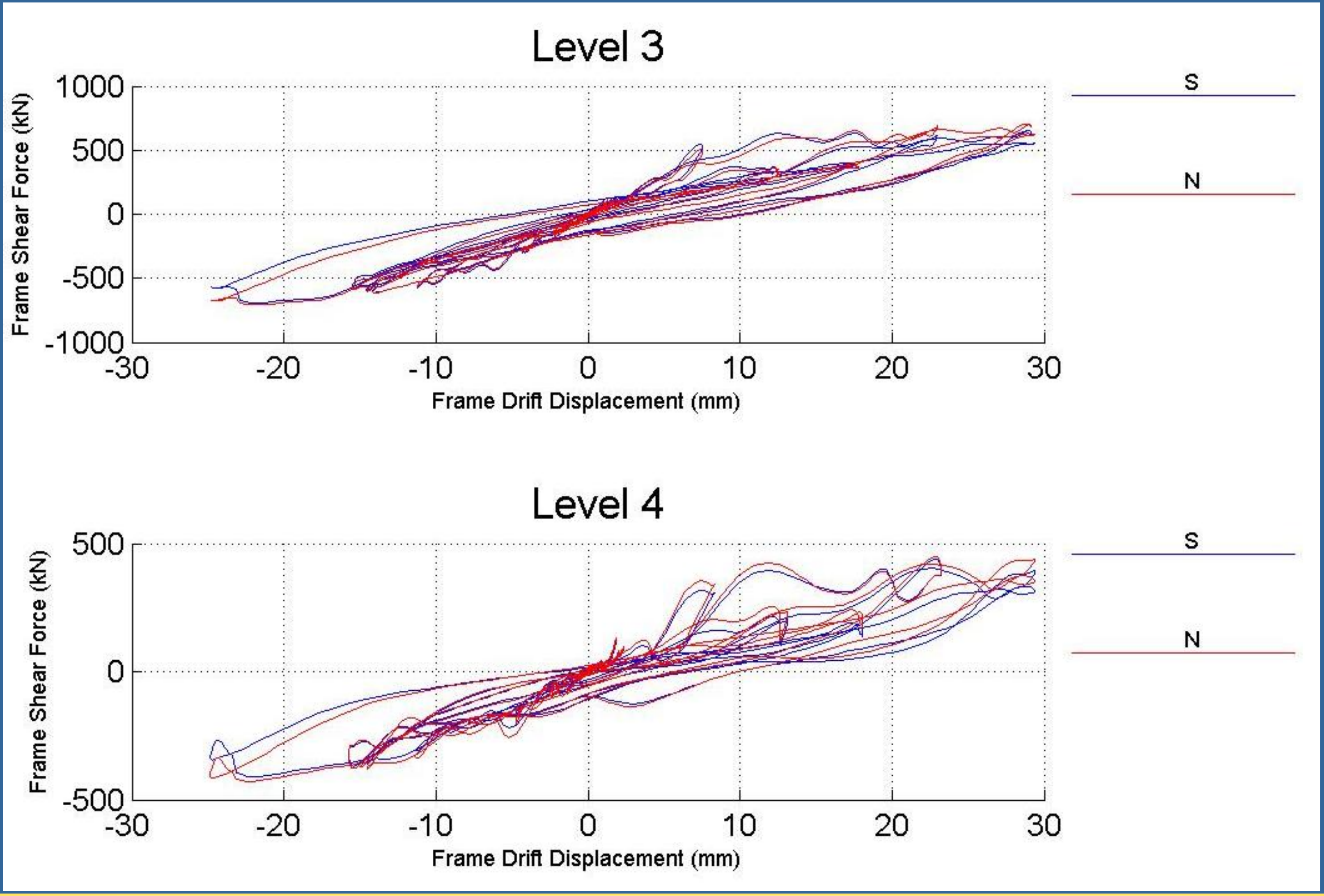
Storey-shears vs. i-d for 0.25 g…



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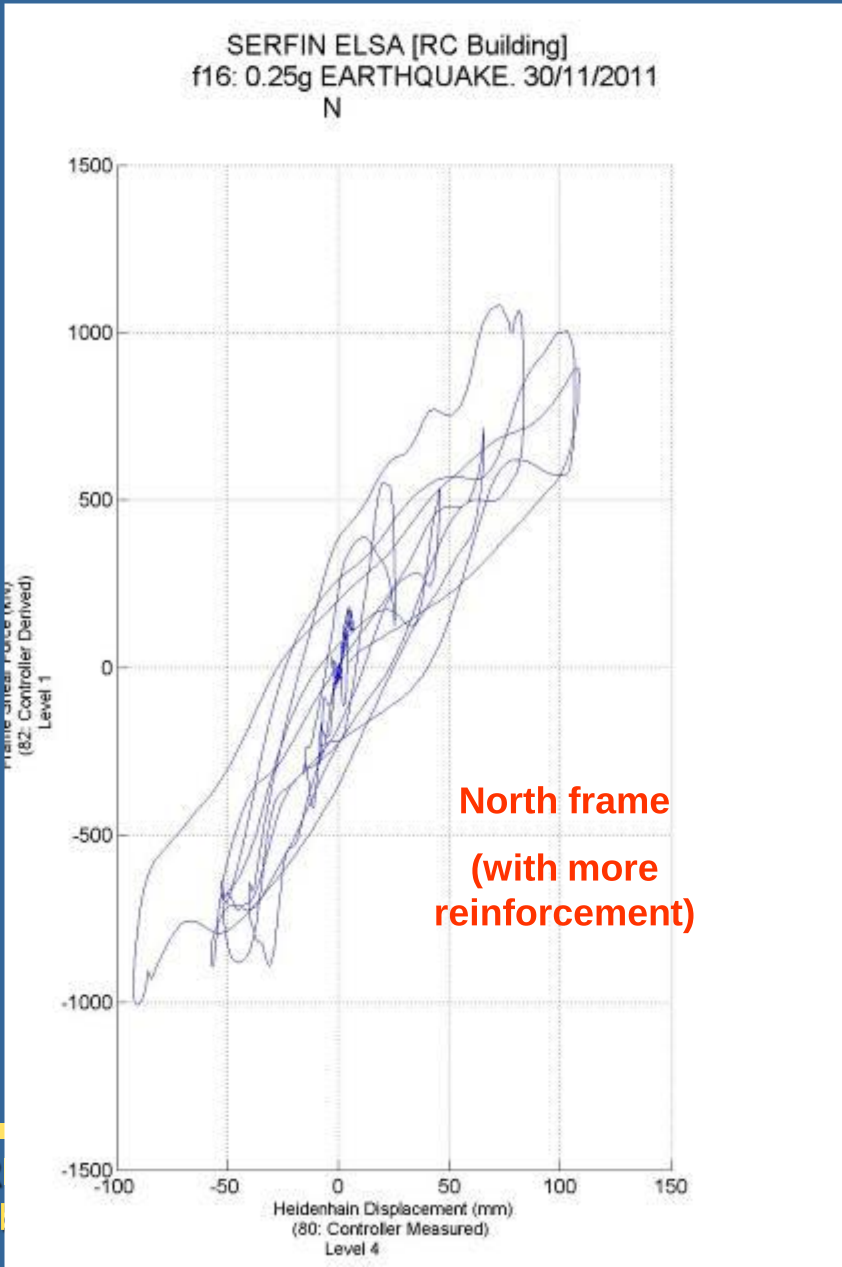
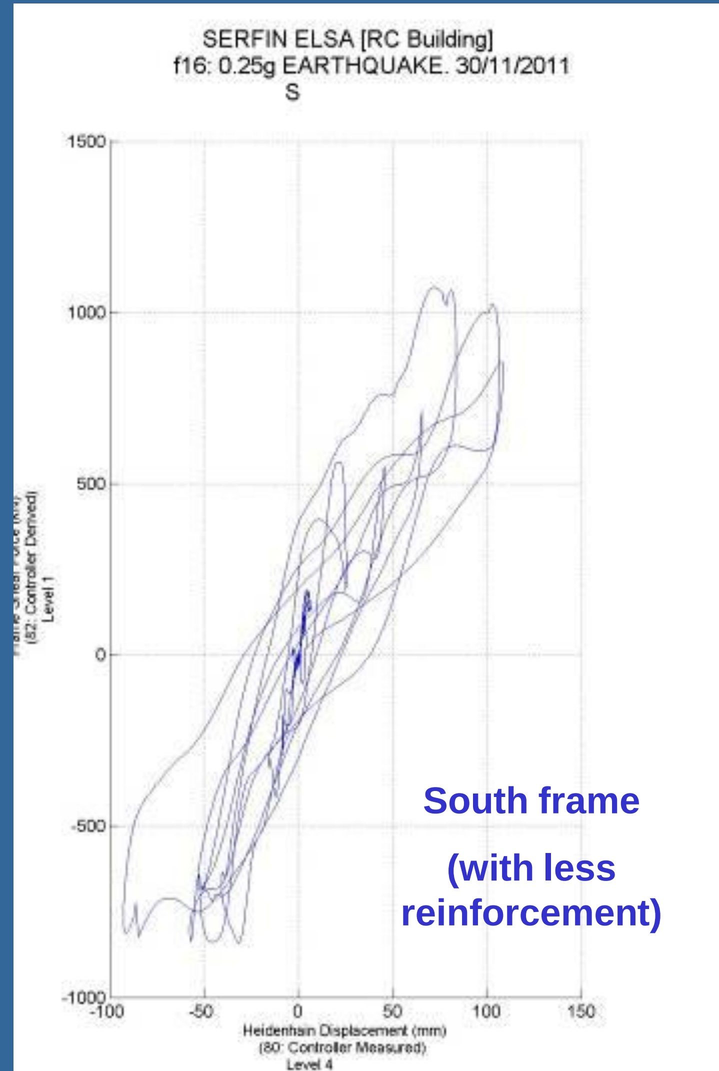
Base-shear vs. top displacement for 0.25 g…





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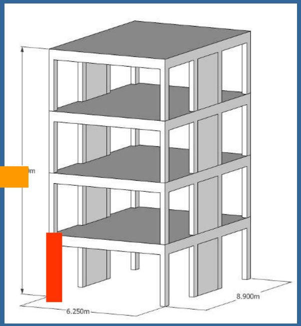
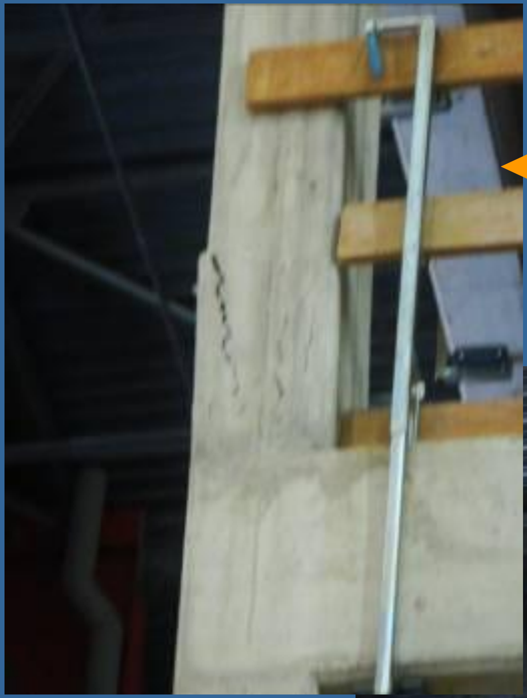
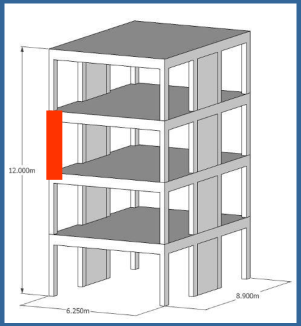
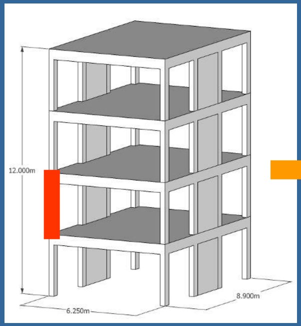
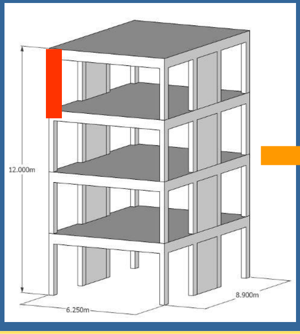
Lap-splice failure –West column of North frame











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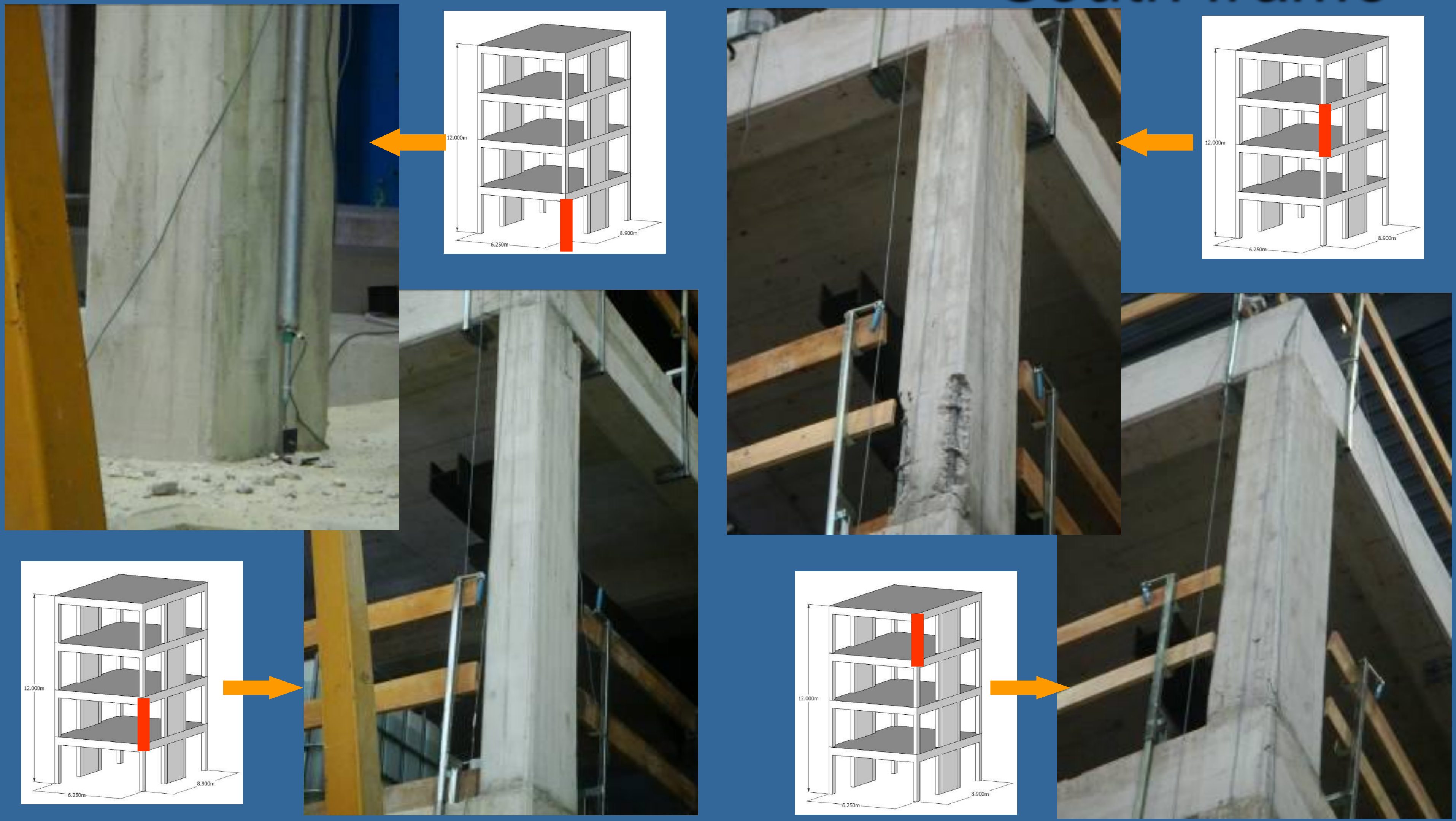
Lap-splice failure –West column of South frame



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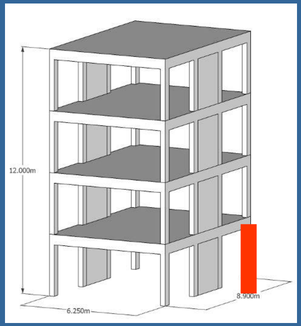
Lap-splice failure –East column of South frame



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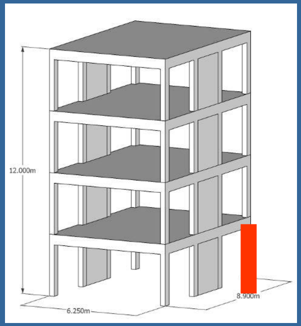
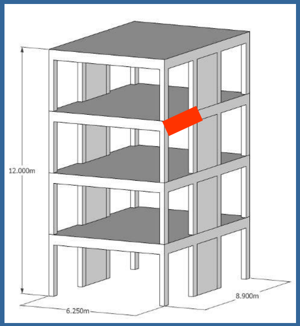
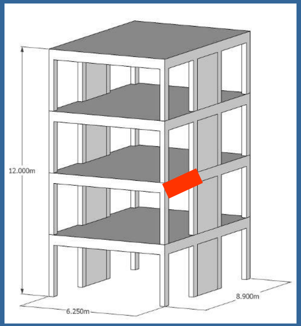
Lap-splice failure –East column of South frame



Beam cracking





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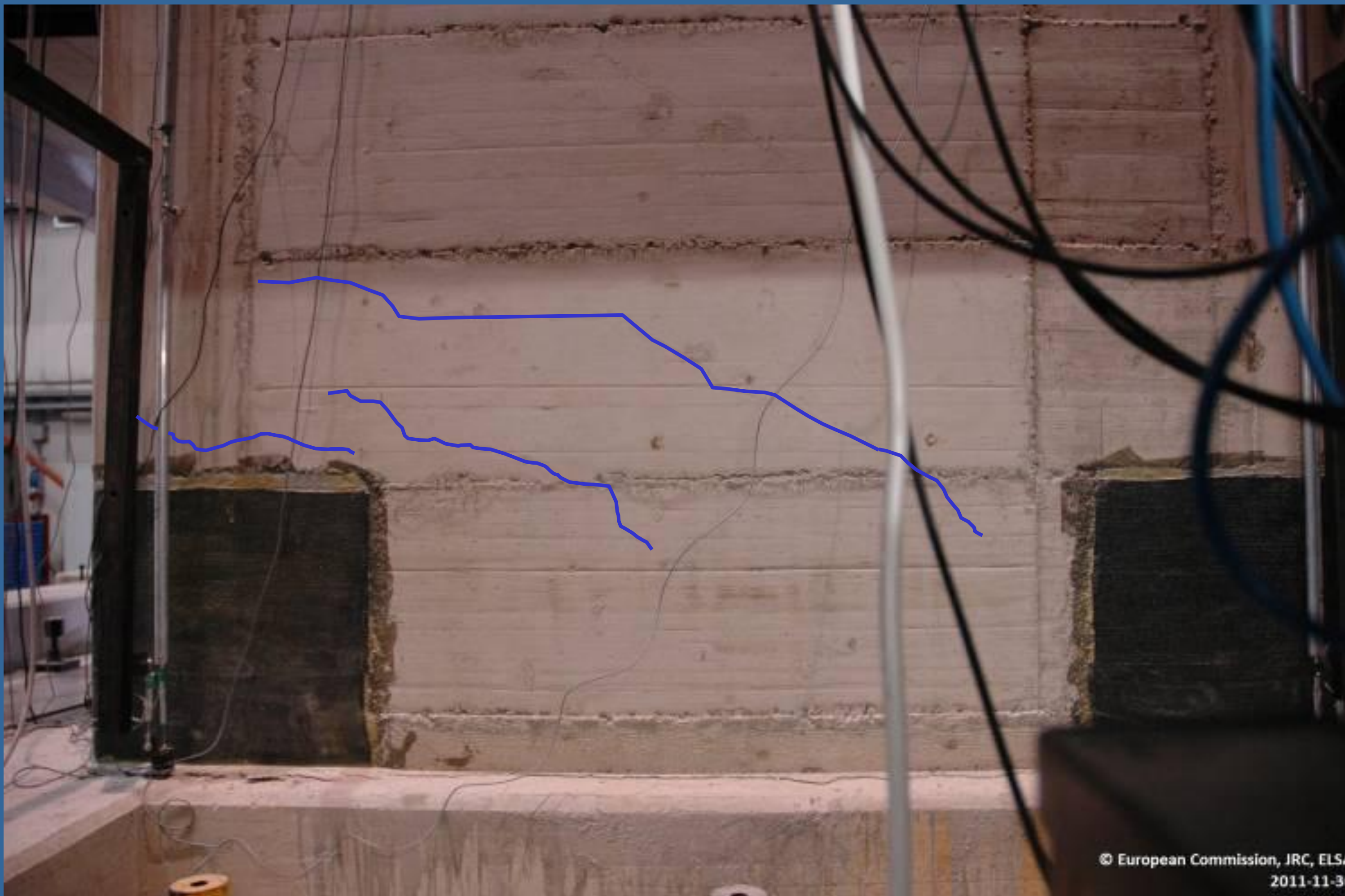
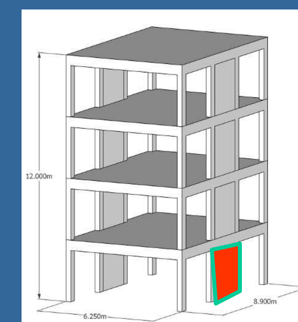
Wall cracking





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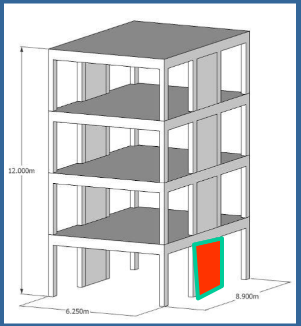
Wall cracking



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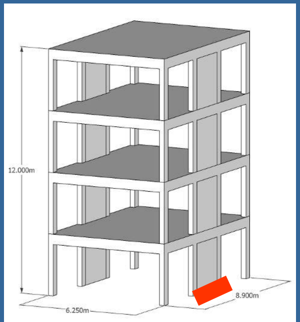
Ground beam cracking – South wall



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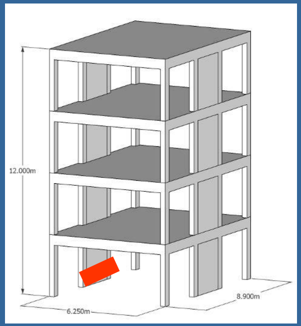
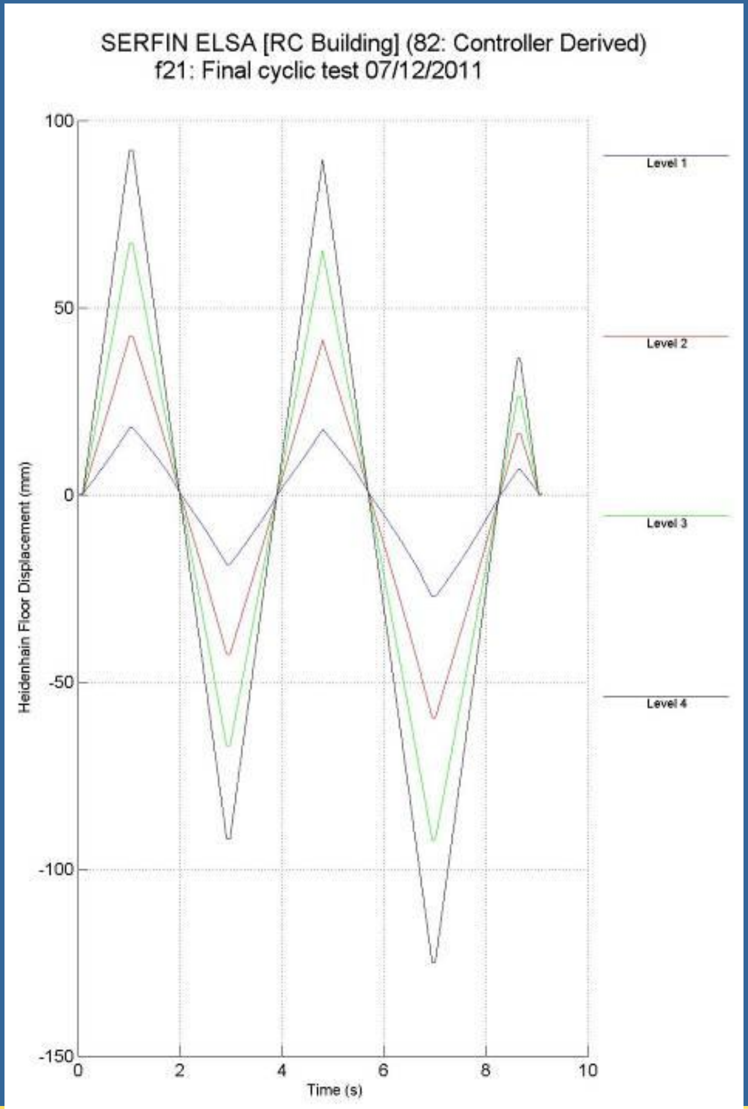
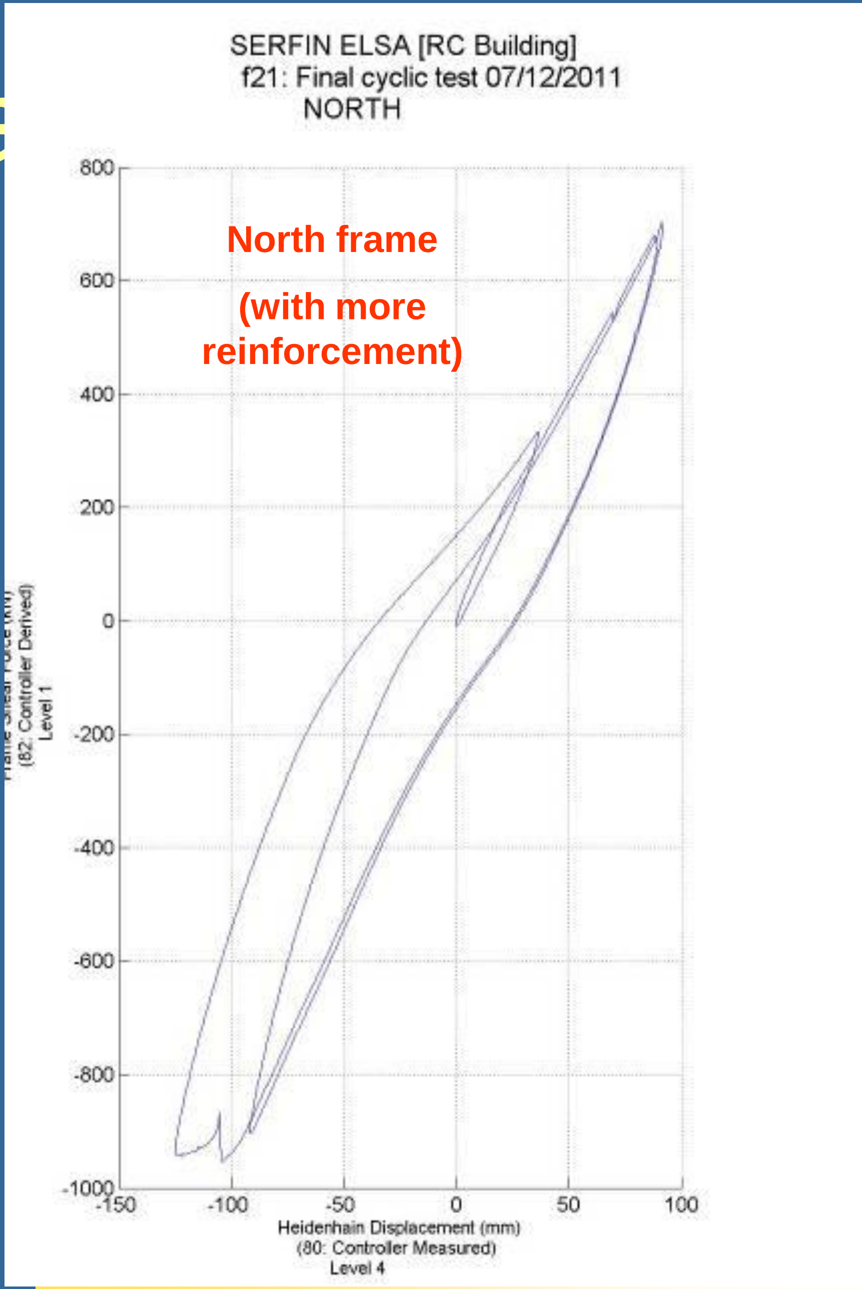
Ground beam cracking – North wall

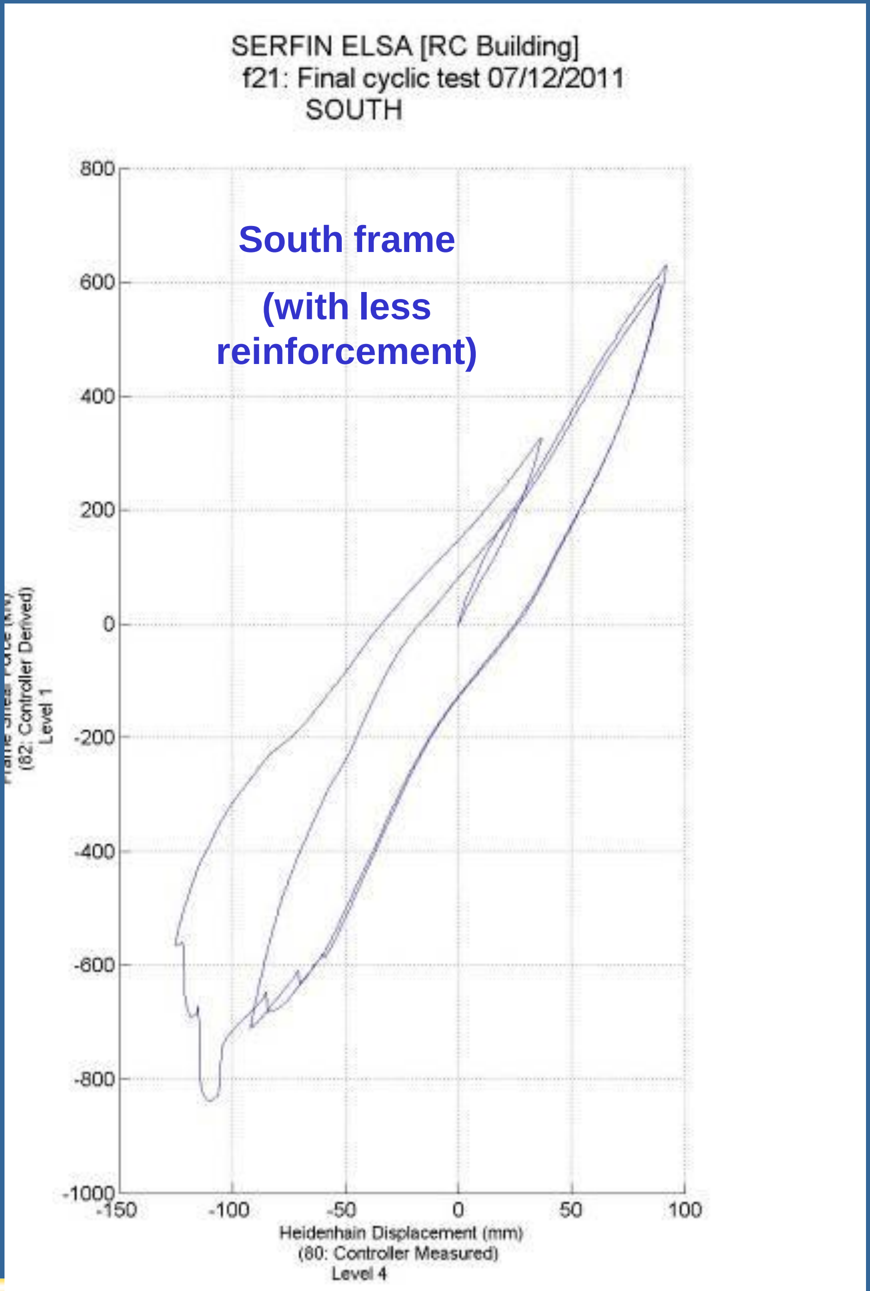


Cyclic testing

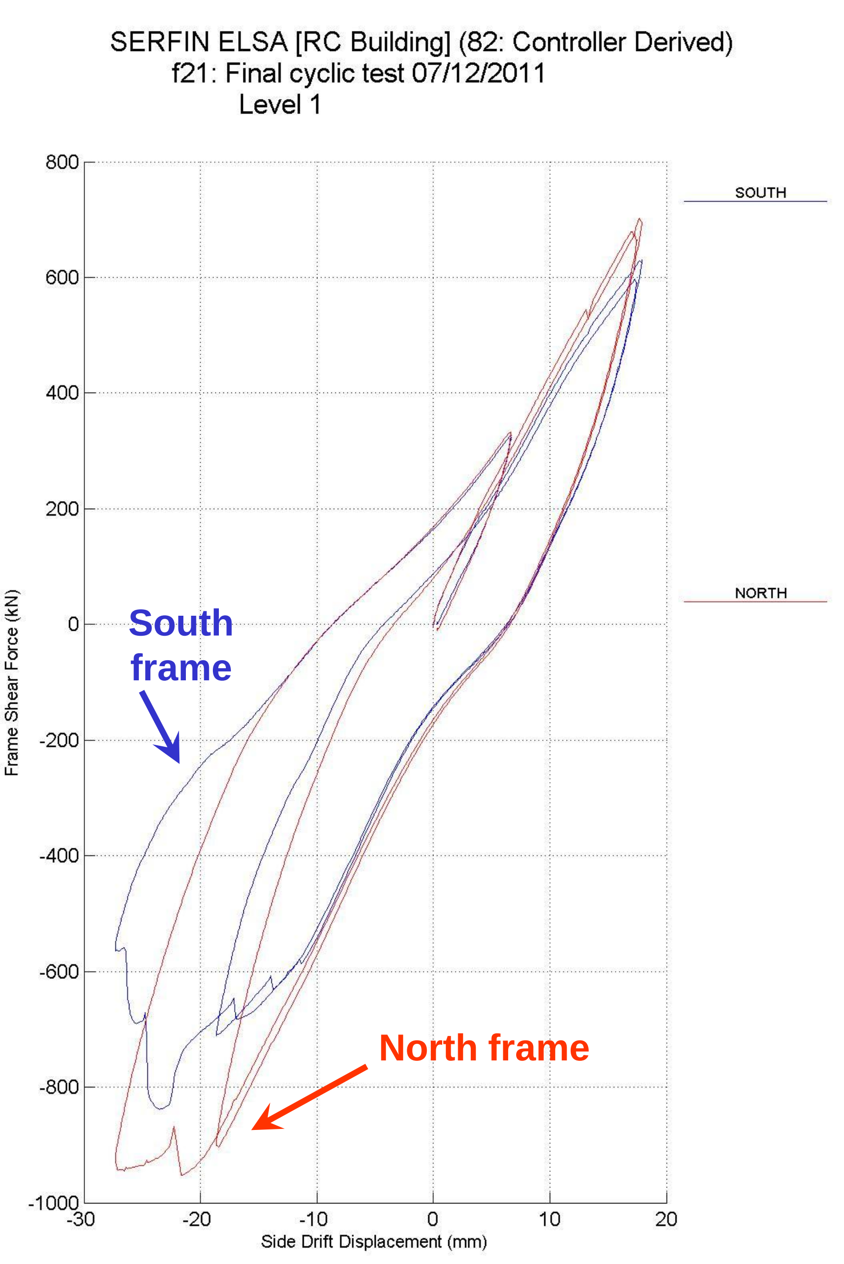


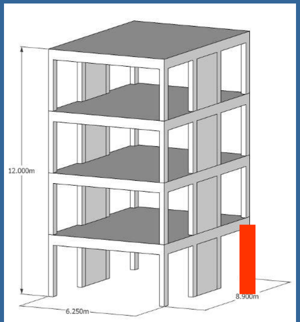

Ready
00:03


SERFIN ELSA [RC Building]
f21: Final cyclic test 07/12/2011
NORTH
North frame
(with more reinforcement)
Heidenhain Displacement (mm)
(80: Controller Measured)
Level 4
(82: Controller Derived)
Level 1


SERFIN ELSA [RC Building]
f21: Final cyclic test 07/12/2011
SOUTH
South frame
(with less reinforcement)
Heidenhain Displacement (mm)
(80: Controller Measured)
Level 4
(82: Controller Derived)
Level 1

Cyclic testing





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Conclusions

- The structure managed to sustain an earthquake of 0.25g without significant damage
- Some column lap-splices failed with concrete spalling, but the structure continued to carry load
- The 3-sided FRPs protected the wall bounding columns at the 1st floor and prevented lap-splice failure

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Conclusions…

- The “weak” frame behaved equally well as the “strong” frame
- There has not been visible movement at the interface between the wall and the bounding frame
- The behaviour of the wall was mainly flexural, although on the south-frame wall some diagonal cracks appeared

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Conclusions…

- Some vertical cracks appeared at the connection of the beams to both the exterior column and the wall columns
- A horizontal crack appeared at the ground beam of the walls, and it was the main reason for loss of strength of the south frame
- The proposed system seems to behave in a satisfactory manner

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Thank you for your attention