RC-FIAP An open platform for high-resolution structural design and inelastic modeling for regional seismic risk assessment

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Colombia

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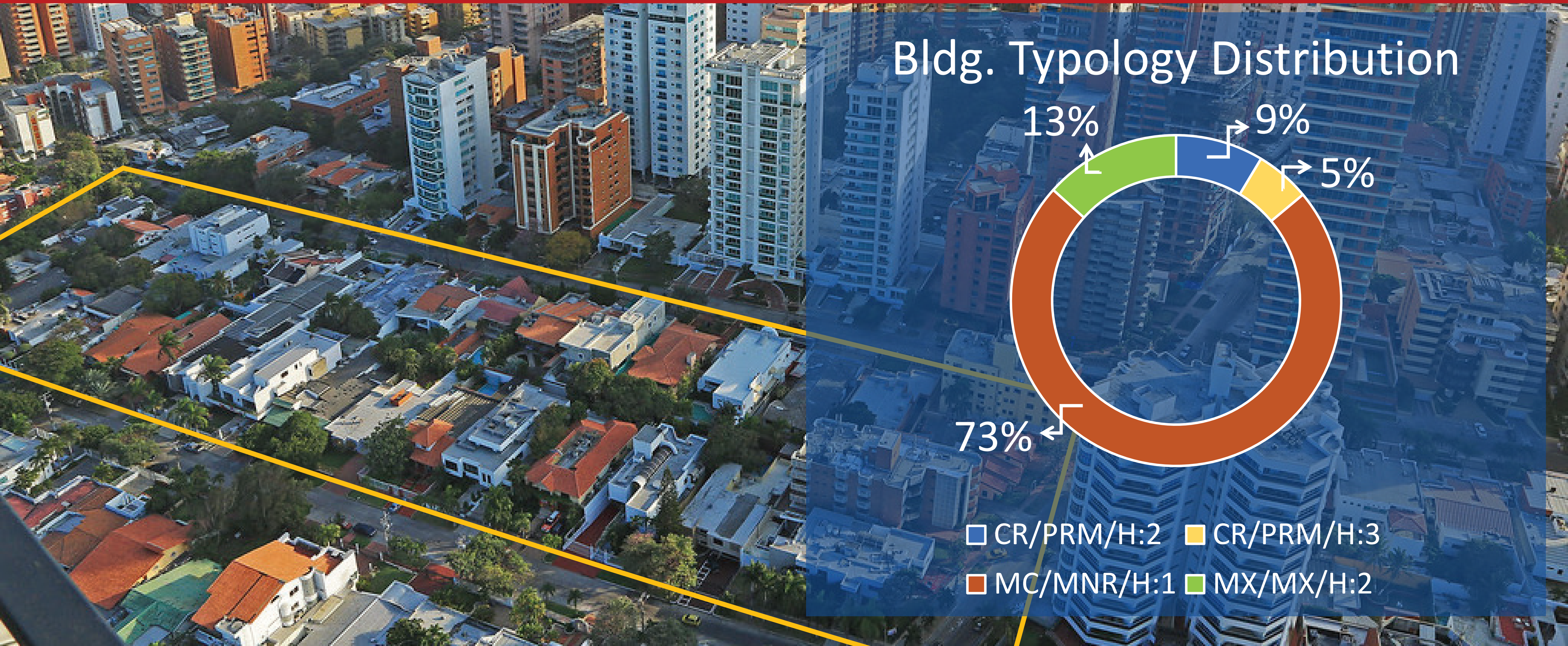
MOTIVATION I: COLOMBIAN NATIONAL RISK MODEL

Task 1: Residential building inventory covering 60% of the population.

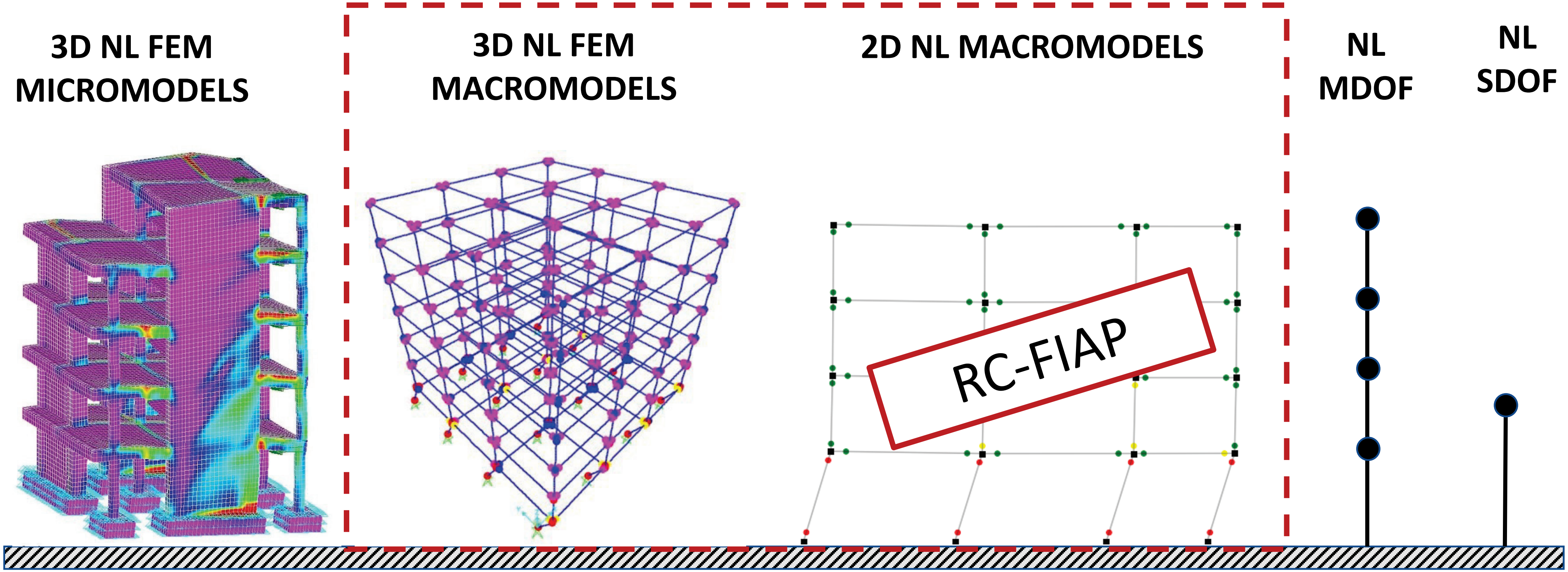
MOTIVATION I: COLOMBIAN NATIONAL RISK MODEL

Blockwide resolution



MOTIVATION I: COLOMBIAN NATIONAL RISK MODEL

Task 2: What is **the seismic fragility and vulnerability** of the Colombian RC frame and frame-wall system?



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MOTIVATION II: FACILITATE INTEGRATION OF THE PEER EQ.

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1 PEER PBEE Equation

$$\lambda(dv) = \iiint G_{DV}\langle dv|dm\rangle|dG_{DM}\langle dm|edp\rangle||dG_{EDP}\langle edp|im\rangle||d\lambda(im)|$$

2 Fragility Formulation

$$P(DS > ds|IM) = \int P(DS > ds|EDP)f(EDP|IM)$$

Continuous Formulation

$$P(DS > ds|im_i) = \sum_{j=1}^{m}\left[P\left(DS > ds|edp_j\right) * p(edp_j|im_i)\right]$$

Discrete Formulation

3 Loss Estimation by Story

$$\mathbf{E}[\mathbf{L_T}|\mathbf{IM}] = E[L_T|NC, ND, IM] * P(ND) * P(NC|IM) + E[L_T|NC, D, IM] * P(D) * P(NC|IM) + E[L_T|C] * P(C|IM)$$

Expected losses due to:

Non-collapse and Non-demolition

Non-collapse and Demolition

Collapse

HOW TO DEVELOP A REGIONAL SEISMIC RISK ASSESSMENT?

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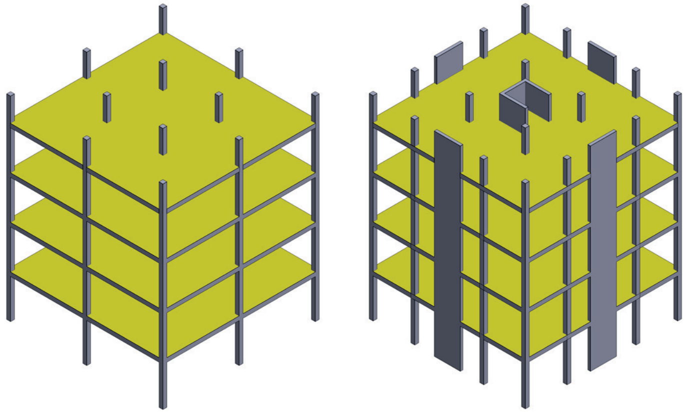
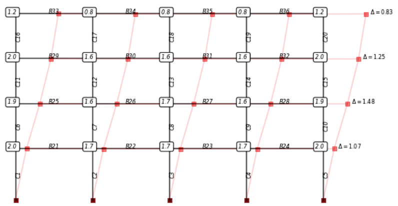
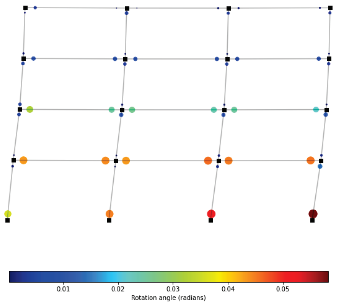
Systems of interest:

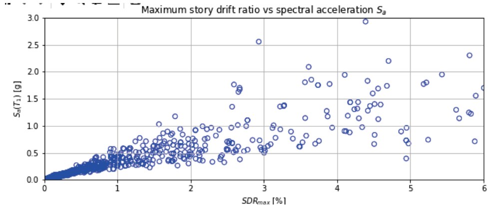


RC Frames   Frame-wall system





Automate the **design** of detailed models

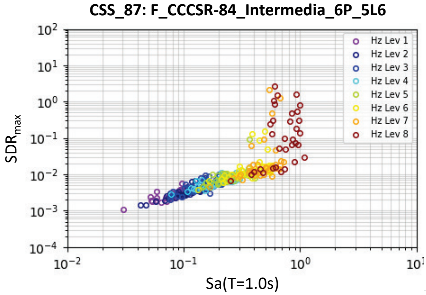


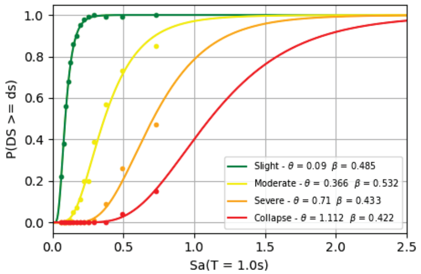
Hazard-consistent NLRHA

RC-FIAP

JUST WITH A CLICK

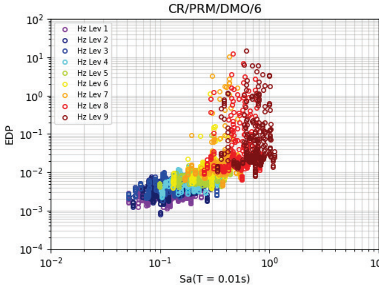
Fragility of a Building

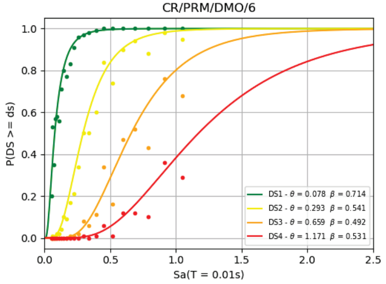




V-FAST

Fragility of a Taxonomy

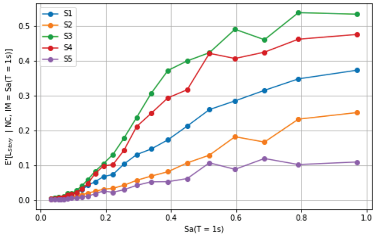




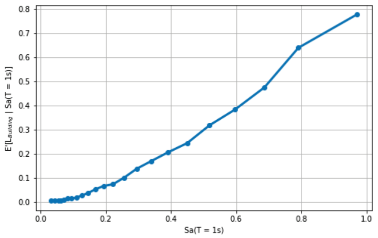
Taxonomy: Group of buildings with the same characteristcs

Losses

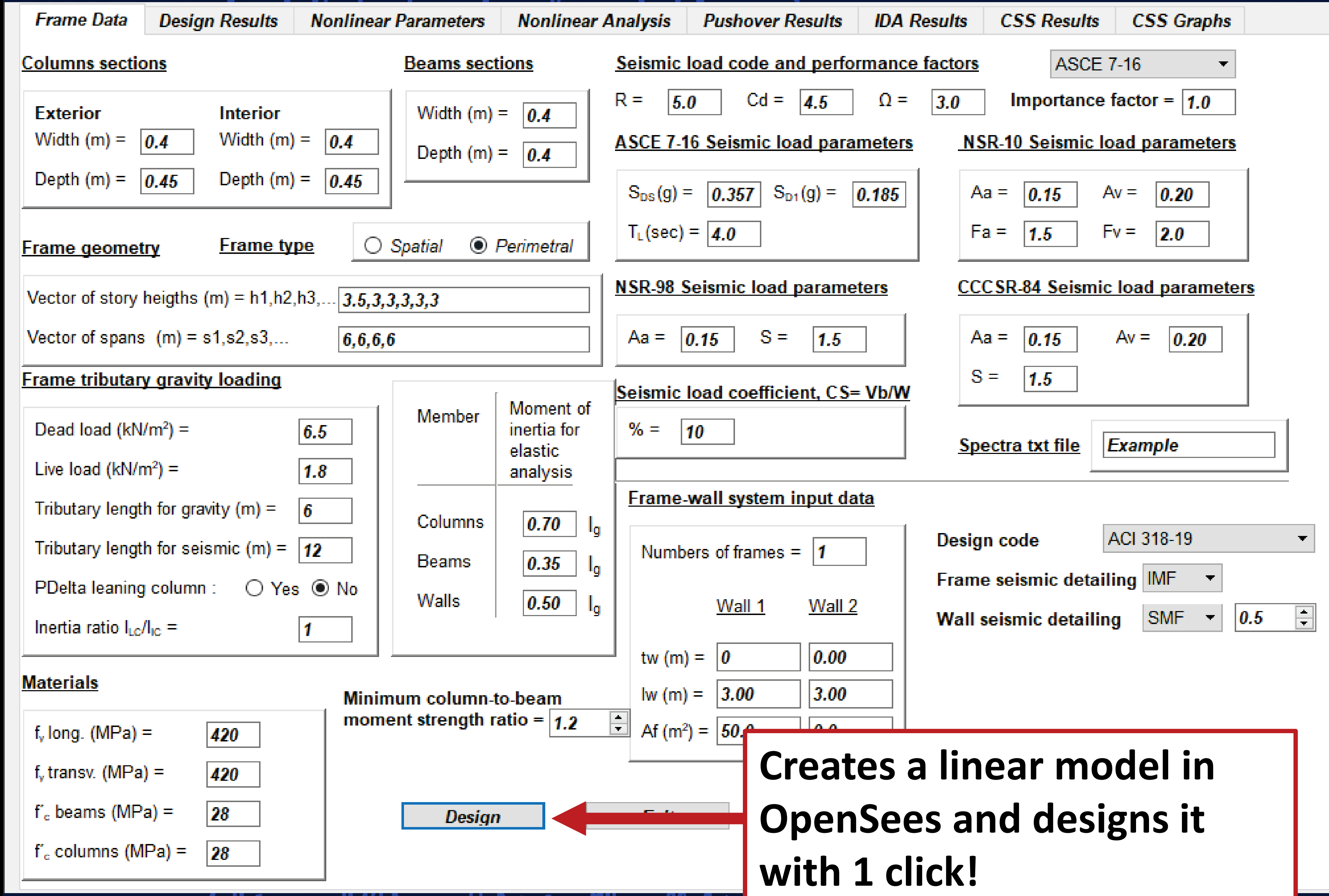
Story level



Building level



INPUT PARAMETERS FOR ELASTIC DESIGN



Creates a linear model in OpenSees and designs it with 1 click!

DESIGN GUI

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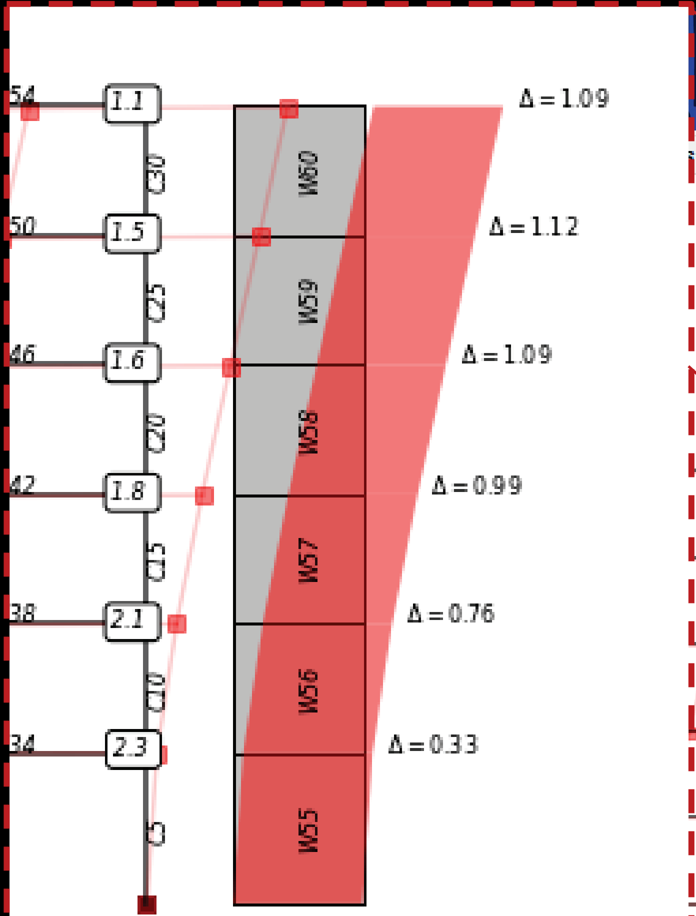
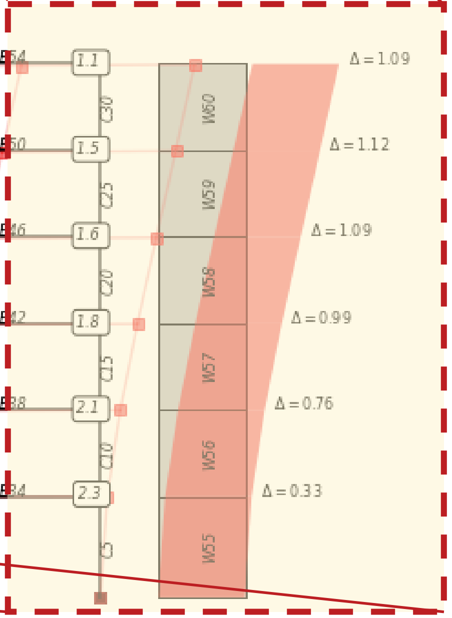
Nonlinear Analysis | Pushover Results | IDA Results | CSS Results | CSS Graphs





C2B Strength Ratios & Design Drifts

Beams detailing

	ID	b [cm]	h [cm]	L-end p_top	L-end p_bot	L-end Leg #	L-end Sstirrup [cm]	R-end p_top	R-end p_bot	R-end Leg #	R-end Sstirrup [cm]
1	B31	40	40	1.254	0.368	2	8	1.254	0.368	2	8
2	B32	40	40	1.254	0.368	2	8	1.254	0.368	2	8
3	B33	40	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	8
4	B34	40	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	8
5	B35	40	40	1.254	0.460	2	8	1.463	0.460	2	8

Columns detailing

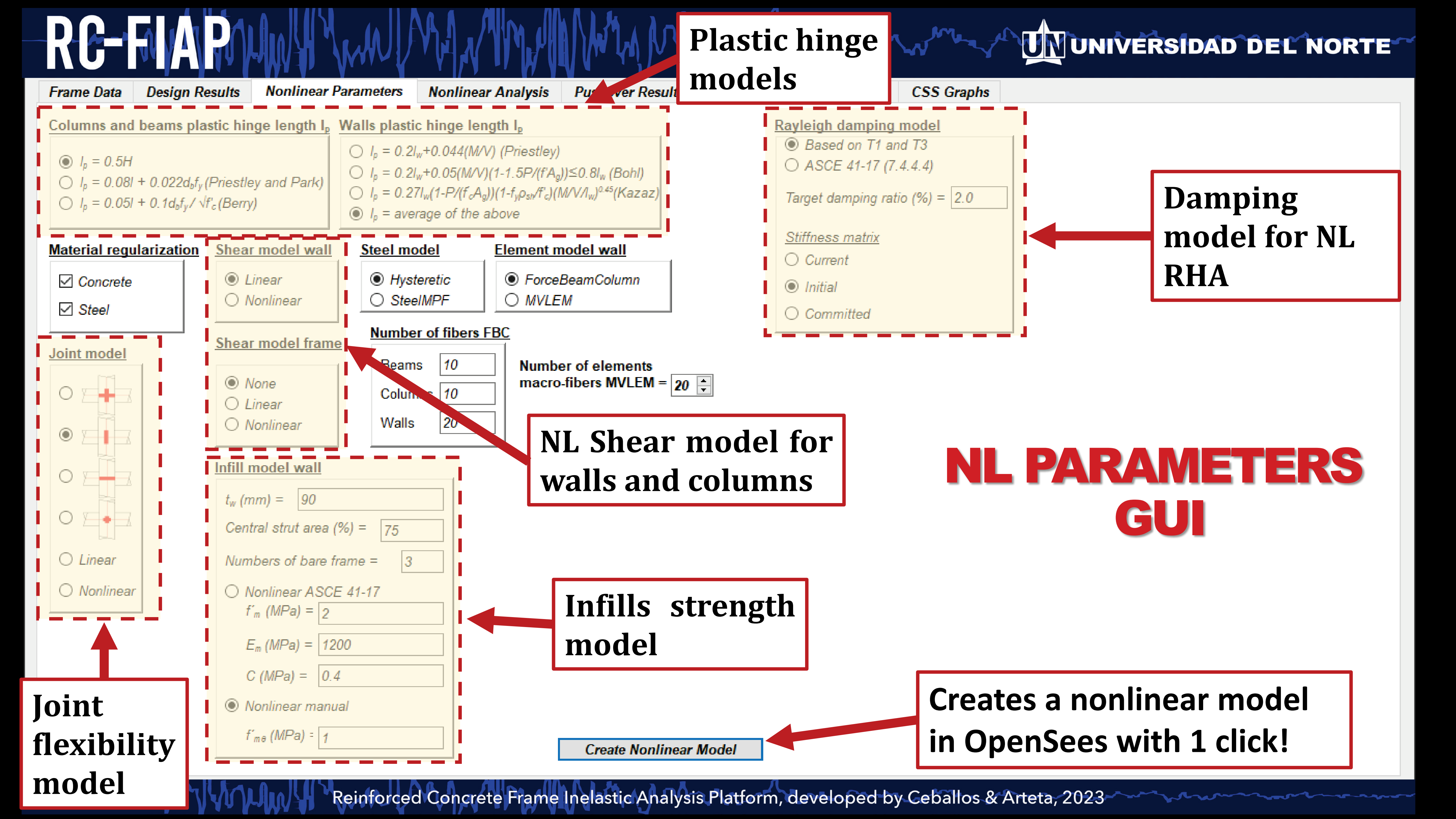
	ID	b [cm]	h [cm]	ρ	db [mm]	dst [mm]	nbH	nbB	Leg # H	Leg # B	Sstirrup [cm]	Vu/Vn
1	C1	40	45	1.13	12.70	9.53	5	5	3	3	10	0.26
2	C2	40	45	1.13	12.70	9.53	5	5	3	3	10	0.33
3	C3	40	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	10	0.34
4	C4	40	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	10	0.32
5	C5	40	45	1.13	12.70	9.53	5	5	3	3	10	0.24

Walls detailing

	ID	tw [cm]	lw [cm]	ρl	ρt	db [mm]	dst [mm]	c/lw	σc/f'c	Boundary Elements
1	W55	30	300	0.25	0.25	9.53	9.53	0.212	0.432	Yes
2	W56	30	300	0.25	0.25	6.35	9.53	0.181	0.297	Yes
3	W57	30	300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.201	Yes
4	W58	30	300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.119	NO
5	W59	30	300	0.25	0.25	6.35	9.53	0.096	0.055	NO

Accept desing parameters

Accept Design



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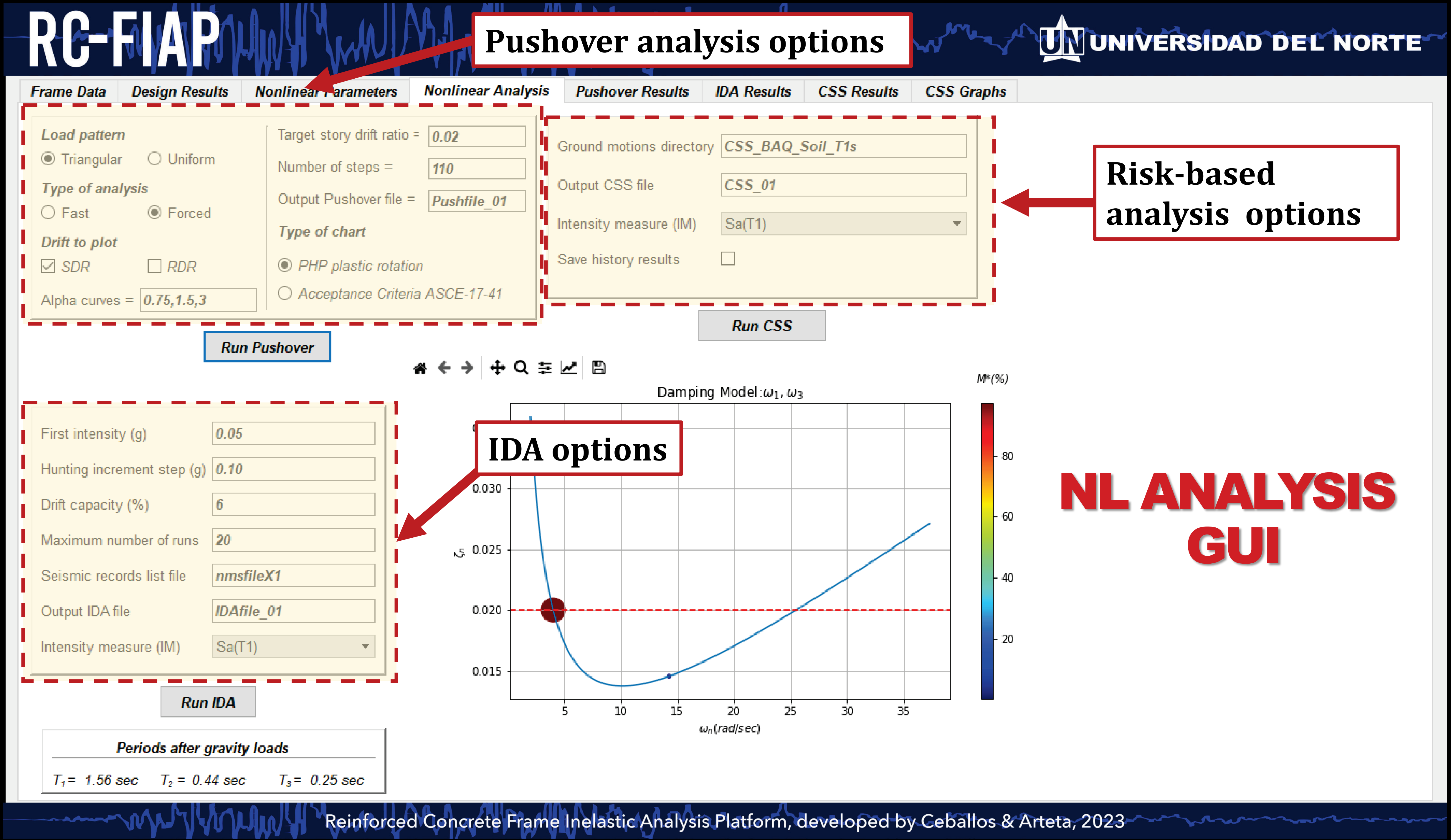
Plastic hinge models
Frame Data
Design Results
Nonlinear Parameters
Nonlinear Analysis
CSS Graphs
Columns and beams plastic hinge length l_p
l_p = 0.5H
l_p = 0.08l + 0.022$d_b f_y$ (Priestley and Park)
l_p = 0.05l + 0.1$d_b f_y$/ √f'c (Berry)
Walls plastic hinge length l_p
l_p = 0.2l_w+0.044(M/V) (Priestley)
l_p = 0.2l_w+0.05(M/V)(1-1.5P/(f'A_g))≤0.8l_w (Bohl)
l_p = 0.27l_w(1-P/($f_c A_g$))(1-$f_y \rho_{sh}$/f'c)(M/V/l_w)$^{0.45}$(Kazaz)
l_p = average of the above
Rayleigh damping model
Based on T1 and T3
ASCE 41-17 (7.4.4.4)
Target damping ratio (%) = 2.0
Stiffness matrix
Current
Initial
Committed
Damping model for NL RHA
Material regularization
Concrete
Steel
Shear model wall
Linear
Nonlinear
Steel model
Hysteretic
SteelMPF
Element model wall
ForceBeamColumn
MVLEM
Number of fibers FBC
Beams 10
Columns 10
Walls 20
Number of elements macro-fibers MVLEM = 20
Shear model frame
None
Linear
Nonlinear
Joint model
Linear
Nonlinear
NL Shear model for walls and columns
NL PARAMETERS GUI
Infill model wall
t_w (mm) = 90
Central strut area (%) = 75
Numbers of bare frame = 3
Nonlinear ASCE 41-17
f'm (MPa) = 2
Em (MPa) = 1200
C (MPa) = 0.4
Nonlinear manual
f'me (MPa) = 1
Infills strength model
Joint flexibility model
Create Nonlinear Model
Creates a nonlinear model in OpenSees with 1 click!
Reinforced Concrete Frame Inelastic Analysis Platform, developed by Ceballos & Arteta, 2023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Pushover analysis options
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Frame Data
Design Results
Nonlinear Parameters
Nonlinear Analysis
Pushover Results
IDA Results
CSS Results
CSS Graphs
Load pattern
Triangular
Uniform
Type of analysis
Fast
Forced
Drift to plot
SDR
RDR
Alpha curves = 0.75,1.5,3
Target story drift ratio = 0.02
Number of steps = 110
Output Pushover file = Pushfile_01
Type of chart
PHP plastic rotation
Acceptance Criteria ASCE-17-41
Run Pushover
Ground motions directory CSS_BAQ_Soil_T1s
Output CSS file CSS_01
Intensity measure (IM) Sa(T1)
Save history results
Run CSS
Risk-based analysis options
First intensity (g) 0.05
Hunting increment step (g) 0.10
Drift capacity (%) 6
Maximum number of runs 20
Seismic records list file nmsfileX1
Output IDA file IDAfile_01
Intensity measure (IM) Sa(T1)
Run IDA
IDA options
Periods after gravity loads
T_1 = 1.56 sec
T_2 = 0.44 sec
T_3 = 0.25 sec
Damping Model: ω_1, ω_3
ζ
0.030
0.025
0.020
0.015
5
10
15
20
25
30
35
ω_n(rad/sec)
M*(%)
80
60
40
20
NL ANALYSIS GUI
Reinforced Concrete Frame Inelastic Analysis Platform, developed by Ceballos & Arteta, 2023

RC-FIAP

PUSHOVER: FRAMES

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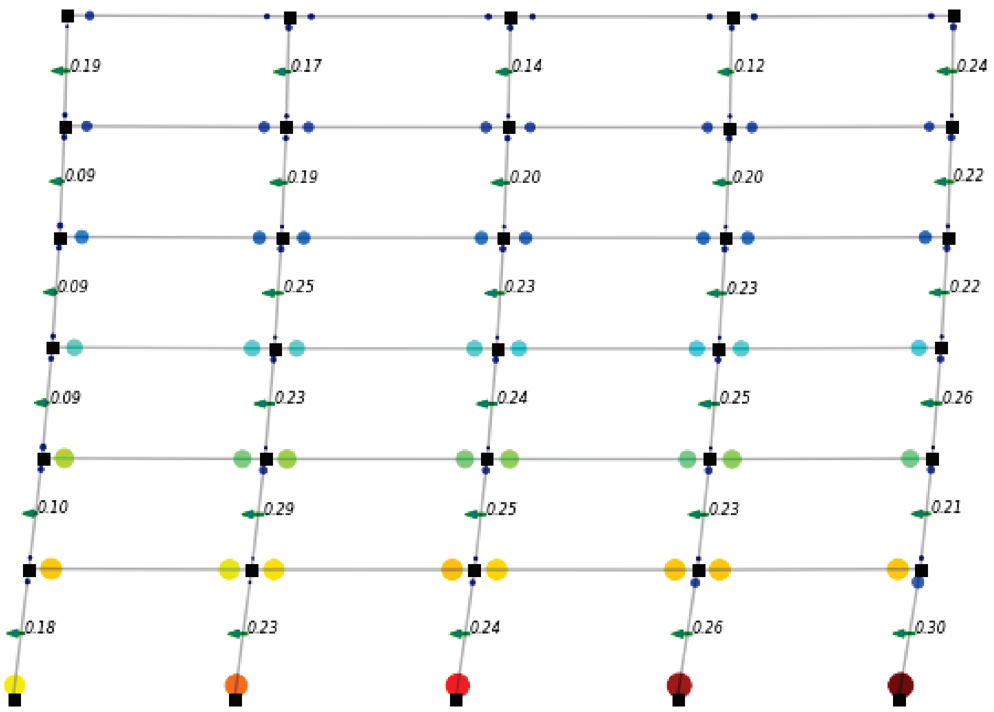
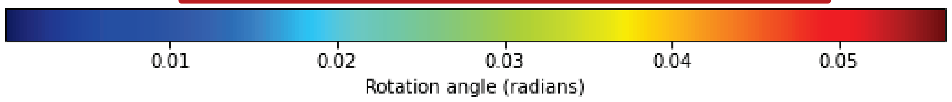
Frame Data | Design Results | Nonlinear Parameters | Nonlinear Analysis | Pushover Results | IDA Results | CSS Results | CSS Graphs

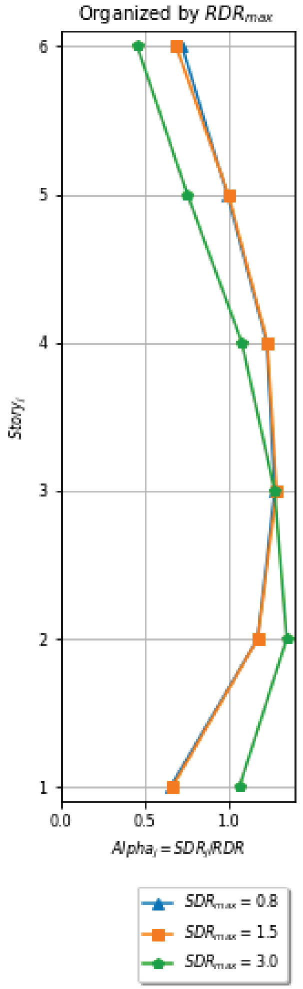
Plastic hinge projector



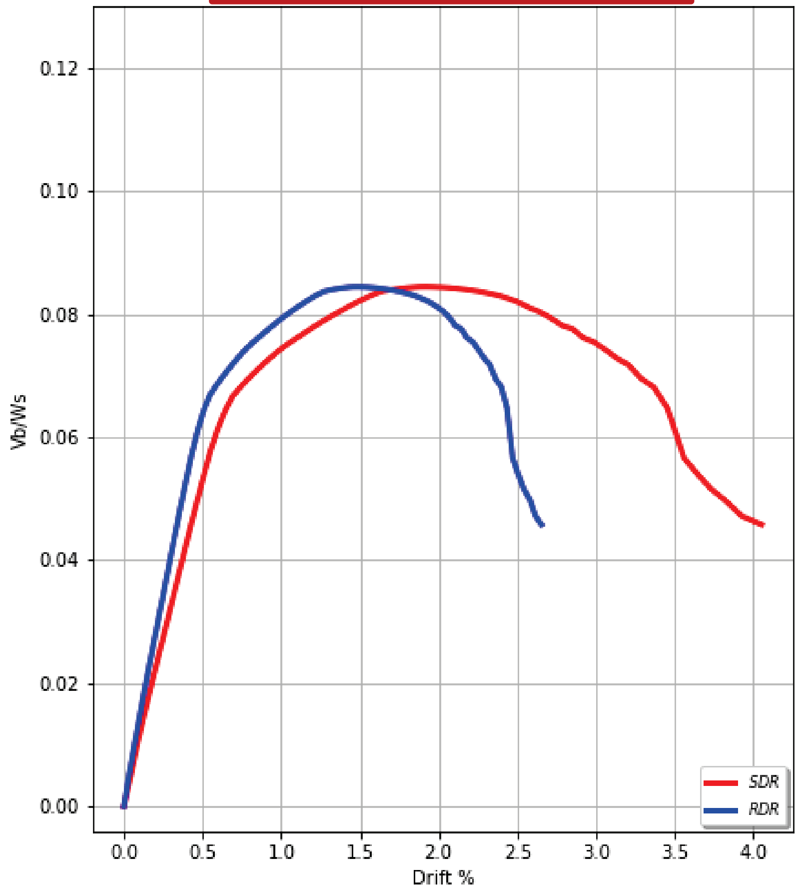
End rotations heatmap



$\alpha = SDR_j / RDR$



Pushover curve



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PUSHOVER: FRAME-WALL

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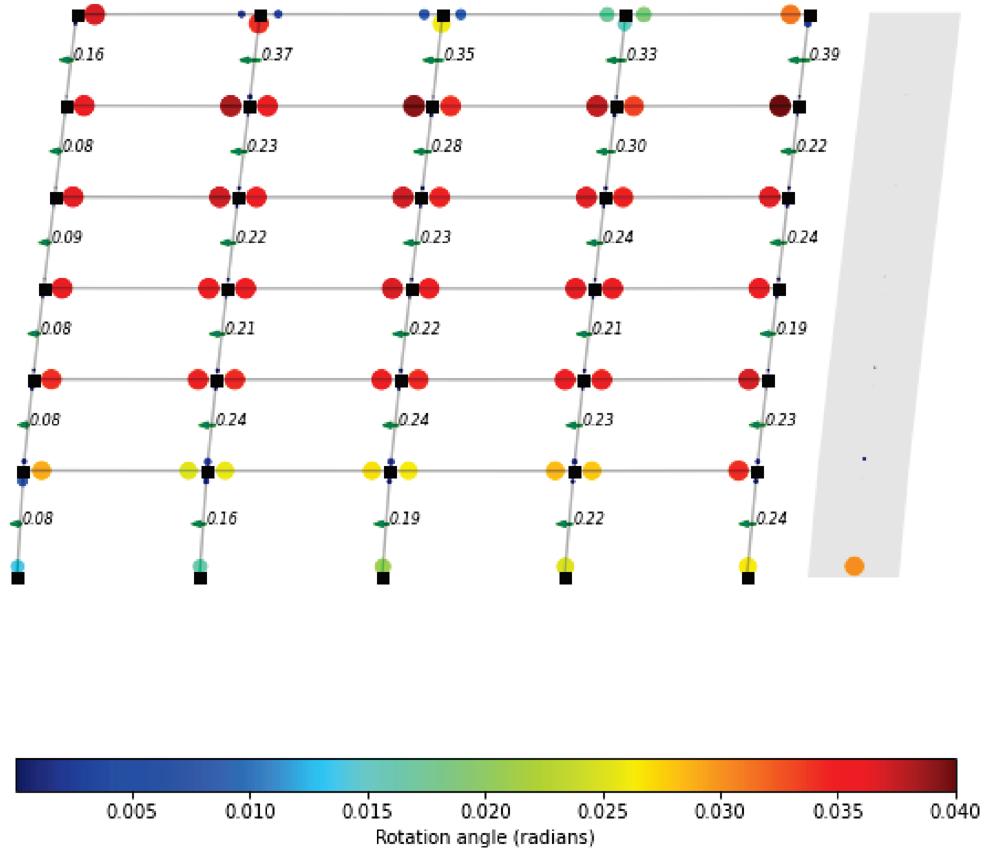
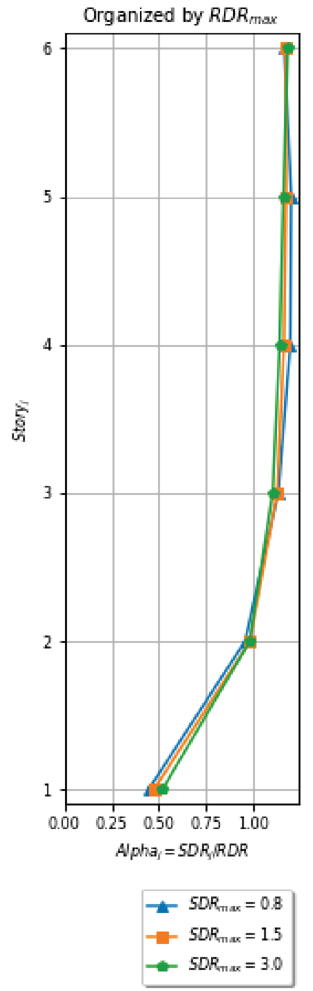
Frame Data | Design Results | Nonlinear Parameters | Nonlinear Analysis | Pushover Results | IDA Results | CSS Results | CSS Graphs

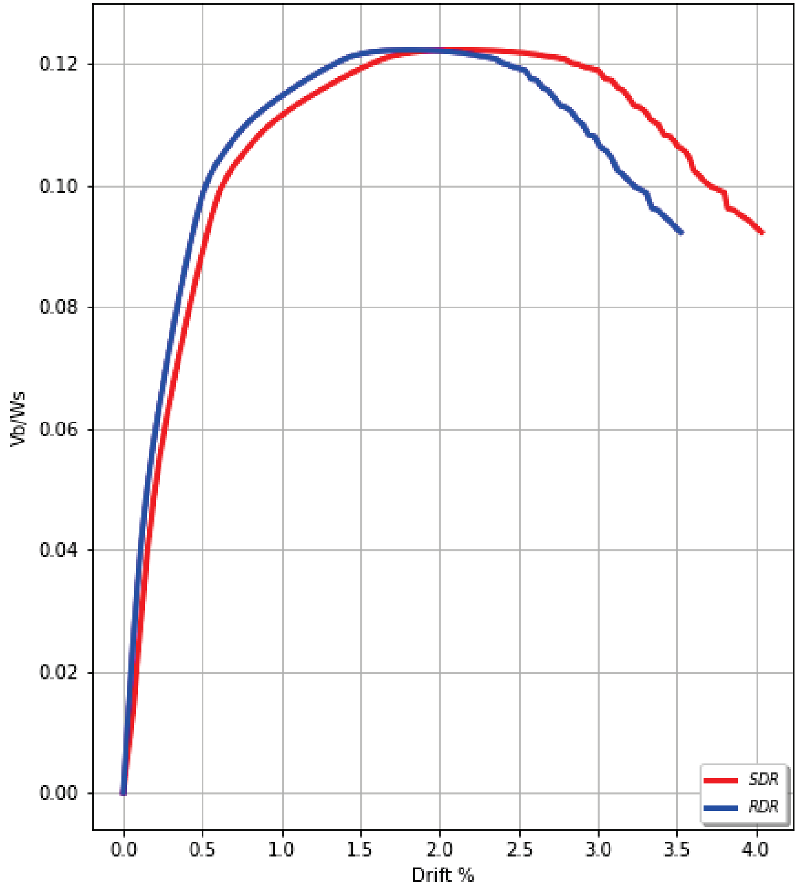
Plastic hinge projector



$\alpha = SDR_j / RDR$



Pushover curve



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PUSHOVER: INFILLED-FRAME

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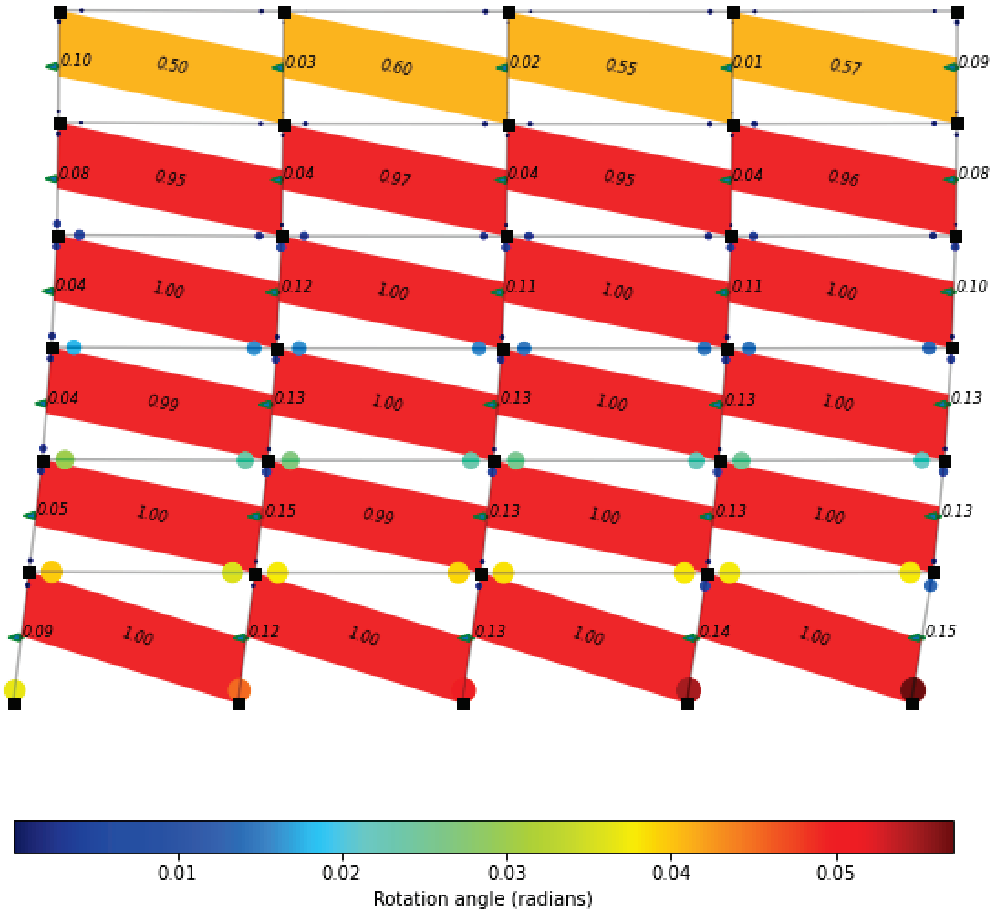
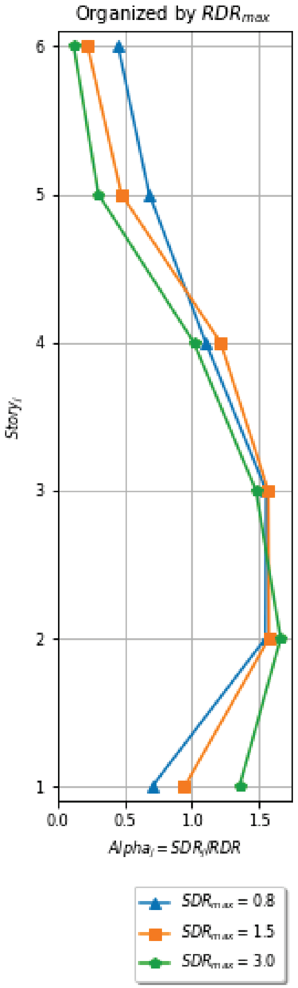
Frame Data | Design Results | Nonlinear Parameters | Nonlinear Analysis | Pushover Results | IDA Results | CSS Results | CSS Graphs

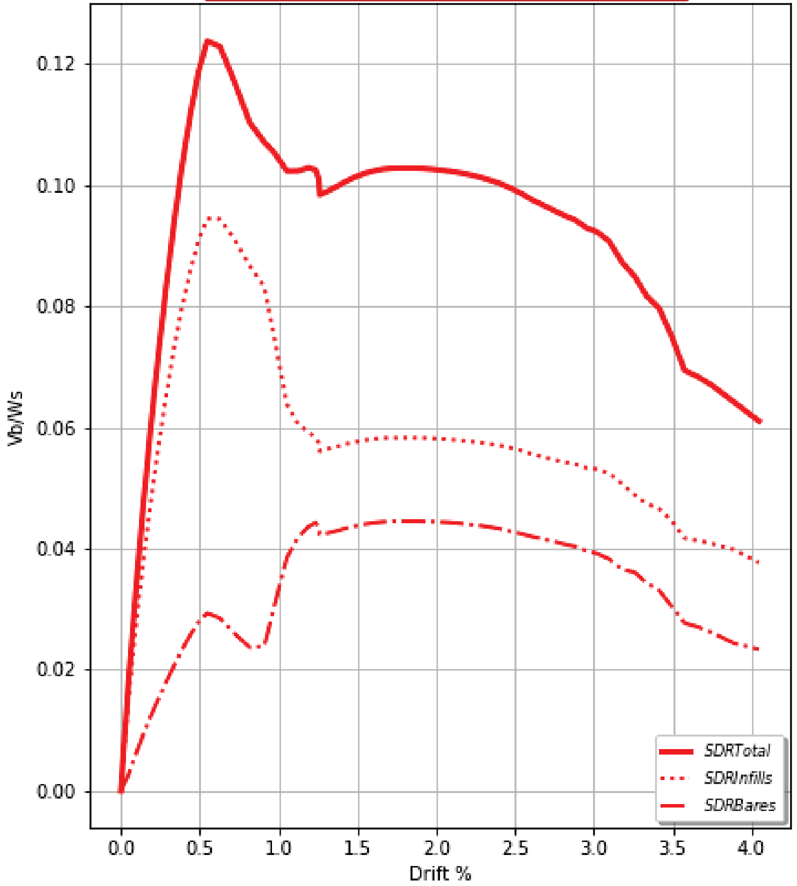
Plastic hinge projector



$\alpha = SDR_j / RDR$



Pushover curve



RC-FIAP PUSHOVER: OLDER INFILLED-FRAME

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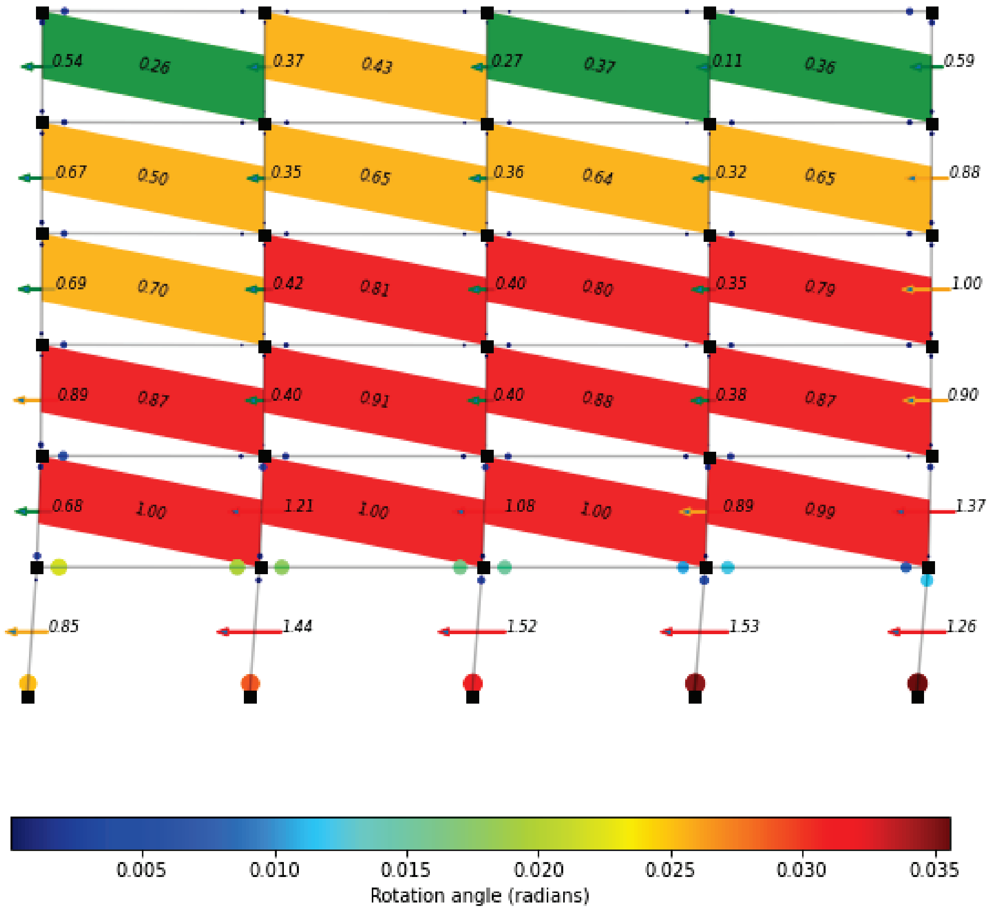
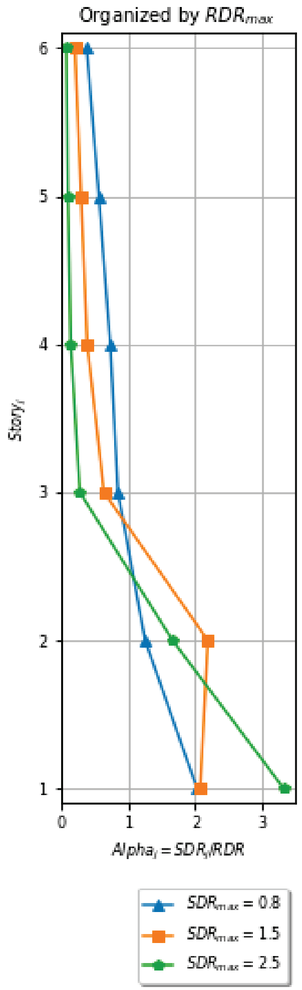
Frame Data | Design Results | Nonlinear Parameters | Nonlinear Analysis | Pushover Results | IDA Results | CSS Results | CSS Graphs

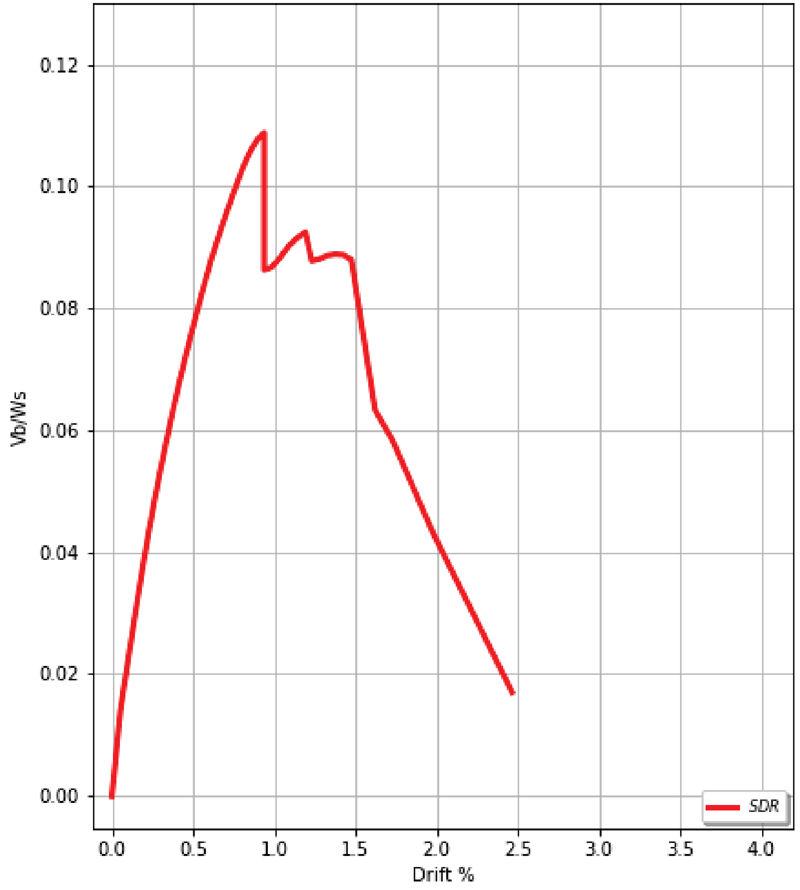
Plastic hinge projector



$\alpha = SDR_j / RDR$



Pushover curve



RC-FIAP CSS RESULTS GUI

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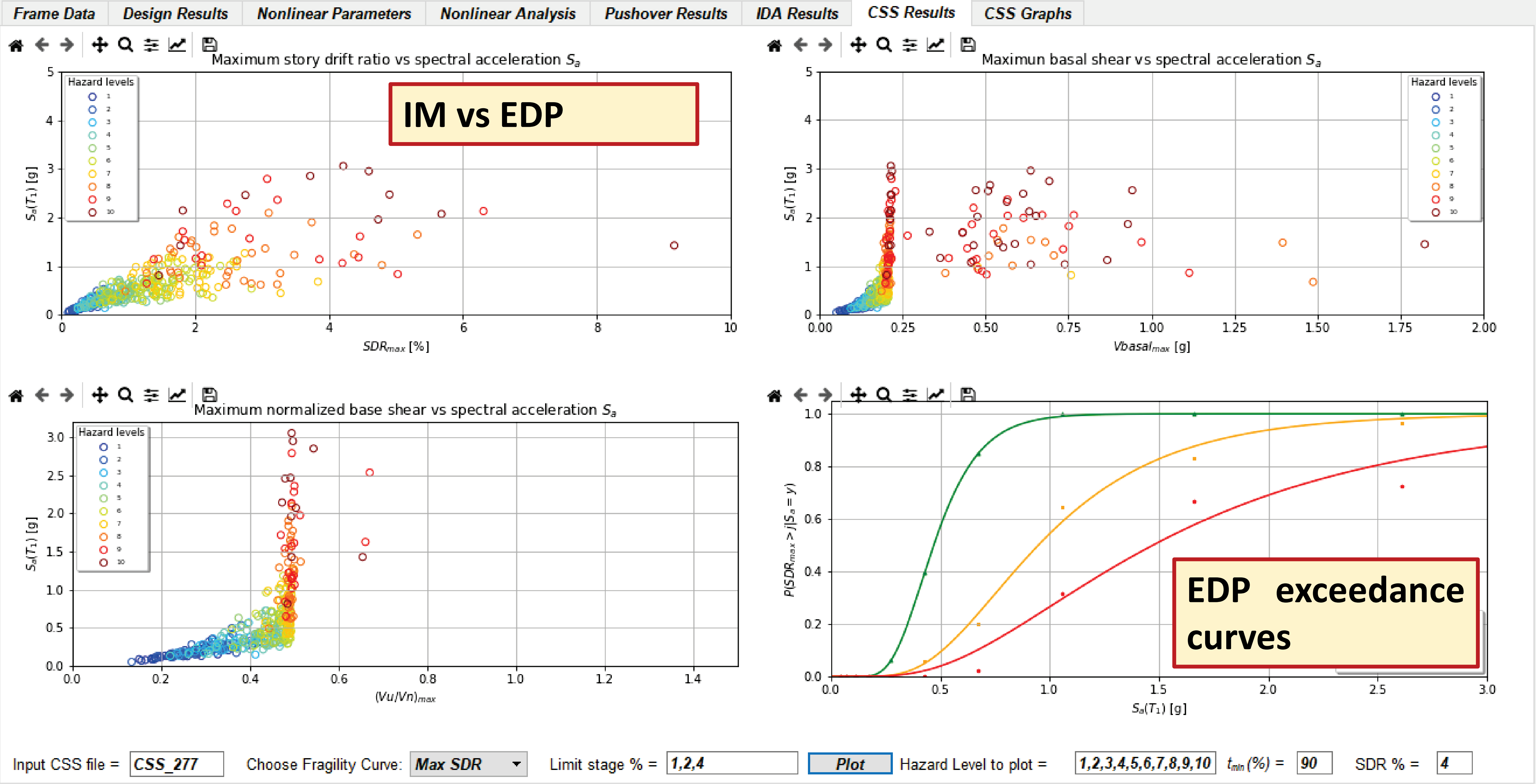
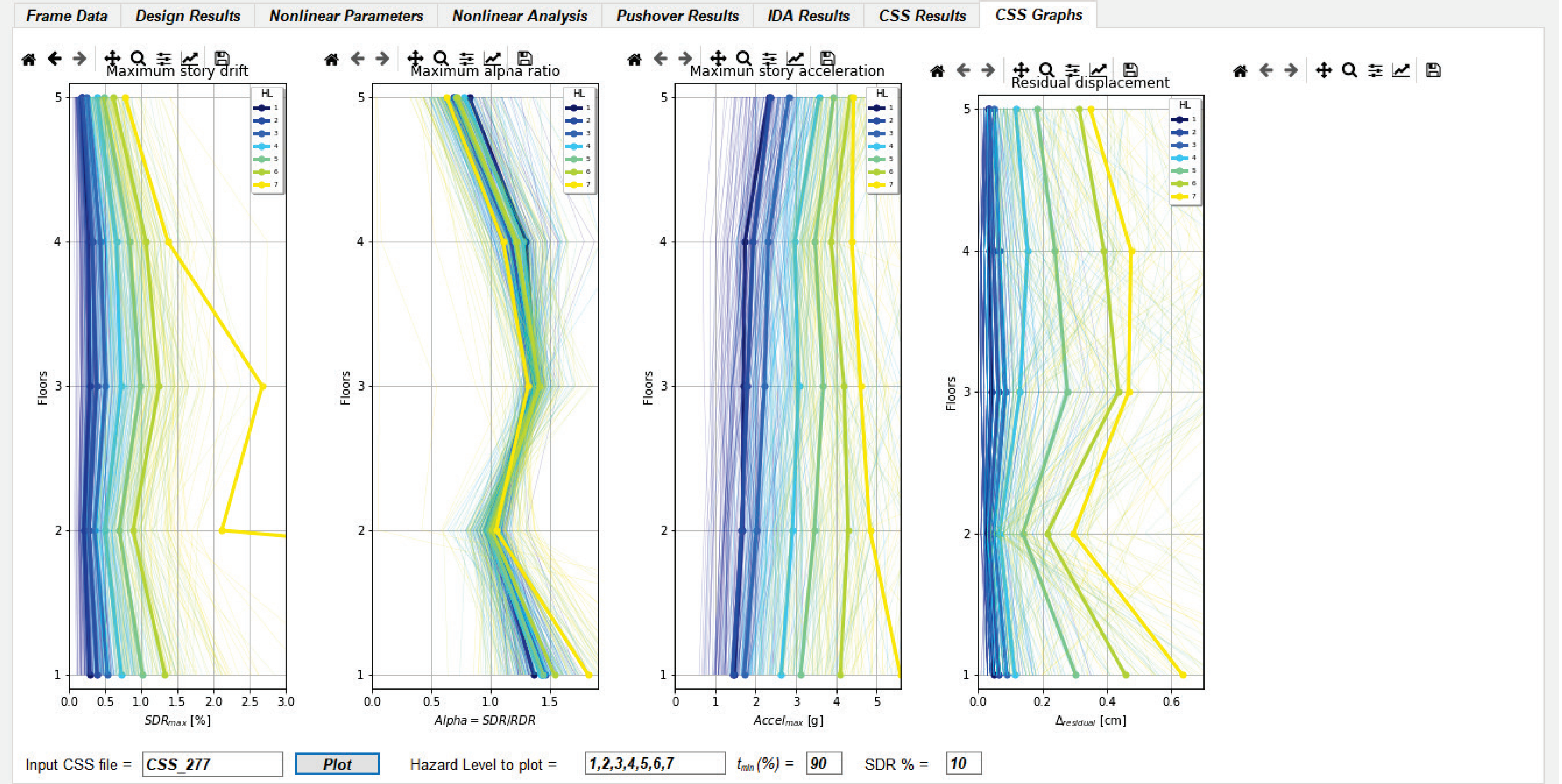


DIST. OF EDP PER STORY



Reinforced Concrete Frame Inelastic Analysis Platform, developed by Ceballos & Arteta, 2023

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FUNDAMENTALS: FRAGILITY AND VULNERABILITY

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V-FAST includes:

Taxonomy fragility estimations of buildings of the same height and construction typology.

Estimation of expected losses by story and by building.

Fragility of Buildings → Fragility of Taxonomies → Loss Components → Loss of Buildings → Loss of Taxonomies

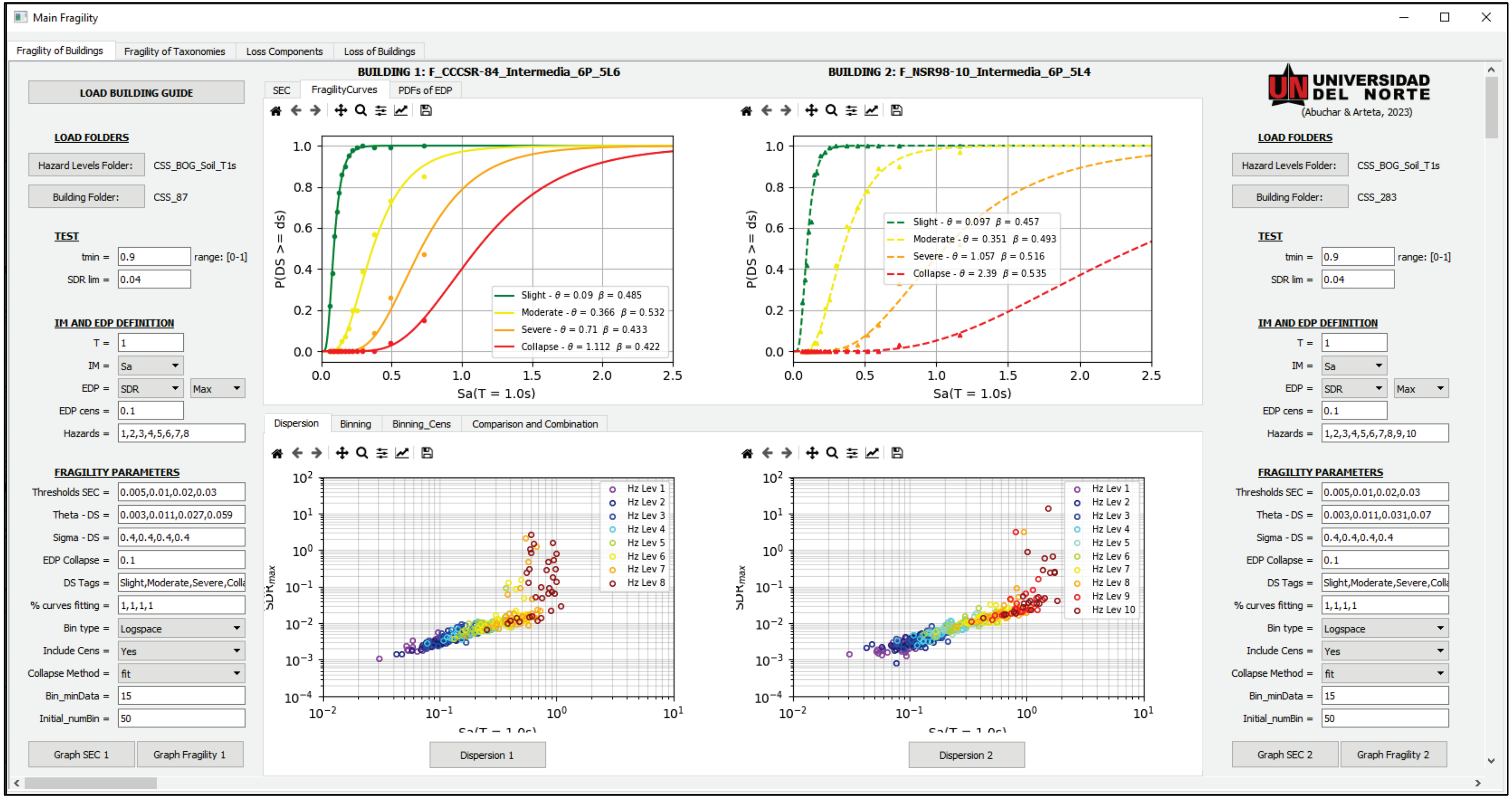
Fragility estimation of up to two buildings at a time for comparison and/or combination.

Loads and plots fragility of components and estimates expected repair cost.

Currently working in this section…

V-FAST

V-FAST: FRAGILITY OF BUILDINGS



DAMAGE STATE DEFINITION PER BUILDING HEIGHT

- Post-earthquake evidence
- Experimental Studies
- Mechanical behavior of structures (*first-principles*)
- Expert opinion and/or judgment

Yielding

$$\theta_y = \phi_y \frac{L_s}{3} + 0.0025 + a_{sl} \frac{0.25 \varepsilon_y d_b f_y}{(d - d')\sqrt{f_c'}}$$ → Experimental Studies, *First-principles*

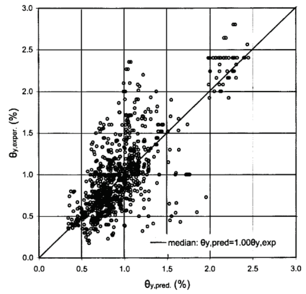


Fig. 2—Comparison of experimental and predicted values of chord rotation (or drift) at yield (963 tests).

Ultimate Capacity

$$\theta_u(\%) = \alpha_{st}\alpha_{cyc}\left(1 + \frac{a_{sl}}{2.3}\right)\left(1 - \frac{a_{wall}}{3}\right)(0.2^{\nu})\left[\frac{max\left(0.01, \frac{\rho' f_y'}{f_c'}\right)}{max\left(0.01, \frac{\rho f_y}{f_c'}\right)} f_c'\right]^{0.275} \left(\frac{L_s}{h}\right)^{0.45} 1.1^{\left(100\alpha\rho_{sx}\frac{f_{yh}}{f_c'}\right)}\left(1.3^{100\rho_d}\right)$$ → Experimental Studies

Panagiotakos and Fardis (2001)

DAMAGE STATE DEFINITION

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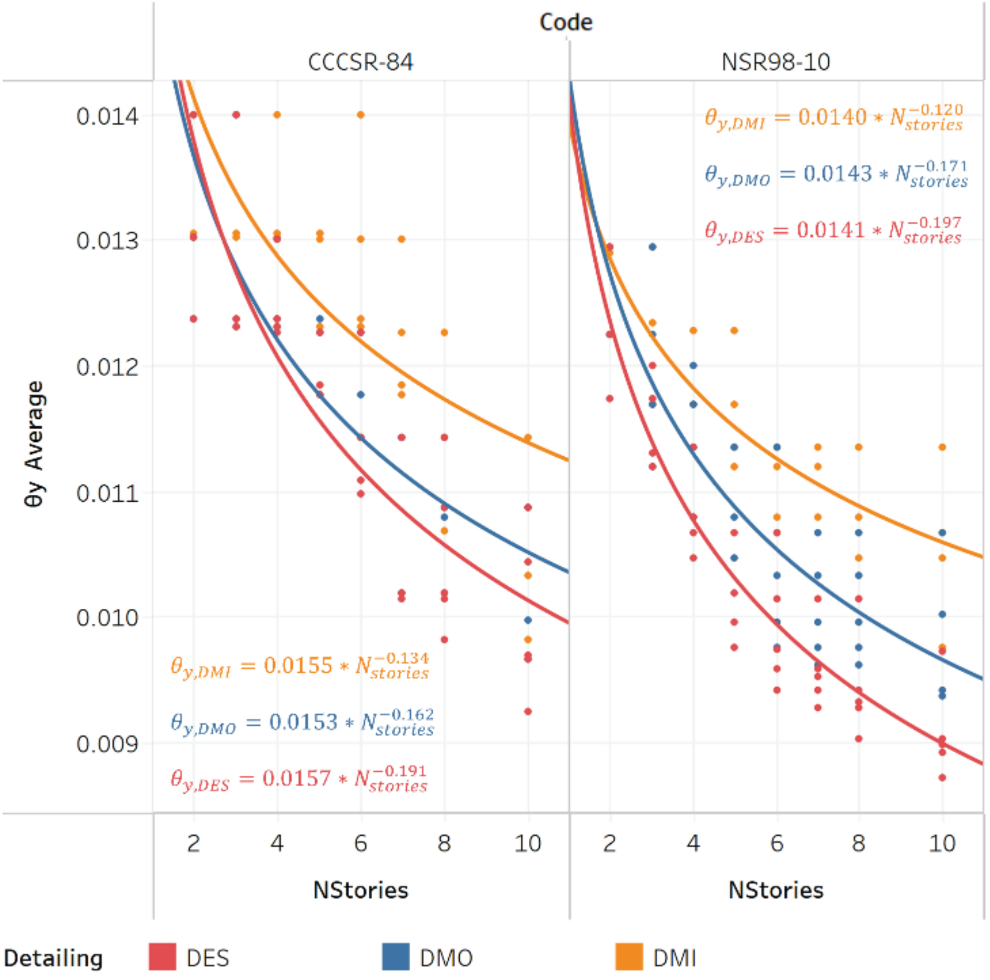
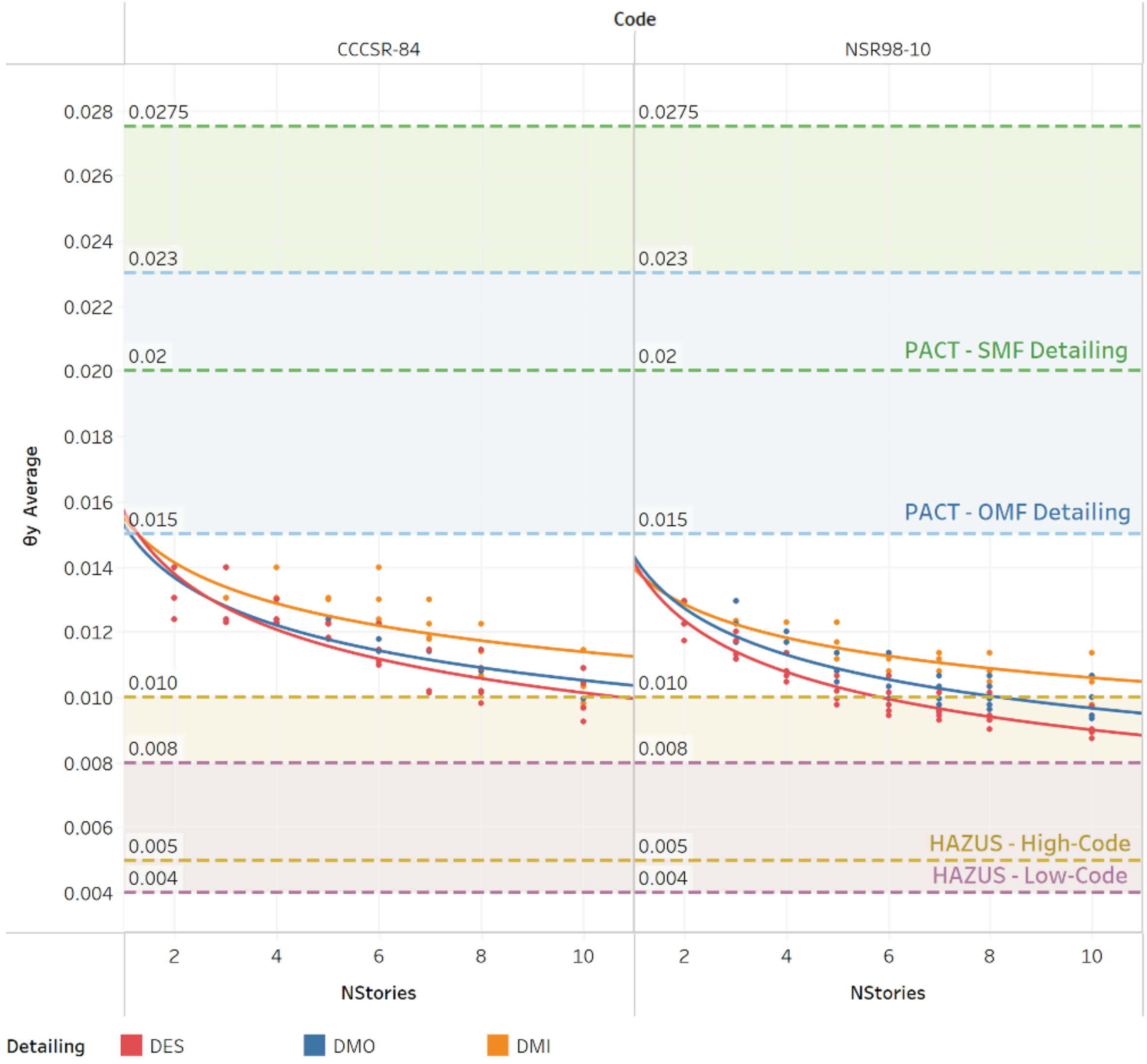
Damage states definition for each building height, detailing and code era

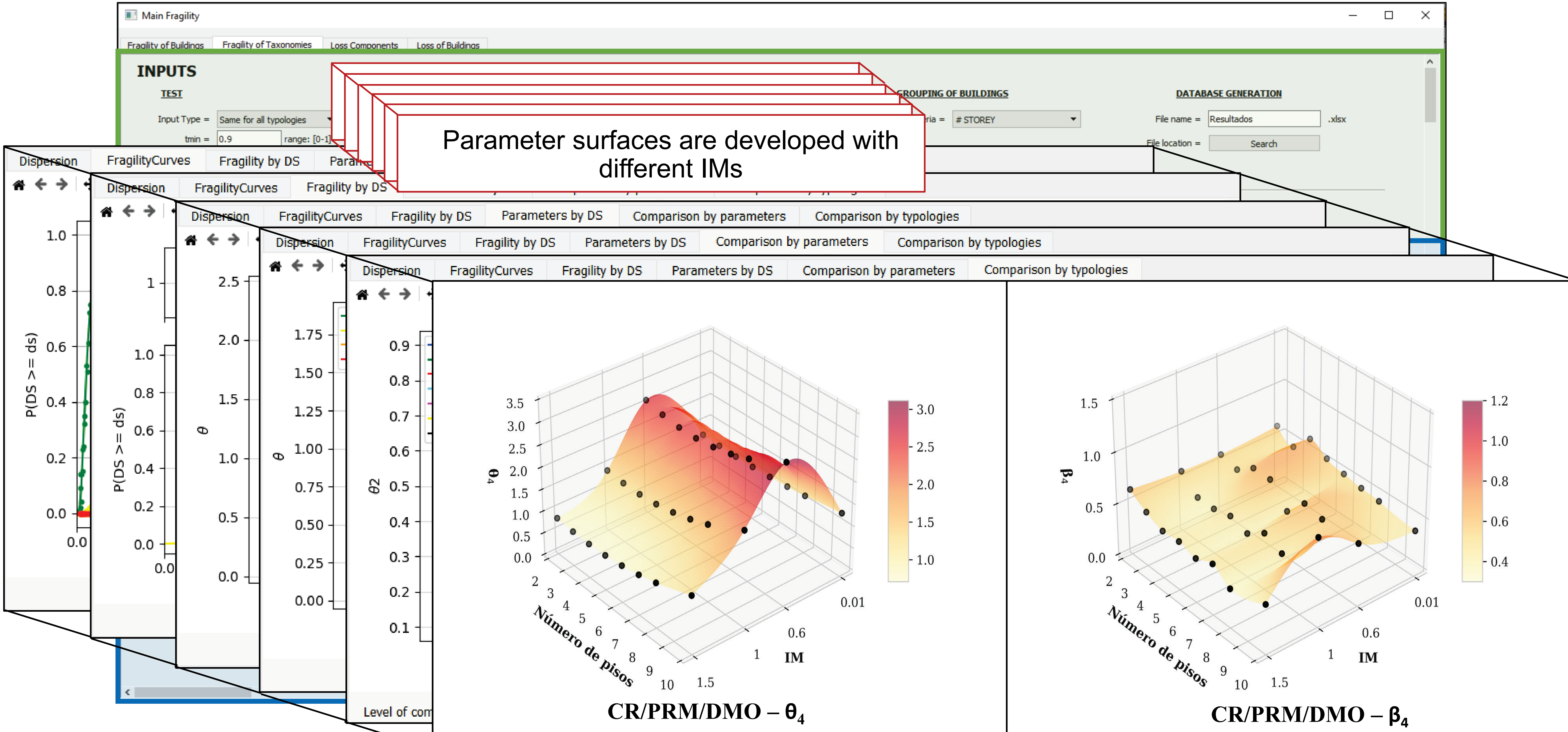


Comparison with PACT and HAZUS



V-FAST: FRAGILITY OF TAXONOMIES

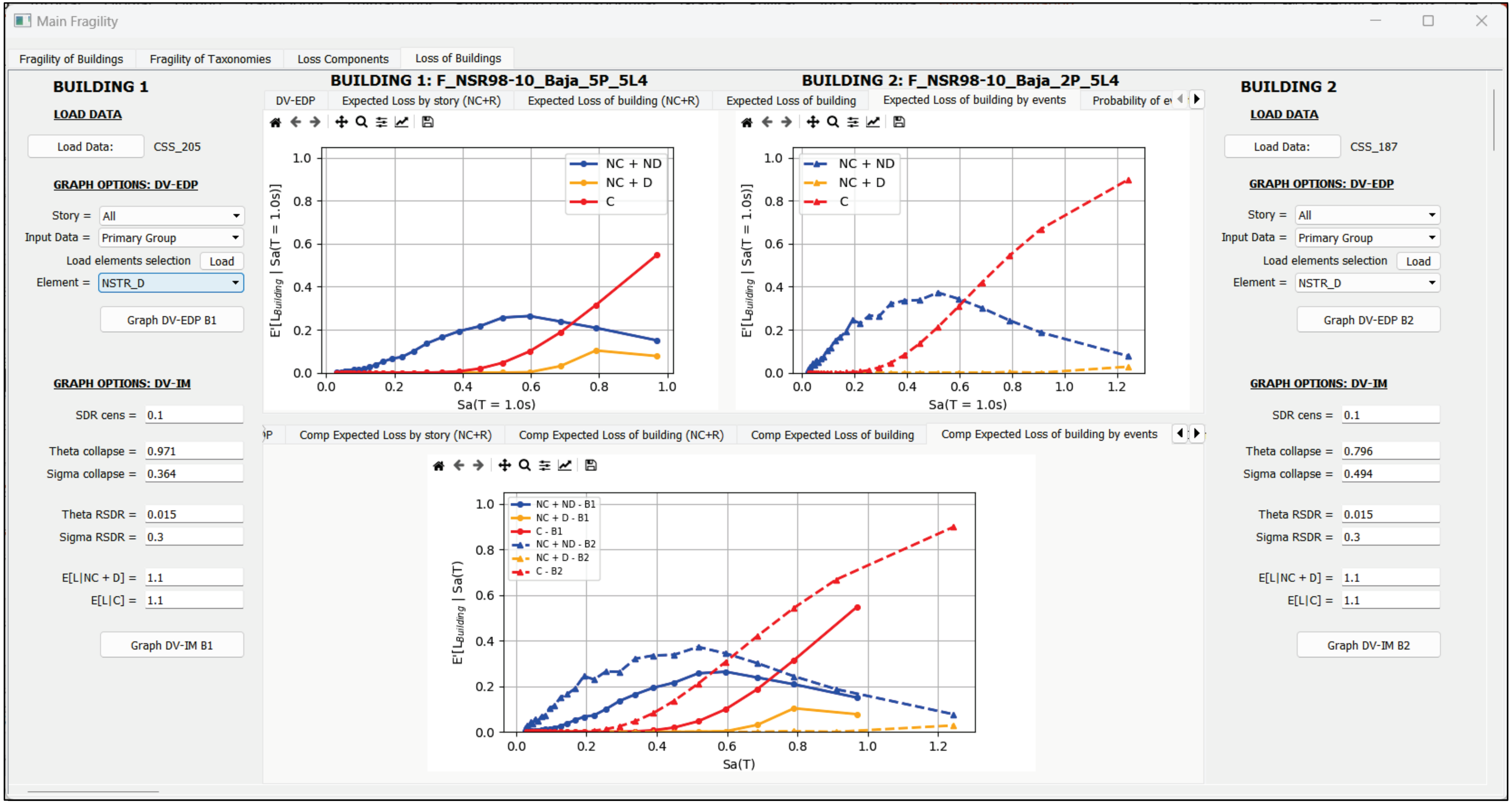
File generation with taxonomy parameters (e.g., CR/PRM/DMO/3)



V-FAST: LOSS OF BUILDINGS

Expected losses of building by events

Based on Ramirez & Miranda (2009)



CONCLUSIONS

- RC-FIAP and V-FAST are open tools for the practice, research and academia.

- Enables high-resolution modeling of a large number of structural models with ease.

- Enables understanding the consequence of detailing decisions in the seismic risk of RC structural typologies.

Acknowledgements

- SGC - Colombian Geological Survey
- ACOFI - Colombian Association of Engineering Schools

Víctor Ceballos, PhD(s)

bit.ly/RC-FIAP