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Numerical aspects of incremental dynamic analysis for the retrofitting of existing industrial steel building utilizing SSCD dampers

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Neapolis University Pafos

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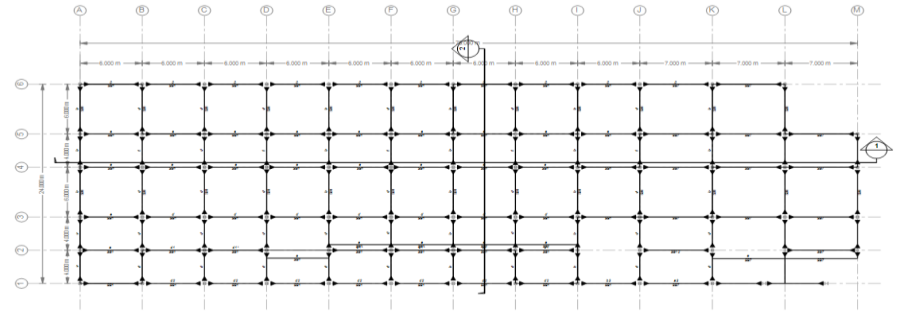
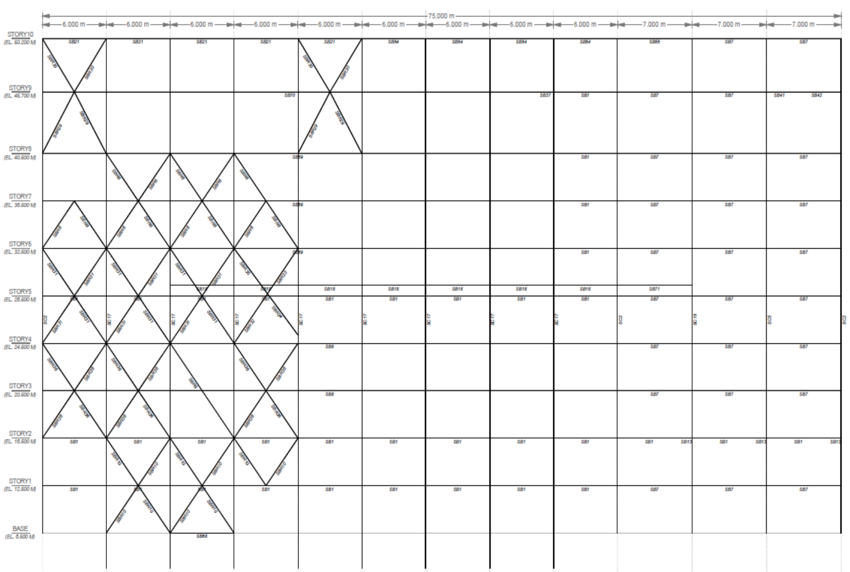
Abstract

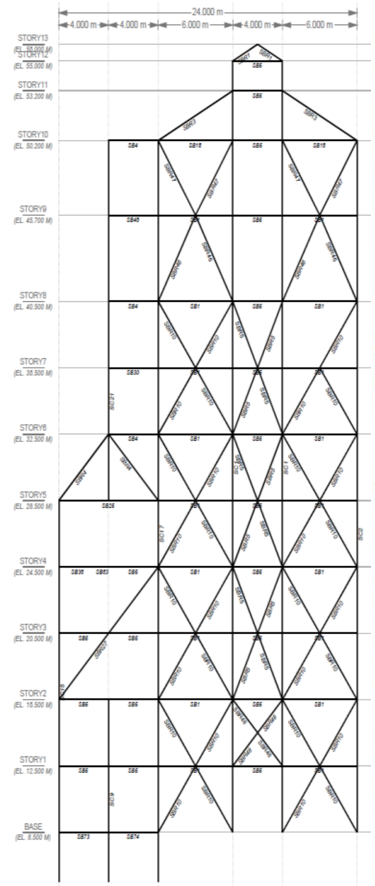
In this work, the nonlinear analysis of an existing industrial steel structure (Sodium building), and its retrofitting using SSCD dampers is demonstrated. Specific numerical complications of incremental dynamic (IDA) and pushover analyses as well as their resolution are presented. In particular, the modelling of a flag shaped, self-centering steel device (SSCD) exhibiting re-centering and recovery, as well as it's connection to the structural frames, the results of IDAs in comparison with the results of the Pushover analysis, the ability of IDA to capture nonlinear behavior for high accelerations where pushover stops, the optimal values of dampers stiffness and strength in order to maximize the energy dissipation within the structure, the comparison of the structural performance before and after retrofitting, as well as the association between the re-centering β-factor and capacity curves, are analytically demonstrated. Additionally, the effect of the variation of the dampers positions along building's height as well as the effect of the damper to the capacity curves is discussed.

Case study

- >3000 structural elements
- Steel cross sections
- Incremental Dynamic Analysis
- With(out) SSCD Dampers
- PRO-INDUSTRY
- EU Funding (Coal & Steel)







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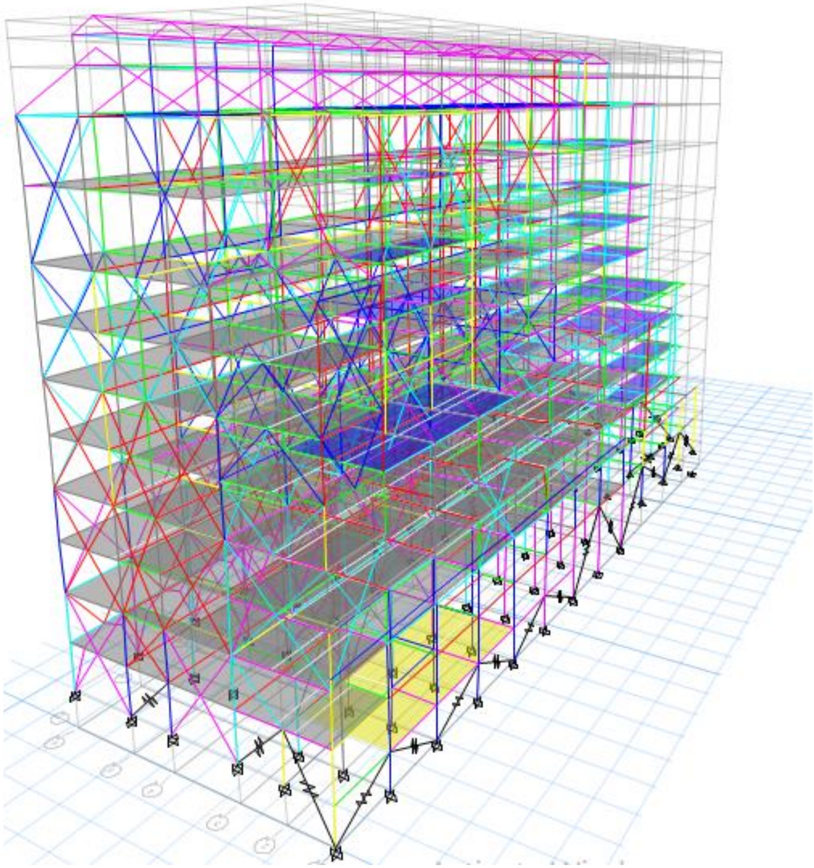
Initial investigation

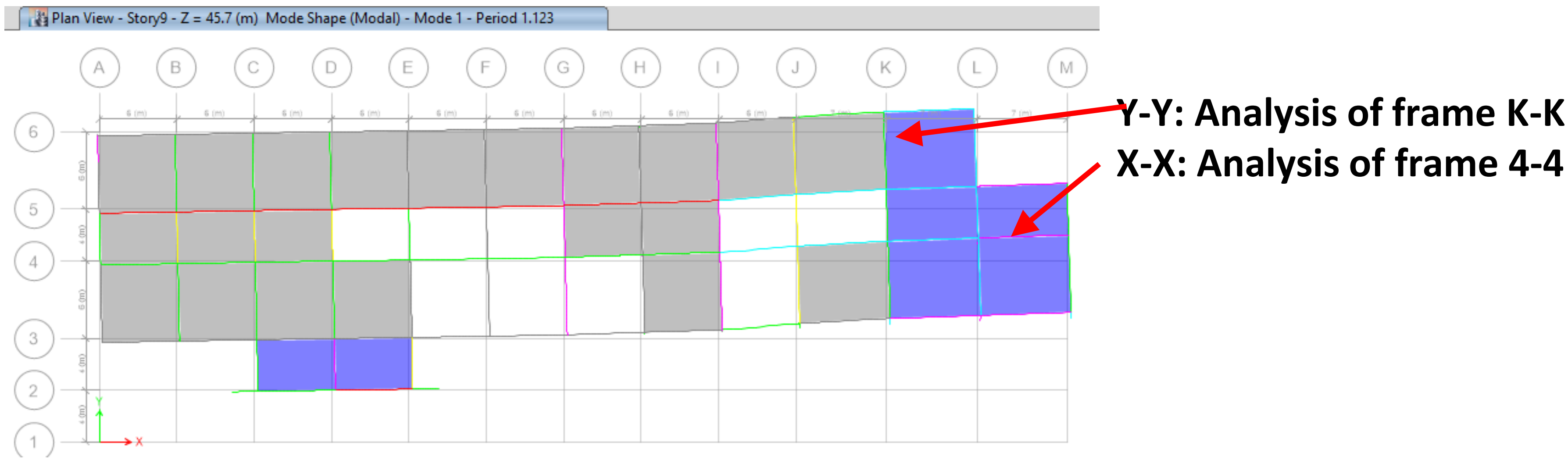
- Analysis of 3D model
- Convergence issues
- SAP2000
- Open programming interface
- Optimization of the dampers
- Numerical instabilities
- Convergence issues, local failures

```
        int ret;
        string pathToETABS =
System.IO.Path.Combine(Environment.GetEnvironmentVariable("PROGRAMFILES"), "Computers and
Structures", "ETABS 2015", "ETABS.exe");
        System.Reflection.Assembly ETABSAssembly =
System.Reflection.Assembly.LoadFrom(pathToETABS);
        ETABS2015.cOAPI ETABSObject =
(ETABS2015.cOAPI)ETABSAssembly.CreateInstance("CSI.ETABS.API.ETABSObject");
        ret = ETABSObject.ApplicationStart();
        //ETABSObject.Hide();
        ETABS2015.cSapModel SapModel = ETABSObject.SapModel;
        ret = SapModel.File.OpenFile(dir);
        ret = SapModel.SetModelIsLocked(false);
        ret = SapModel.SetPresentUnits(ETABS2015.eUnits.kN_m_C);
```

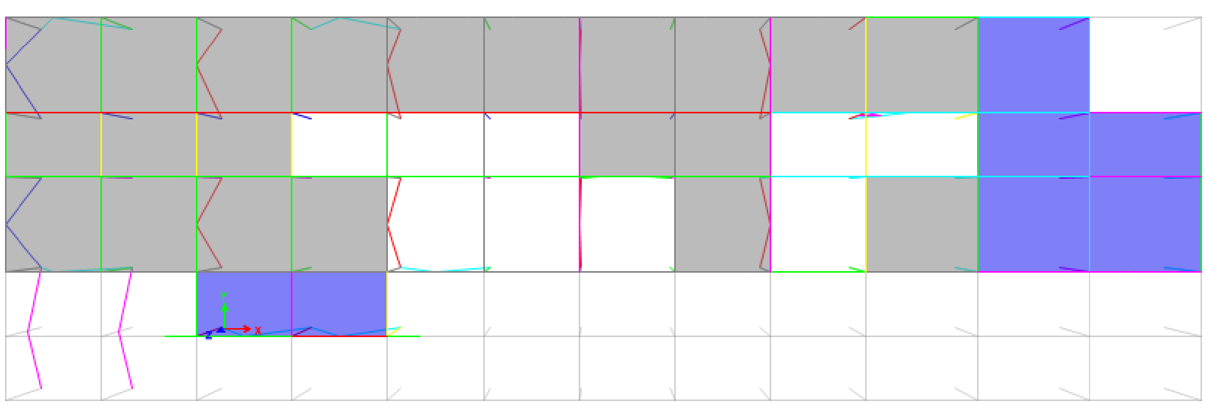


Frame selection

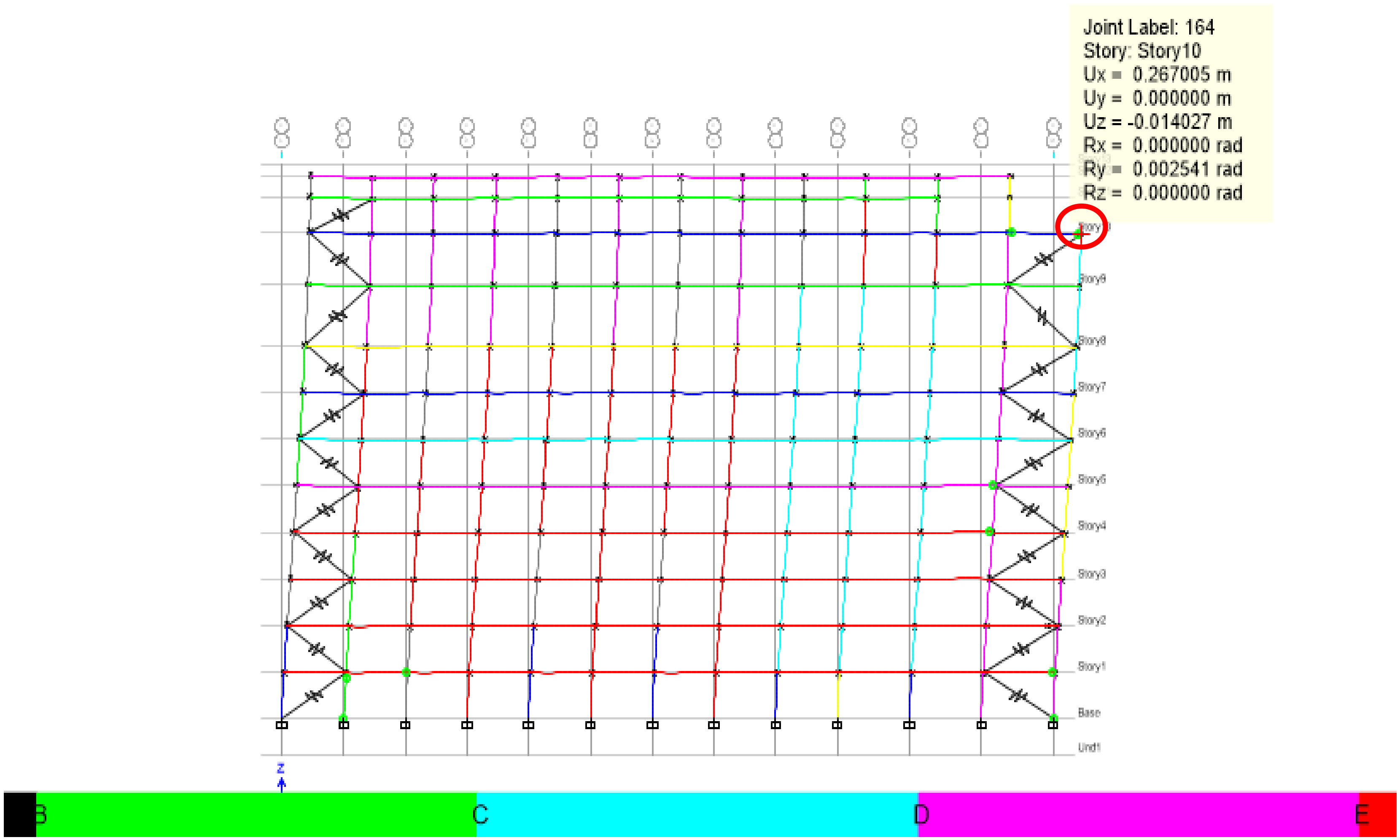
- 13 plane frames exist in yy direction (views A to M)
- The first Eigenmode contains a torsional component, thus frames at the right x-x side should be strengthened



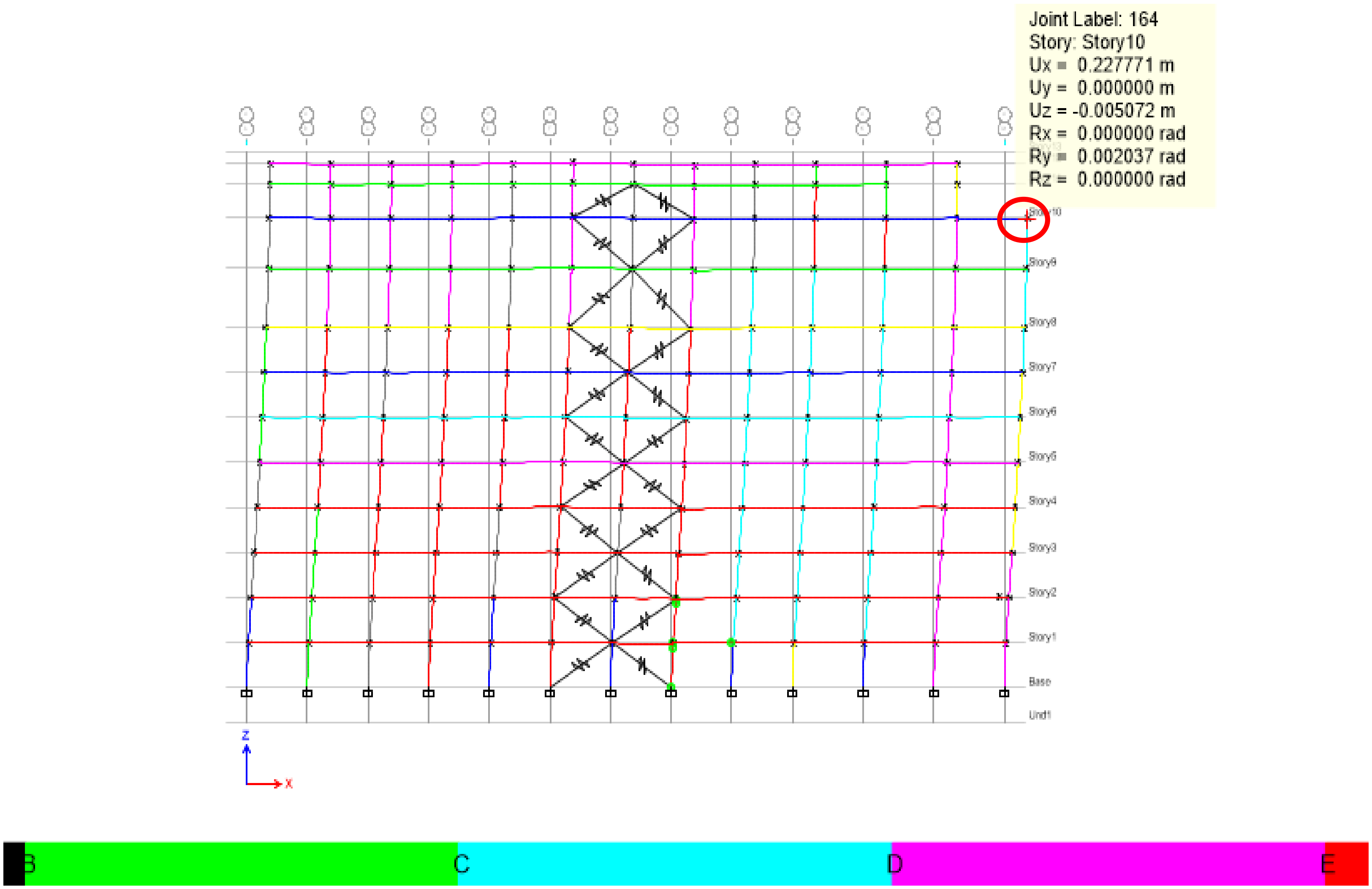
- In the following frames already exist diagonal braces (perspective toggle)



X-X: Case 1

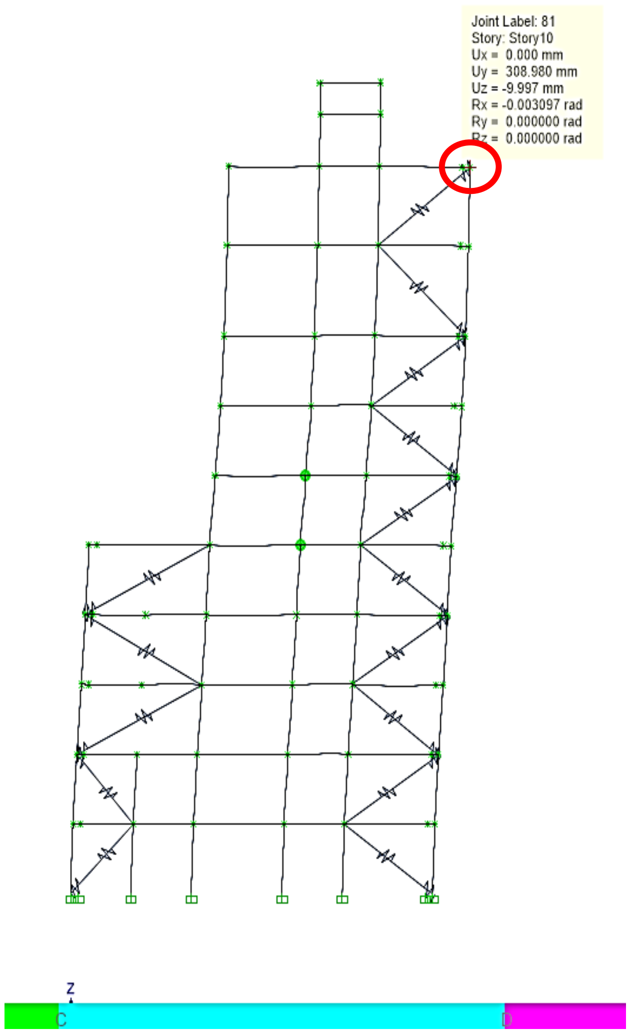

Joint Label: 164
Story: Story10
Ux = 0.267005 m
Uy = 0.000000 m
Uz = -0.014027 m
Rx = 0.000000 rad
Ry = 0.002541 rad
Rz = 0.000000 rad
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
B
C
D
E

X-X: Case 2

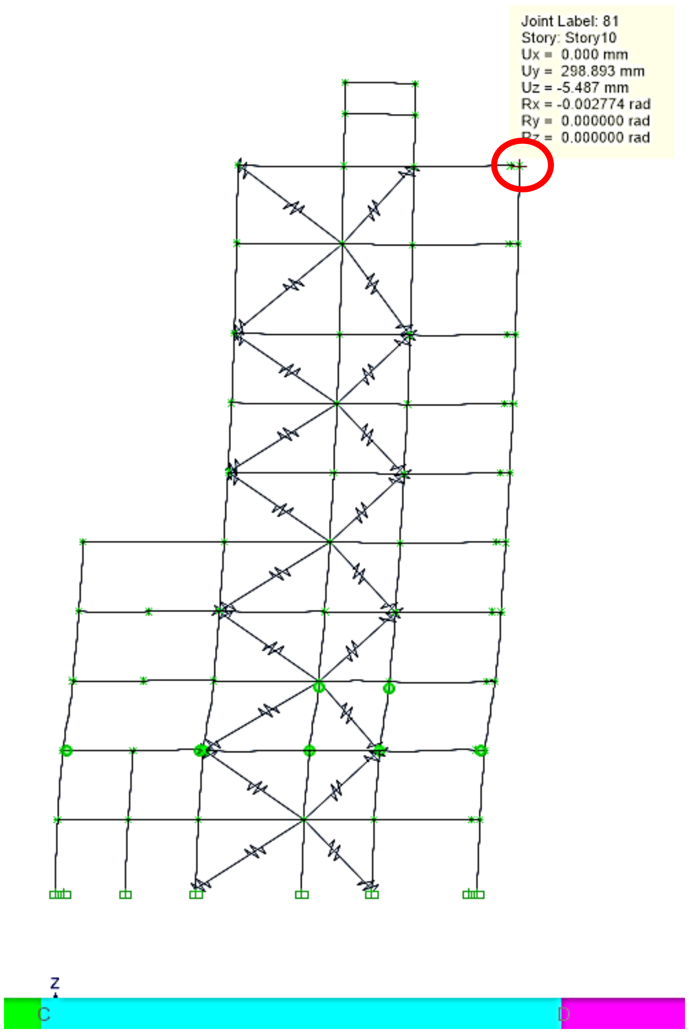


Joint Label: 164
Story: Story10
Ux = 0.227771 m
Uy = 0.000000 m
Uz = -0.005072 m
Rx = 0.000000 rad
Ry = 0.002037 rad
Rz = 0.000000 rad
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
B
C
D
E

Y-Y: Case 1



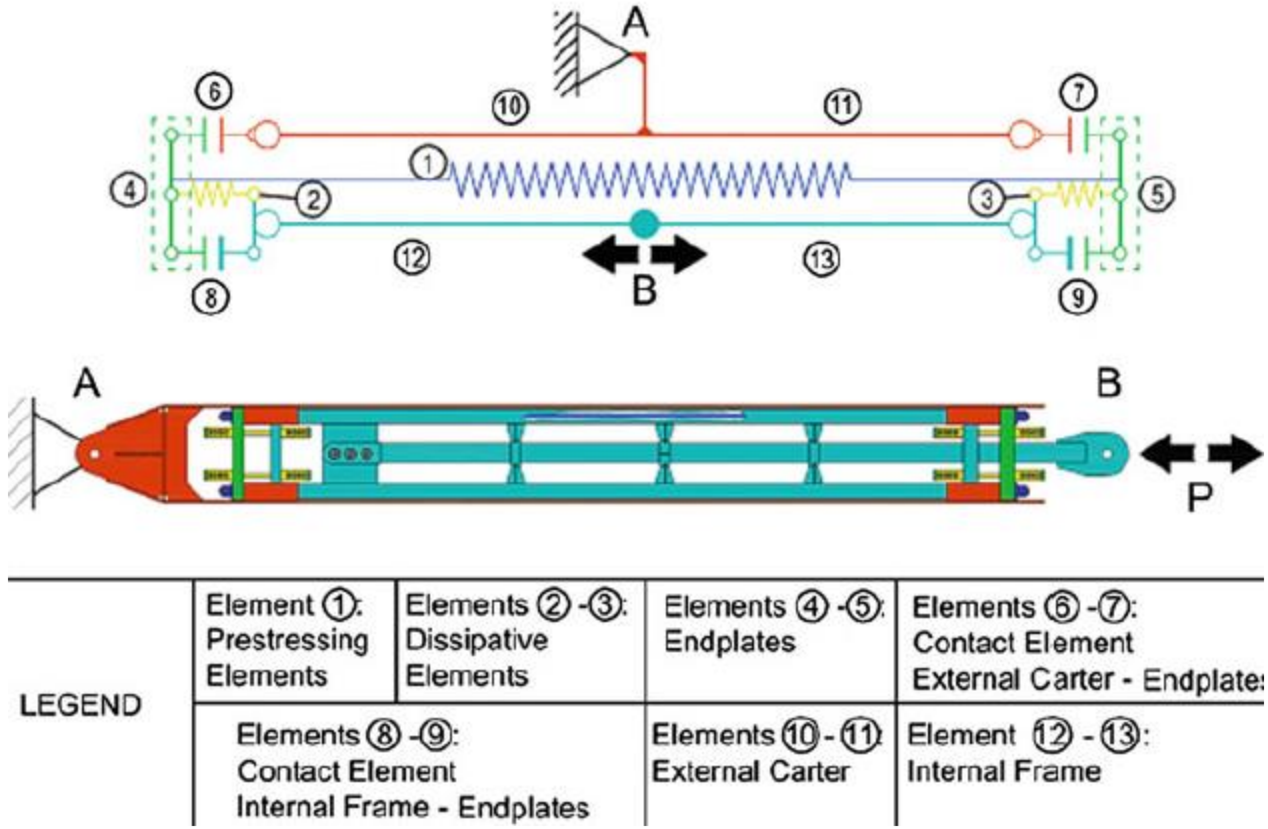
Y-Y: Case 2



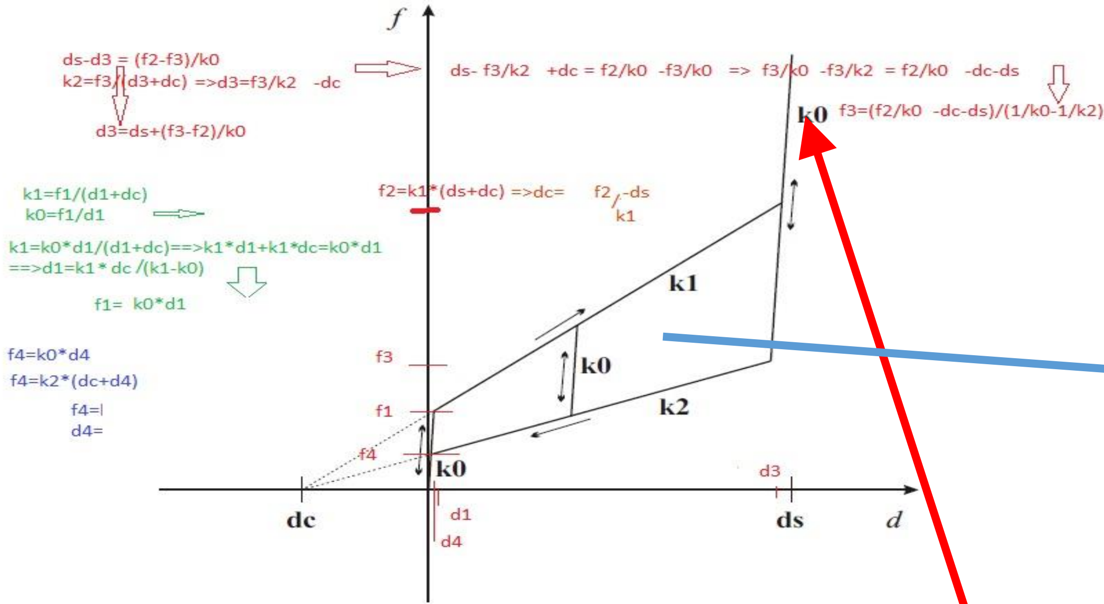
Device

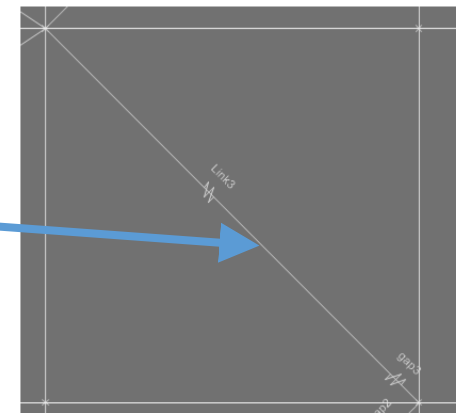
- Steel self-centering device (SSCD) for seismic protection of buildings
- Improve the level of seismic protection of new and pre-existing structures
- Hysteretic device
- Re-centering and recovery of the structure’s original dissipative resources

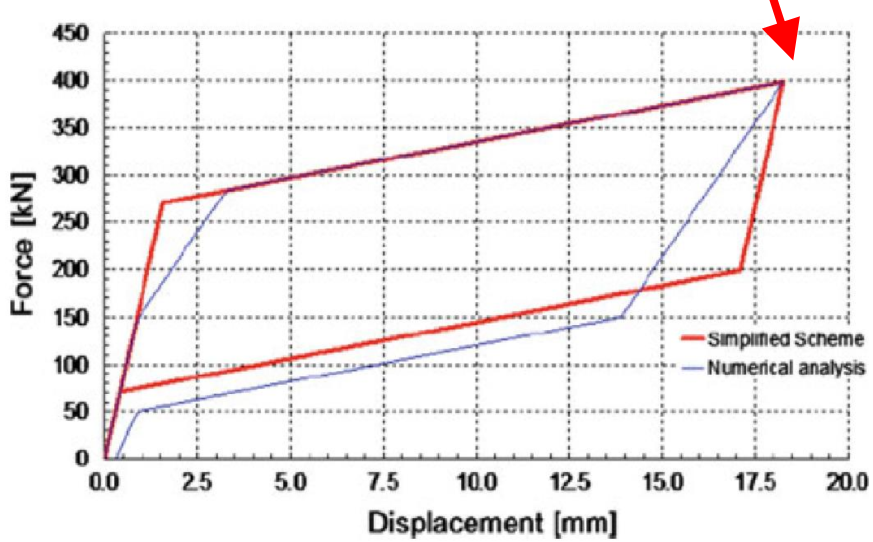
Braconi, Aurelio, Francesco Morelli, and Walter Salvatore. "Development, design and experimental validation of a steel self-centering device (SSCD) for seismic protection of buildings." Bulletin of Earthquake Engineering 10.6 (2012): 1915-1941.



Dampers Modelling







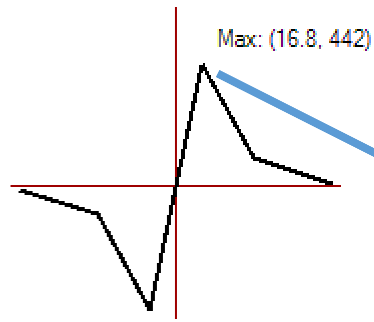
- Friction-Spring Damper
- elastic stiffness k_0
- linear stiffness k_1
- unloading-slipping k_2

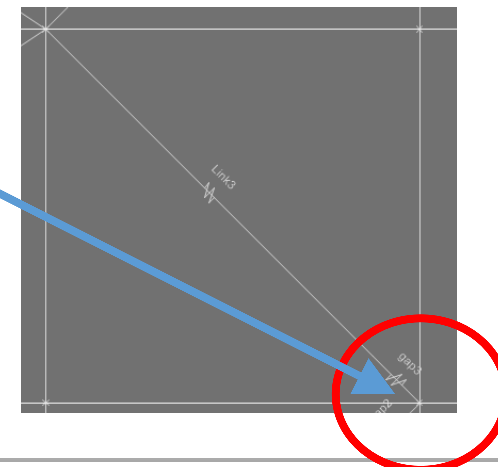
Multi-Linear Plastic Property

- Tension limit
- Rigid element / constraint
- Multi-Linear Plastic Property

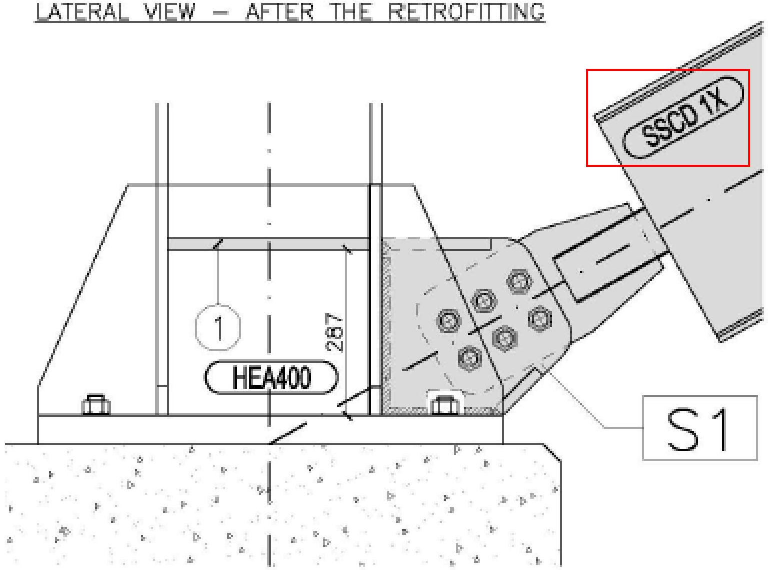
Multilinear Force-Displ Relation

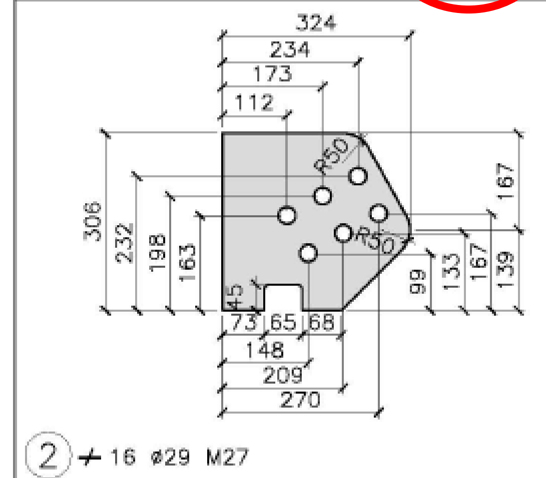
Pt	Displ (mm)	Force (kN)
1	-100	-10
2	-50	-100
3	-16.8	-442
4	0	0
5	16.8	442





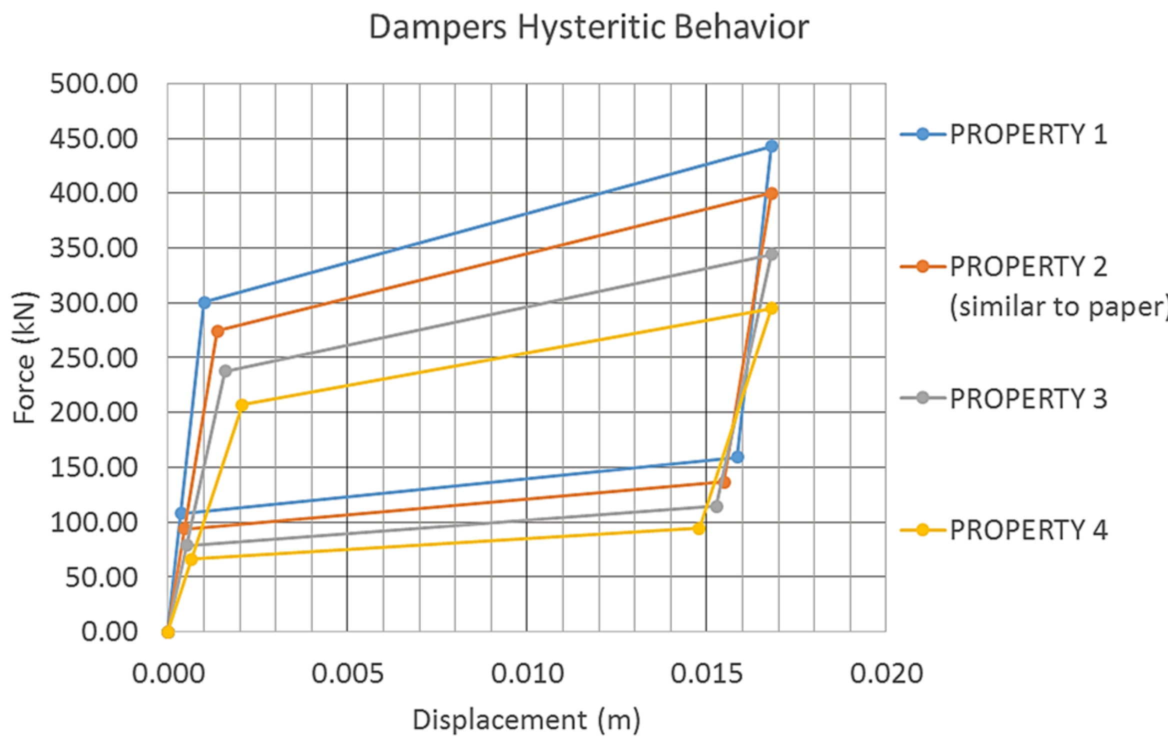
LATERAL VIEW — AFTER THE RETROFITTING





We distinguish **3 cases**:

- **Case 0**: analysis without dampers
- **Case 1**: dampers in spans A-B and L-M, from Und1 to Story 12
- **Case 2**: dampers in spans F-G-H, from Und1 to Story 12

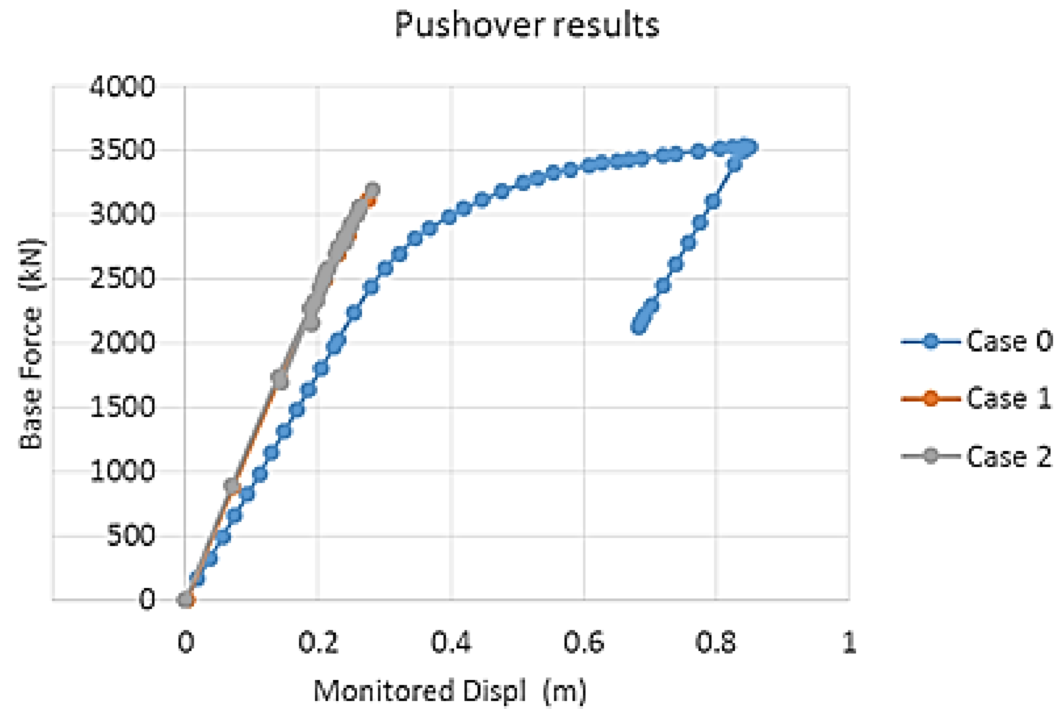


For each case, the property sets (k0, k1 and k2) of the dampers, for groups of 3 floors

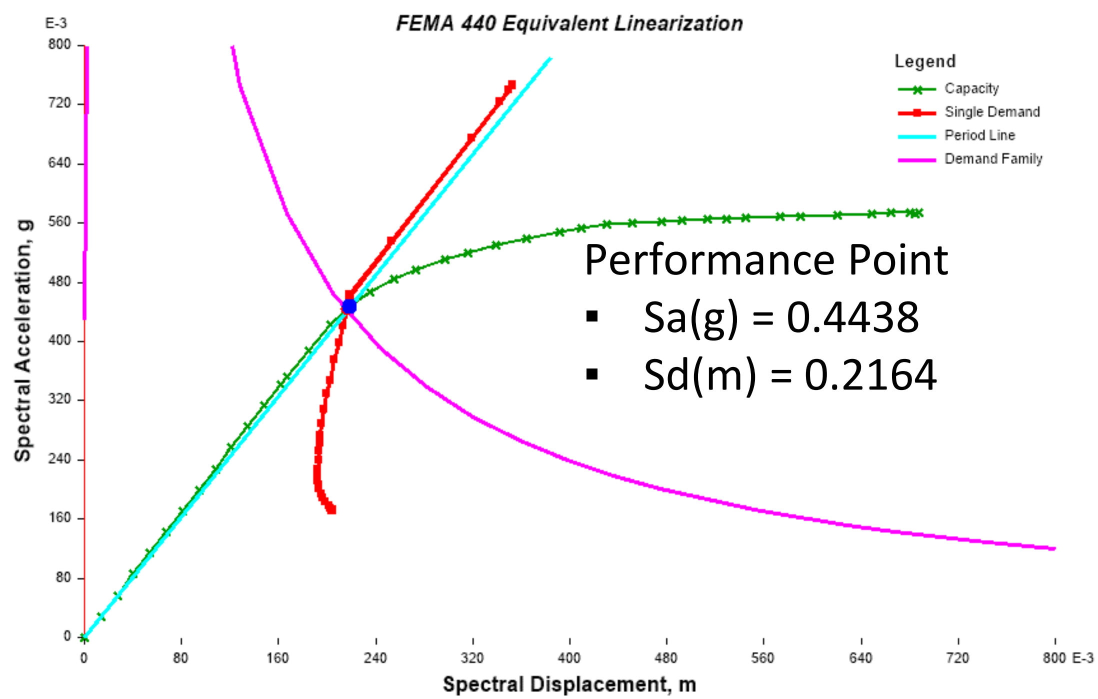
- Property set 1 (from **base to storey 3**),
- Property set 2 (from **storey 3 to storey 6**),
- Property set 3 (from **storey 6 to storey 9**) ,
- Property set 4 (from **storey 9 to storey 12**) ,

with Property set 1 >Property set 2>Property set 3>Property set 4.

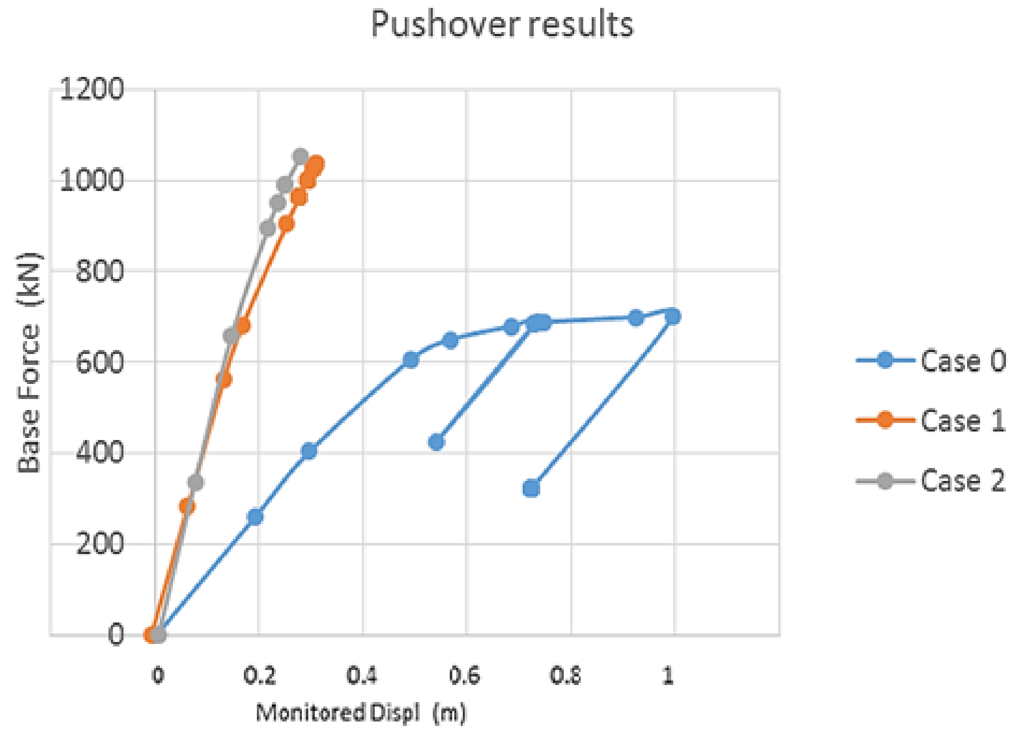
X-X: Pushover results before and after interventions



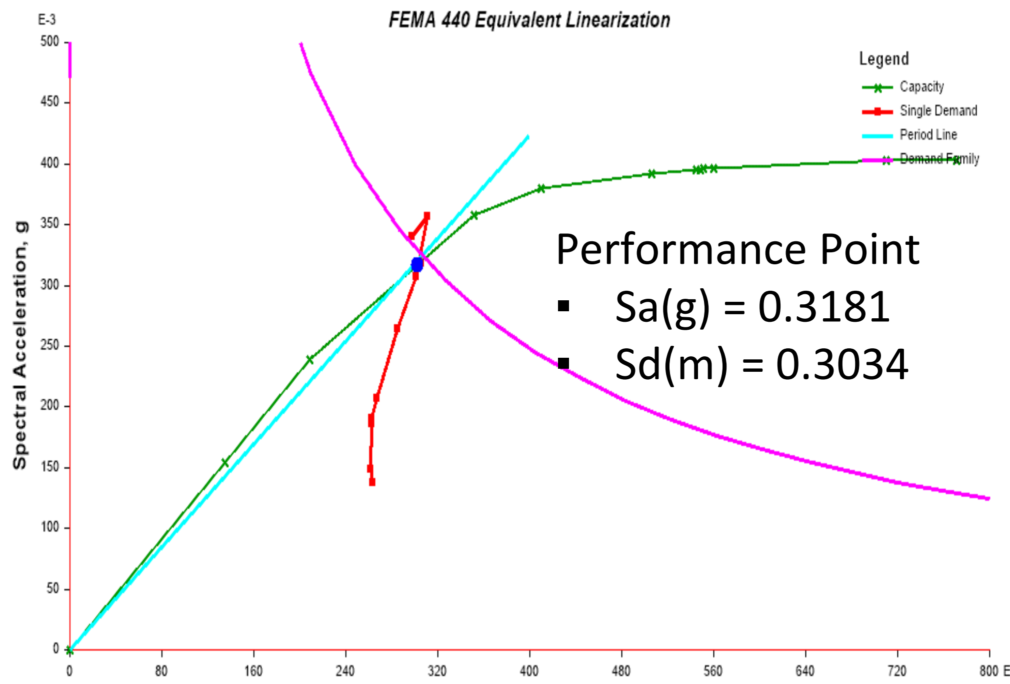
X-X, Case 0:
Capacity Spectrum



Y-Y: Pushover results before and after interventions



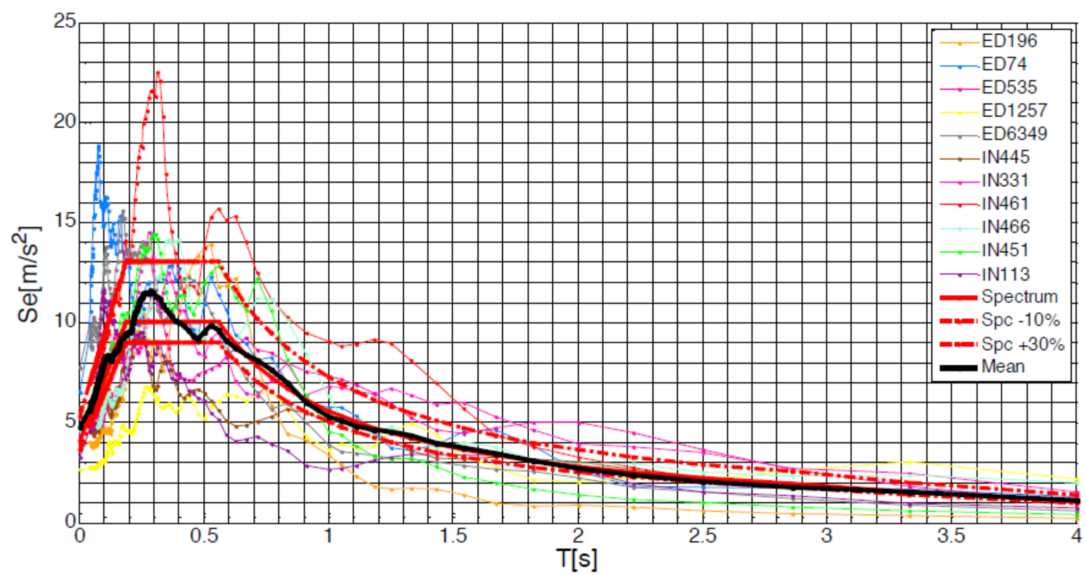
Y-Y, Case 0: Capacity Spectrum



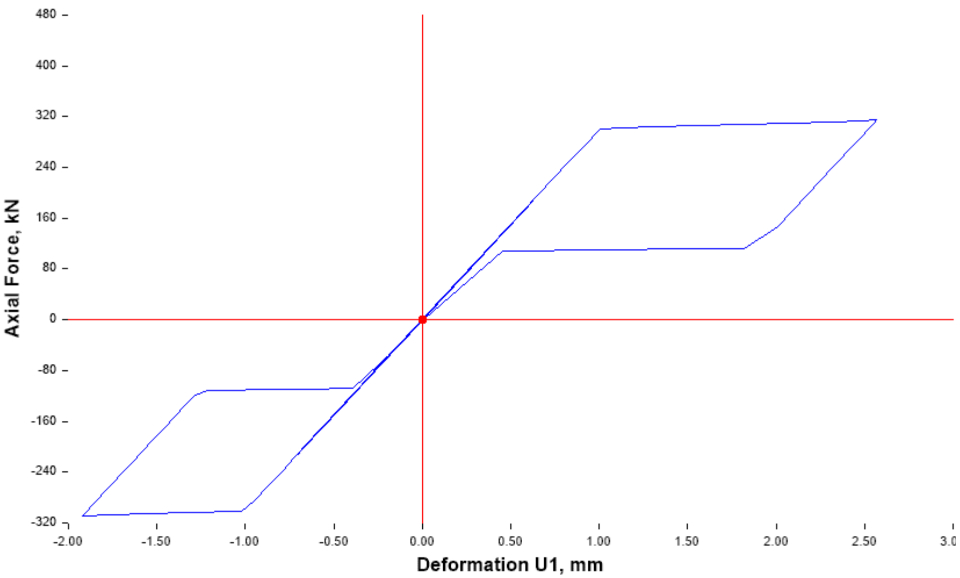
Ground Motions

- Ground Motions (GMs) selected for use in Incremental Dynamic Analyses
- High seismicity (Reggio Calabria, Italy)
- The sets are taken from three different databases available in Rexel (Iervolino et al. 2009)
- Consistent with the requirements of Eurocode 8 (§3.2.3.1)
- Reggio Calabria target spectrum and GMs spectra coherence

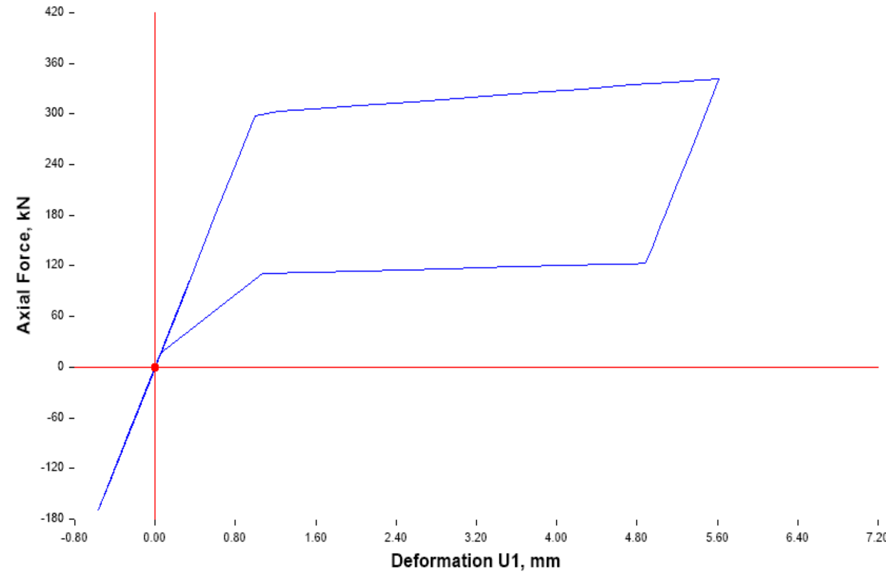
	REGGIO CALABRIA					
	Vr	P_{vr}	λ	Tr	ag	S.F.
	yrs	%	1/yrs	yrs	g	\
0	100	4%	0.0004	**2475**	0.512	1.43
1	100	**5%**	0.0005	1950	0.4687	1.307
2	100	**10%**	0.0011	949	0.3586	**1.000**
3	100	22%	0.0025	402	0.2502	0.698
4	100	30%	0.0036	280	0.2122	0.592
5	100	39%	0.0049	202	0.1829	0.510
6	100	50%	0.0069	144	0.1552	0.433
7	100	**63%**	0.0099	101	0.1292	0.360
8	100	**81%**	0.0166	60	0.0987	0.275



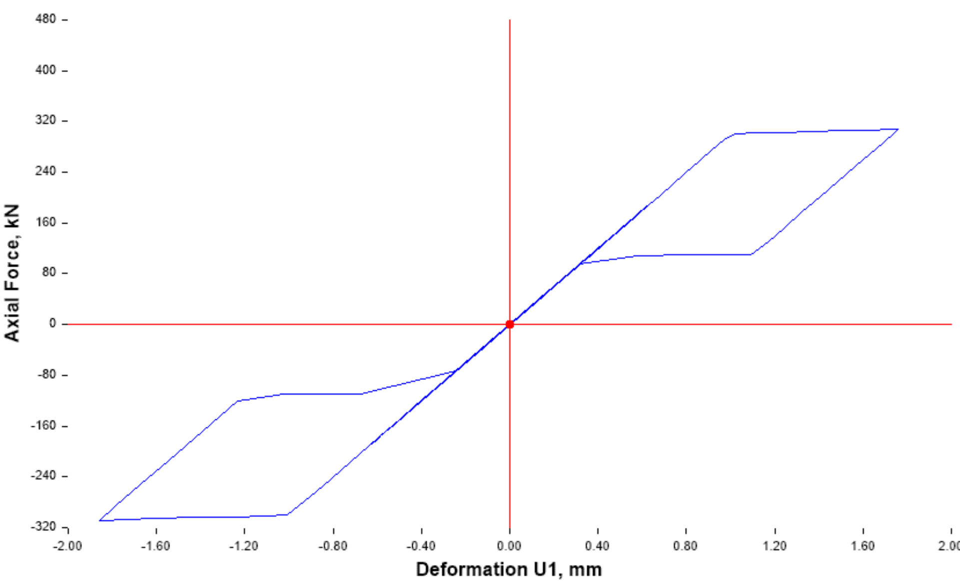
X-X-1: **K14** Damper Hysteresis of ED6349 with scale factor **1.43**



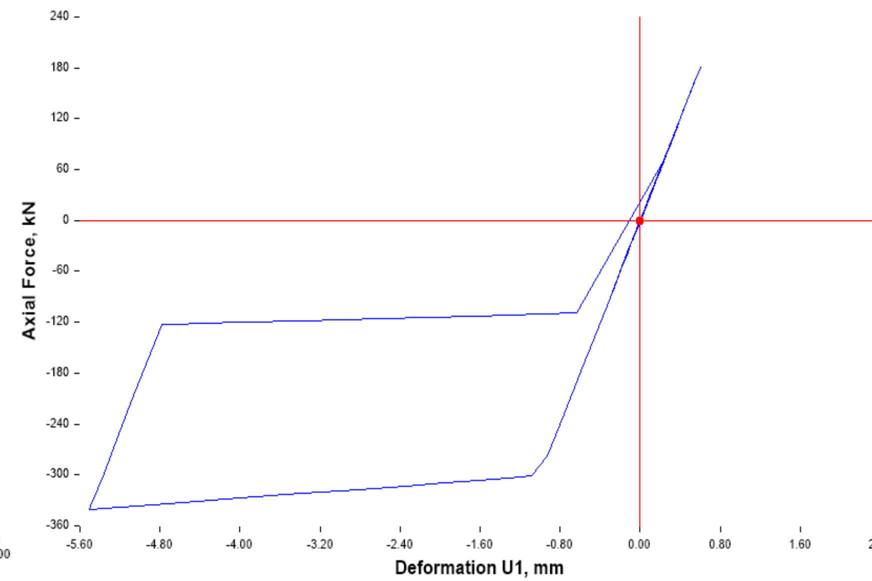
X-X-1: **K14** Damper Hysteresis of ED6349 with scale factor **3.00**



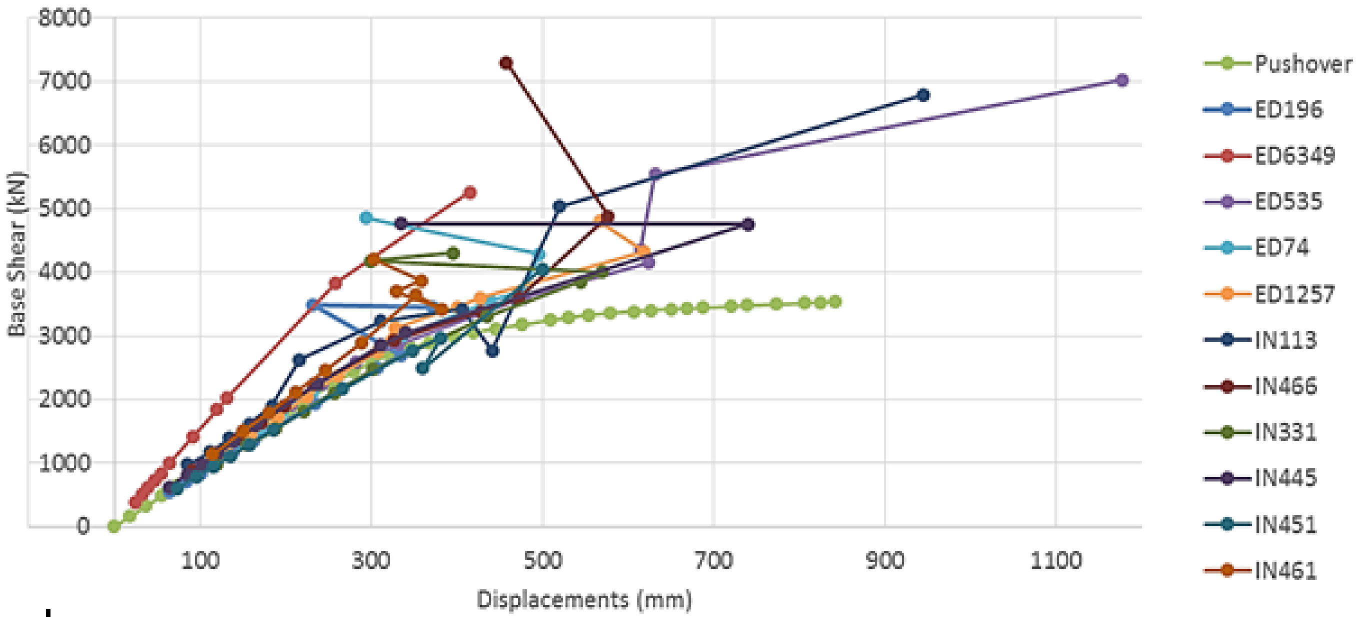
X-X-1: **K13** Damper Hysteresis of ED6349 with scale factor **1.43**



X-X-1: **K13** Damper Hysteresis of ED6349 with scale factor **3.00**

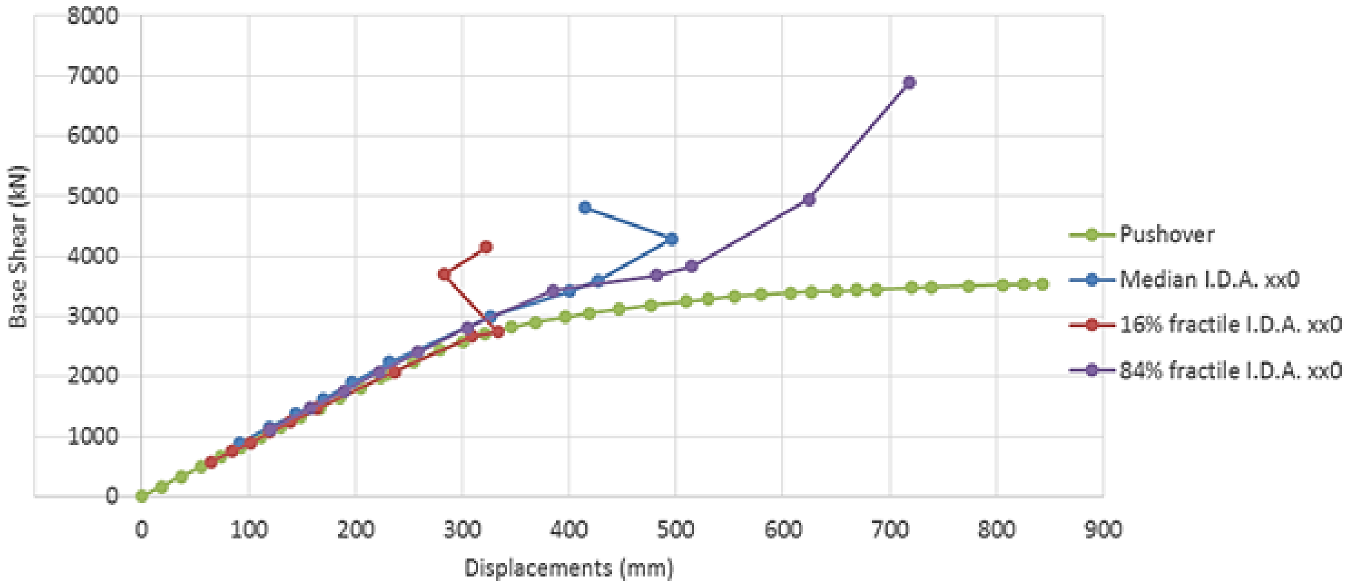


XX IDA curves without dampers (Base Shear – Displacements)

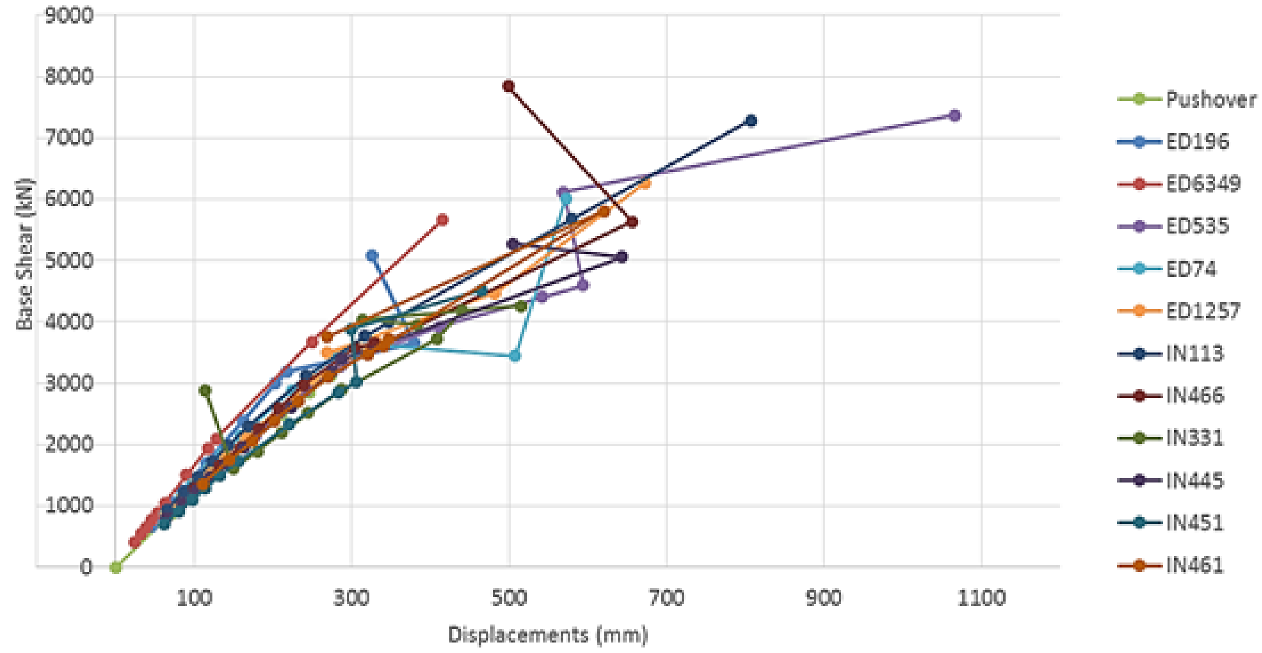


- Newmark
- Wilson
- Hilber-Hughes-Taylor

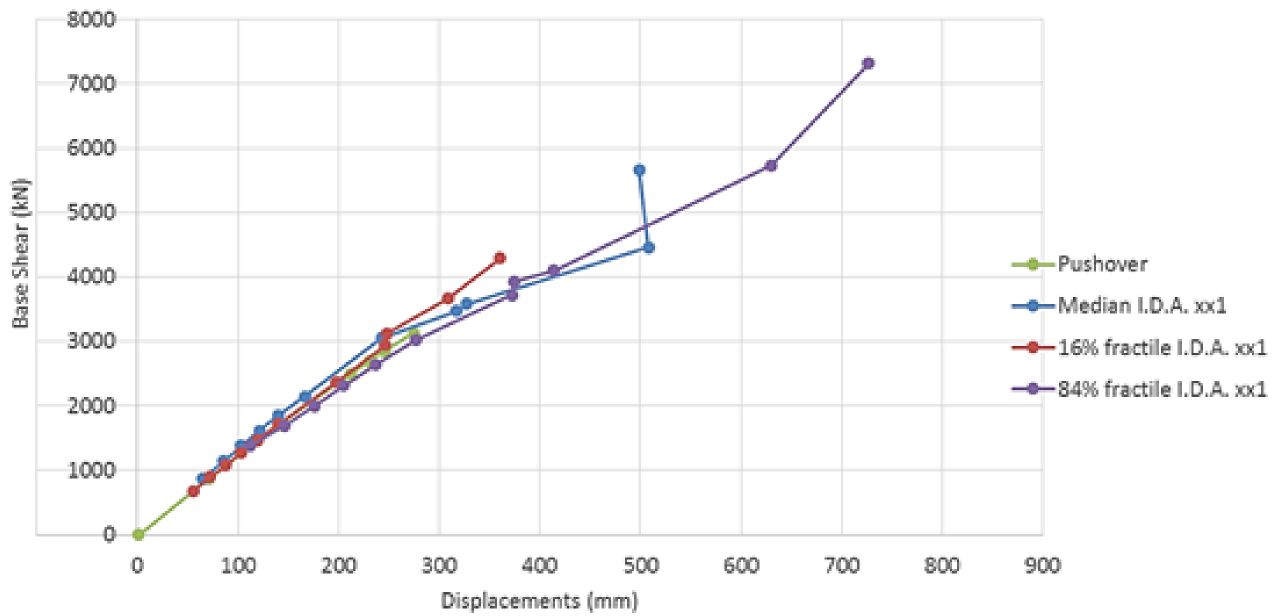
XX IDA curves without dampers (fractiles)



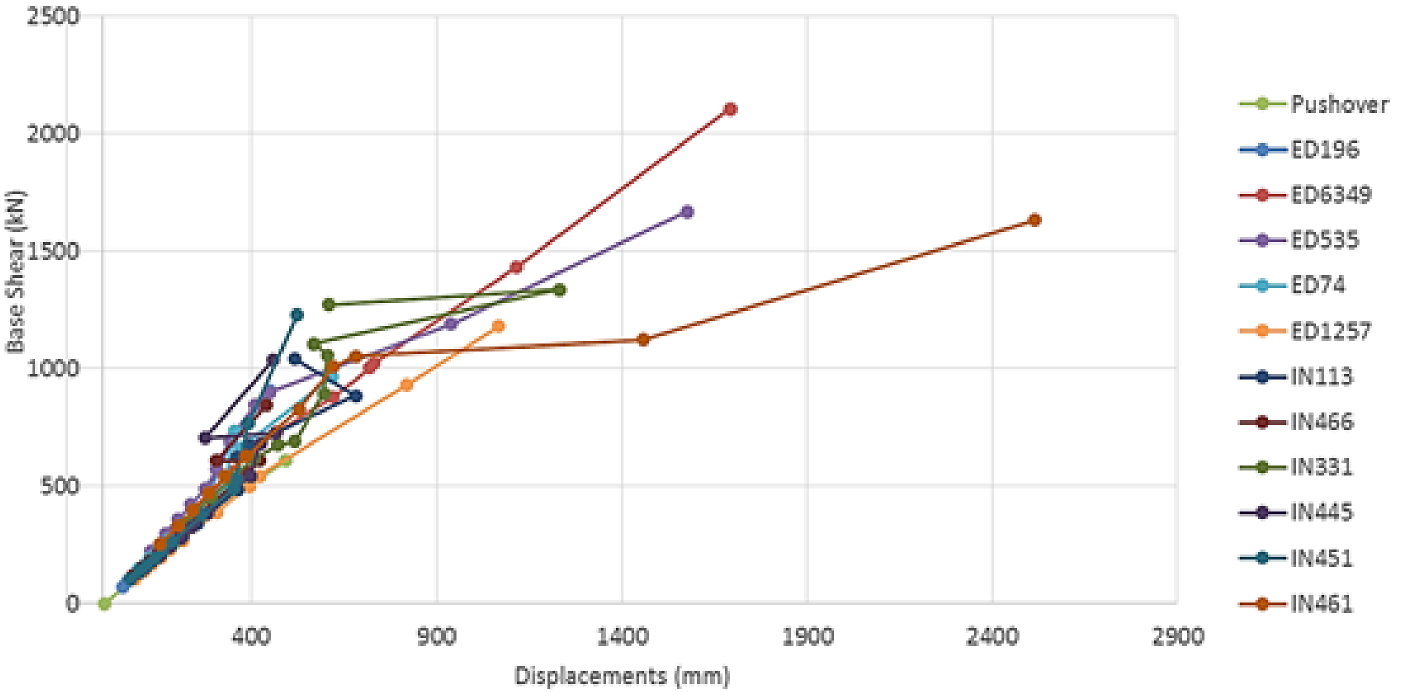
XX IDA curves with dampers (Base Shear – Displacements)



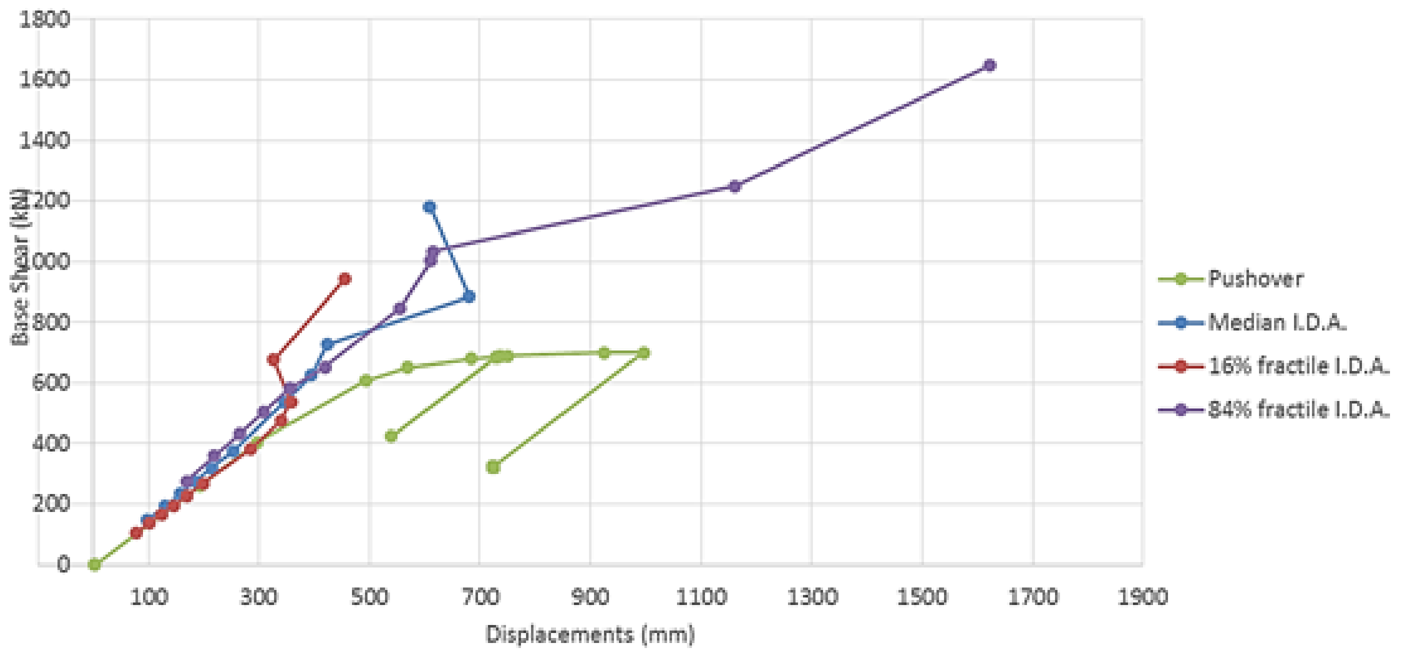
XX IDA curves with dampers (fractiles)



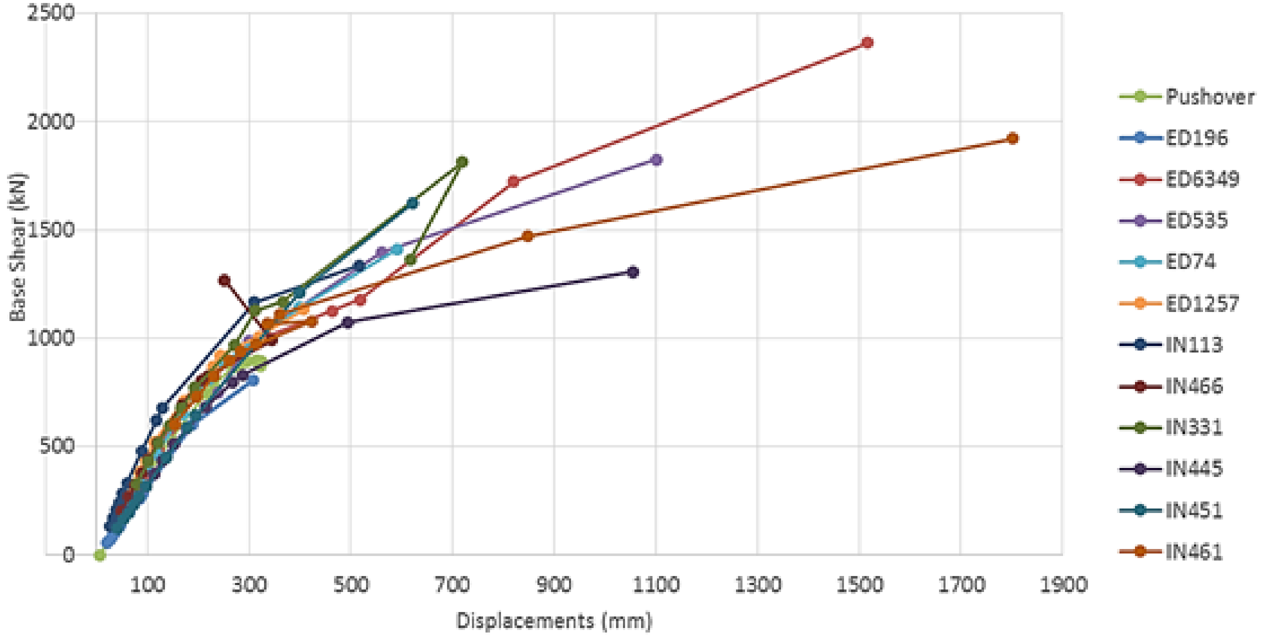
YY IDA curves without dampers (Base Shear – Displacements



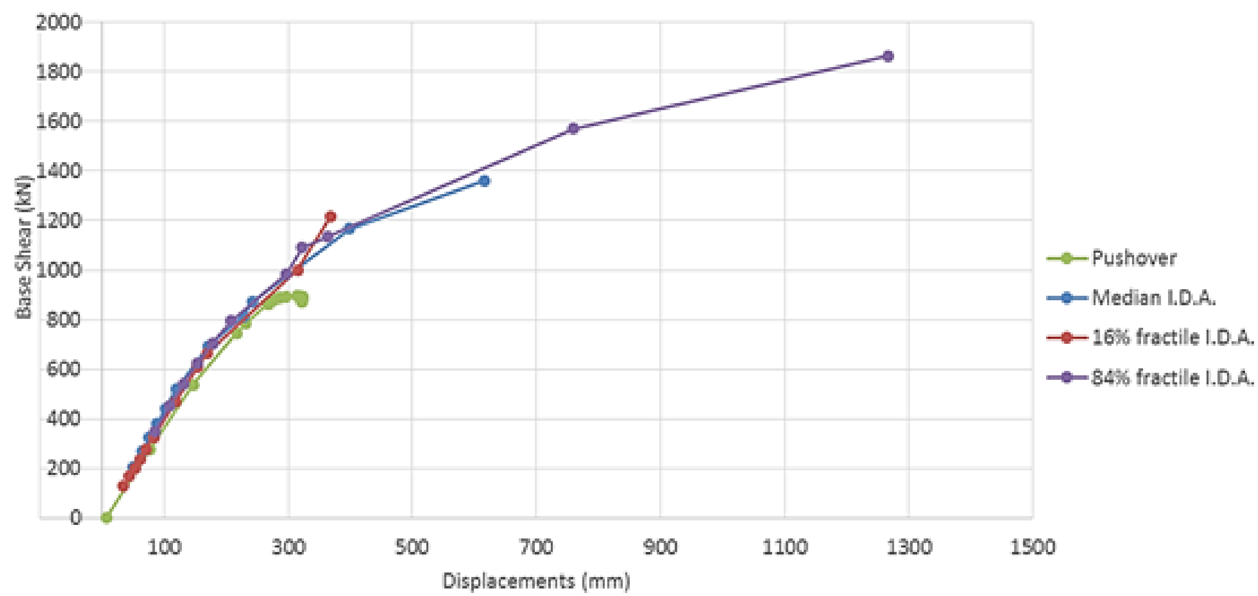
YY IDA curves without dampers (fractiles)



YY IDA curves with dampers (Base Shear – Displacements



YY IDA curves with dampers (fractiles)



Conclusions

- Modelling of dampers and structure is crucial
- Numerical instabilities & convergence issues
- Early failures of secondary elements
- The results of IDAs are similar to the results of Pushover
- The IDA results were practically the same for the various nonlinear time-history algorithms (Newmark, Wilson, Hilber-Hughes-Taylor)
- Step-size, convergence tolerance and number of iterations
- The dampers increase the stiffness of the frames, and decrease the displacements and interstory drifts of the frames
- The dampers dissipate energy, through the flag-shaped behavior
- IDA capture nonlinear behavior for high accelerations, where pushover stops
- Lower values of dampers stiffness and strength were proposed, in order to achieve the yielding of the damper and the dissipation of energy within the structure.

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Funding: PROtection of INDUSTRial plants by enhanced steel based sYstems

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