Development of an aluminium restricted buckling bracing with a dissipative component (BRD_AL device)

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Presentation outline

- Objectives;
- Assessment of the mechanical behaviour of aluminium alloys (Experimental campaigns);
- Design and assessment of the dissipative component of the bracing system (BRD_Al device);
- Design and assessment of the bracing system;
- Case study analyses – Application of the bracing system to a Pilotis type building;
- Recommendations for future studies.

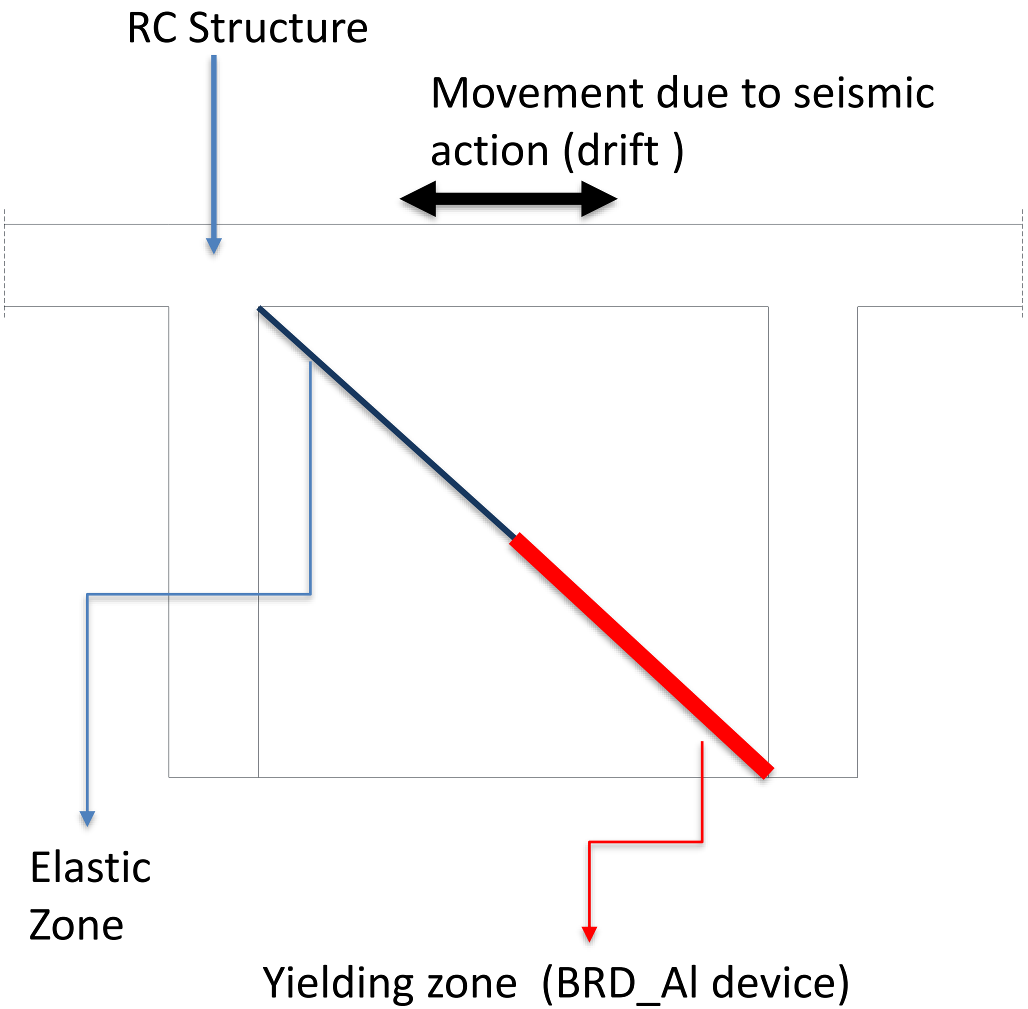
Objectives

- Design of a buckling restrained bracing system using only extruded aluminium alloy members;

- With two components: an elastic component and a dissipative component (BRD_Al device) easy to replace after an earthquake

- Stable hysteretic behaviour when subjected to axial displacements (both in tension and compression);

- To be used in the seismic protection of specific R/C buildings (Pilotis buildings)



Assessment of the mechanical behaviour of aluminium alloys

Selected group of aluminium alloys → AW 5083-H1 alloy; AW 6082-T6 alloy

Also

Selection of thermal treatments for the AW 6082 alloy ⇒

1. Solution treatment at 535ºC (45 min)+ageing at 190 ºC (2h);
2. Solution treatment at 535ºC (45 min)+ageing at 100 ºC (32h);
3. No solution treatment +ageing at 350 ºC (2h)
4. No solution treatment + ageing at 280 ºC (8h)

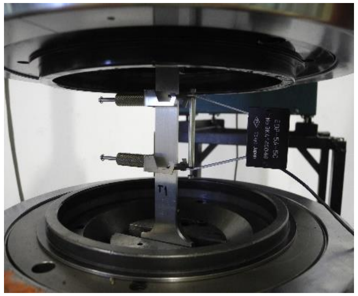
Objective ⇓

Enhance ductility of the AW 6082 alloy

Assessment of the mechanical behaviour of aluminium alloys

Experimental testing

Uniaxial tension tests



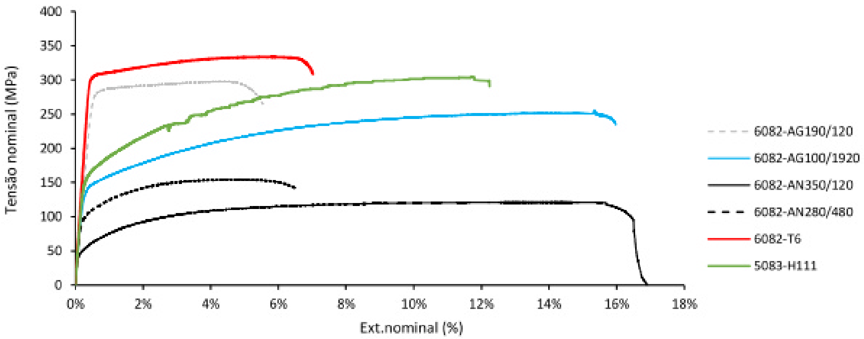
Uniaxial cyclic tests

Objectives:

- Assess the mechanical behaviour of the alloys, especially when subjected to cyclic loading;
- Determine the most suitable alloy to be used in the composition of the BRD_AL device;

Aluminium alloy selection for the BRB_Al – Experimental tests

Results of experimental uniaxial tension tests

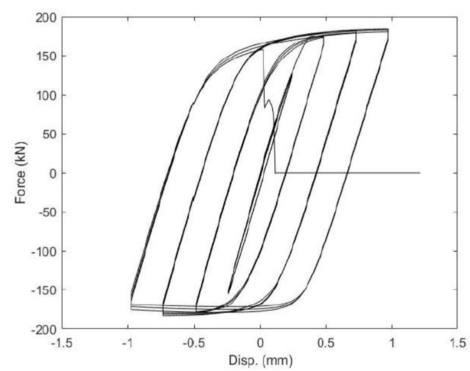


Provete	$E_t(GPa)$	$\sigma_{y0.2}(MPa)$	$\epsilon_y(\%)$	$\sigma_{ult}(MPa)$	$\epsilon_{ult}(\%)$
6082-T6	77	311	0,4	334	6
6082-AG190/120	61	274	0,4	298	4
6082-AG100/1920	63	145	0,2	256	16
6082-AN350/120	69	55	0,1	121	16
6082-AN280/480	67	109	0,2	155	5
5082-H111	67	151	0,2	305	12

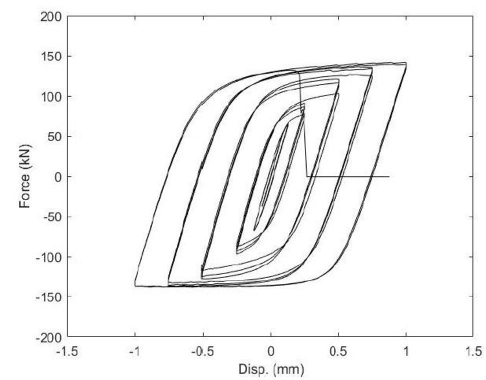
Beside the reference alloys 6082-T6 and the 5083-H1, cyclic tests were performed to the alloys that showed the best performance in terms deformation capacity in the uniaxial tests – the 6082 AG100/1920 and the 6082 -AN350/120 alloys

Results of experimental uniaxial cyclic tests

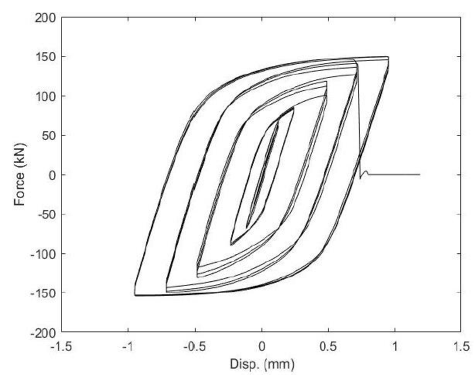
6082 - T6



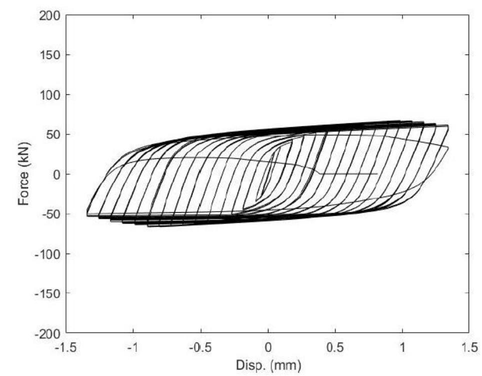
5083-H1



6082-AG100/1920



6082-AN350/120



Selection of aluminium alloy for the composition of the dissipative component (BRB_Al device)

Cyclic performance assessment

→

Evaluation parameters recommended in *ATC-24- Guidelines for cyclic testing of components of steel structures*

→

Deformation capacity parameters (μ, $\Delta\delta_{cum}$, $\Delta\delta_{cum}^{norm}$, $E_t/\sigma_{y\ 0.2}$);

Energy dissipation capacity parameter (W_{cum}^{norm});

Number of stable inelastic cycles (N_i)

↓

The 6082AN350/120 has shown the highest values of all of the evaluation parameters.

↓ Conclusion

Selection of the 6082-AN350/120 for the composition of the BRD_Al device

Design and assessment of the dissipative component of the bracing system (BRD_Al device)

Main development stages

1. Parametrization of the non linear behaviour of the selected alloy ;
2. Numeric modeling of 2 idealized configurations for the BRD_Al device;
3. Evaluation of the cyclic performance of the idealized configurations ;
4. Selection of the most suited configuration for the BRD_device

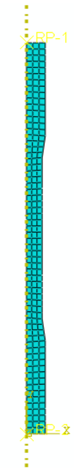
Parametrization of the cyclic performance of the 6082- AN350/120 aluminium alloy

<u>Basis</u> : Simulation of cyclic test of the 6082AN350/120 specimen

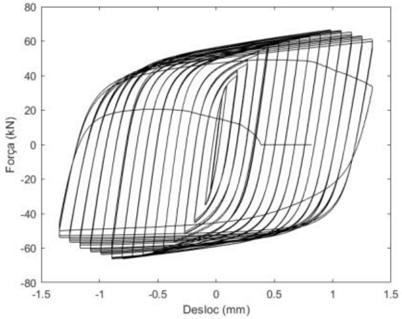
- Material behavior:
  - The alloy as an isotropic material assuming the generalized Hooke law in the elastic domain;
  - Assumes a combined non linear isotropic and kinematic hardening (Chaboche Model), considering the Von Mises yielding criterion for its inelastic behaviour;
  - Assume ductile damage where :

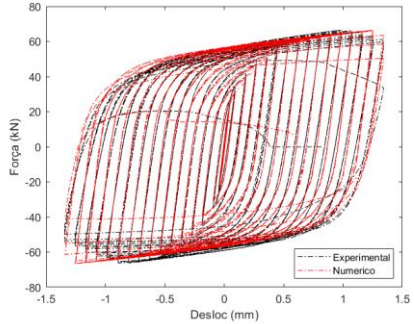
1) Damage initiation triggered by specific strain equivalent plastic value;

2) Damage evolution defined considering a exponential evolution law for the plastic decay and limited dissipation energy after damage initiation.



Numeric model of the test specimen used in the cyclic test of the 6082AN350/120 alloy





Idealized configurations for the BRB_AL device

Configuration T1

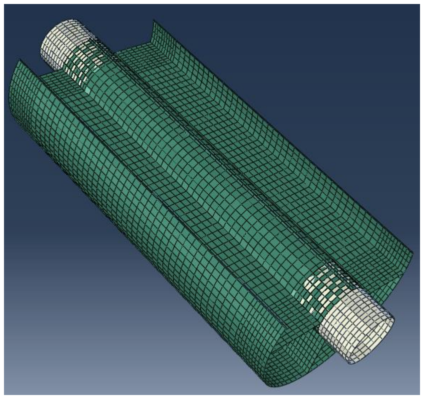


Fig 1.

Configuration T2

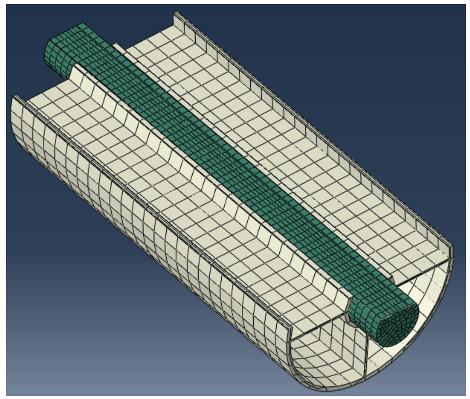
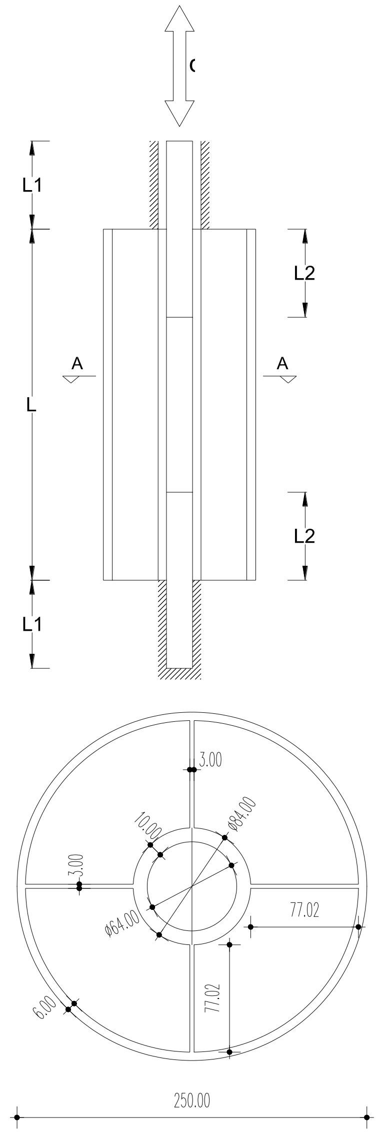
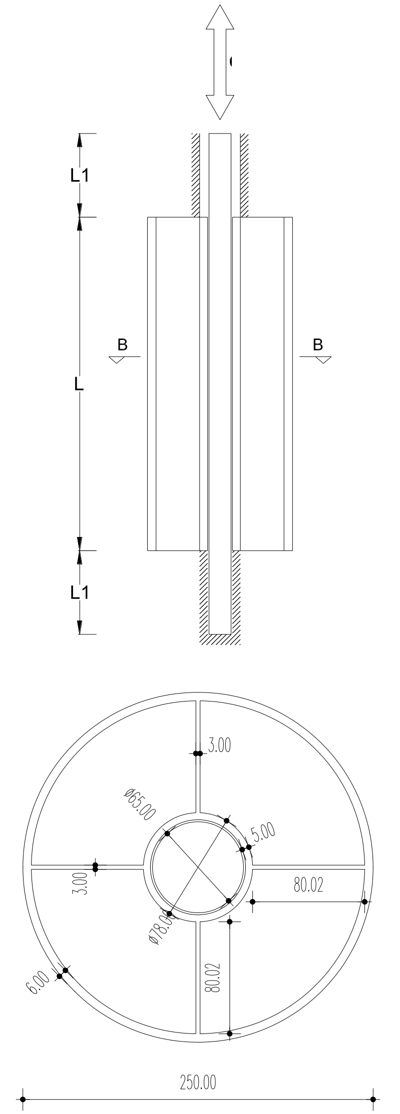


Fig 2.



Config. T1 – Section A-A



Config. T2 – Section B-B

Assumptions:

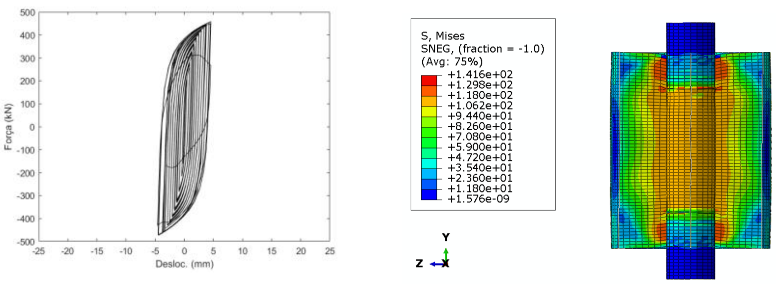
Two different configurations of the device admitting a reference yielding force of 200 kN

Dissipative parts (indicated in green) are composed by the 6082AN350/120.

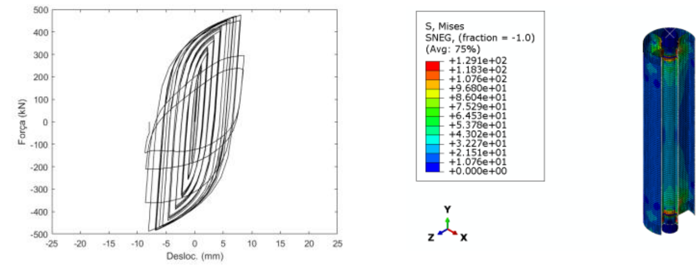
Non-dissipative parts are composed of the 6082-T6 alloy (in white)

Evaluation of the cyclic performance of the BRD_Al device

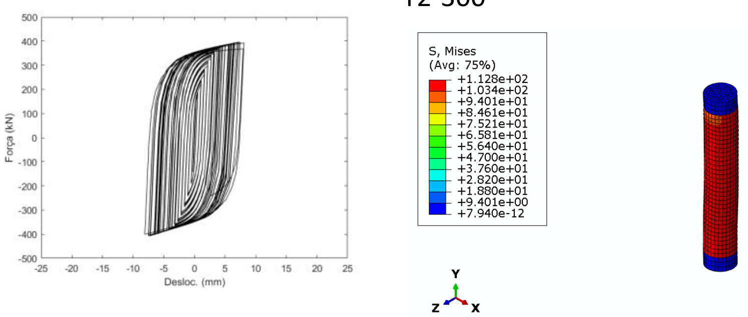
T1-300



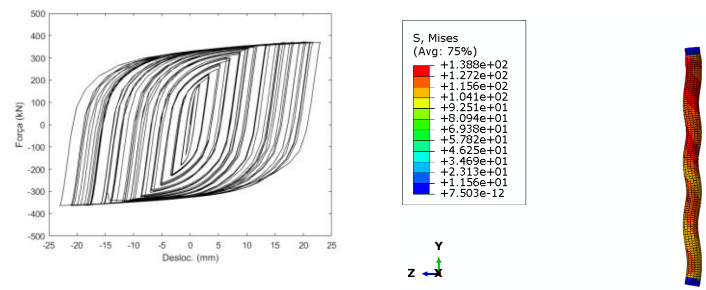
T1-1000



T2-300



T2-1000



Numeric simulation of cyclic tests of configurations T1 and T2 using software ABAQUS

- Different cases for each configuration (variation of length L (L=300 to 1000 mm);
- Same cross section configuration in each case;
- **Cyclic performance evaluation-** ECC report nº45 evaluation parameters

Evaluation of the cyclic performance of the BRD_Al device

<u>The T2 configuration</u> showed the highest:

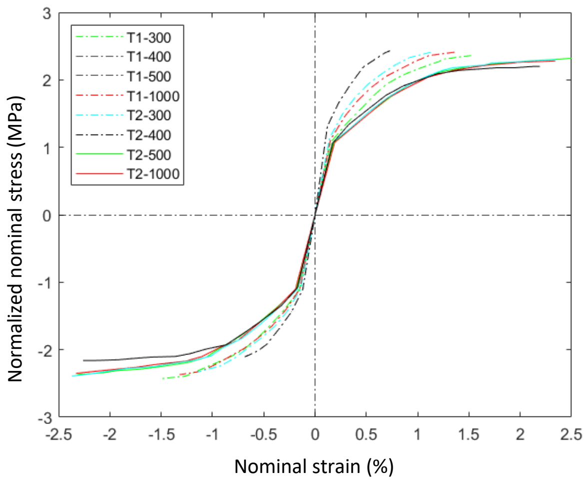
1) Values of deformation capacity ;

2) Highest number of stable cycles under inelastic deformation;

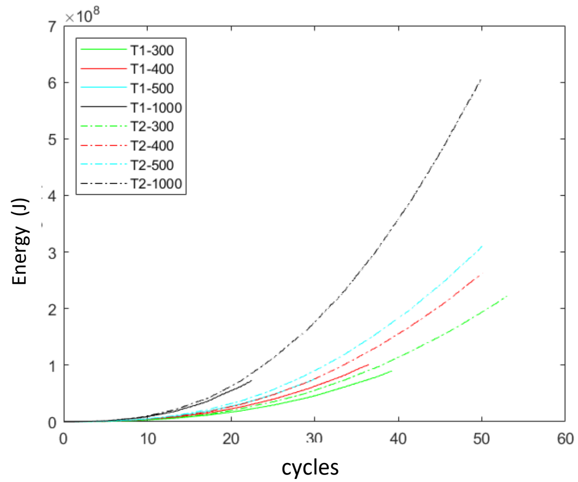
3) Highest values of intrinsic dissipated energy;

Conclusion

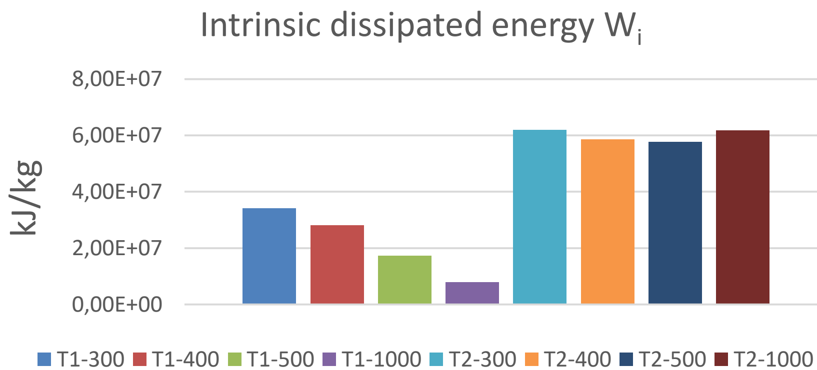
Selection of the T2 configuration for the BRD_Al device



Backbone curves of the cyclic behaviour of the devices



Accumulated dissipated energy during cyclic loading



Design and assessment of the bracing configuration

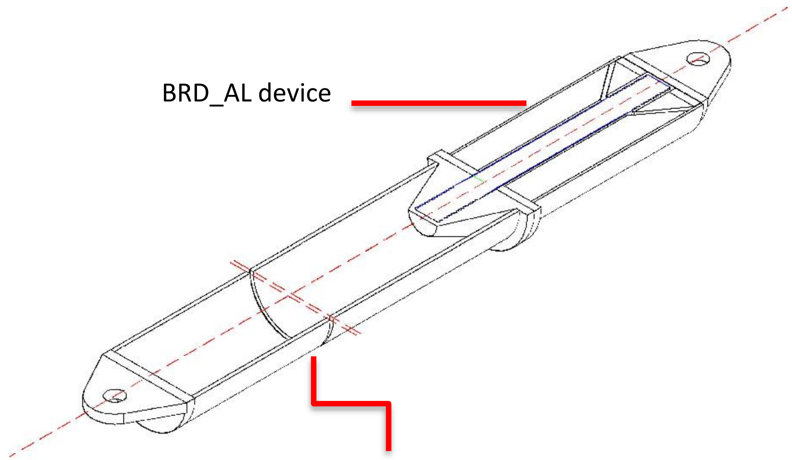
Development Stages

1. Design of the connecting parts between the elastic component of the bracing and the BRD_Al device;
2. Assessment of cyclic behaviour of the bracing system considering different lengths of the BRD_Al device (L_P=300, 500, 1000 e 5000 mm);
3. Definition of expressions to relate the length of the device with its maximum deformation and cyclic stability;
4. Definition of a simplified bilinear model to describe the cyclic behaviour of the bracing system.

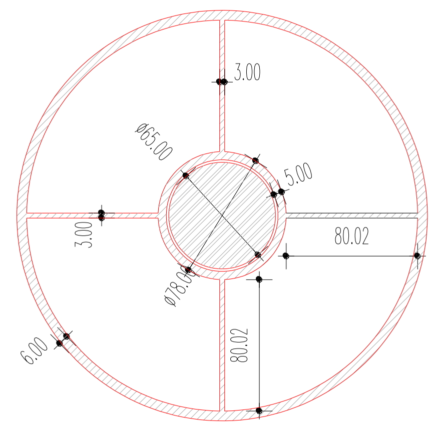
Design and assessment of the bracing configuration

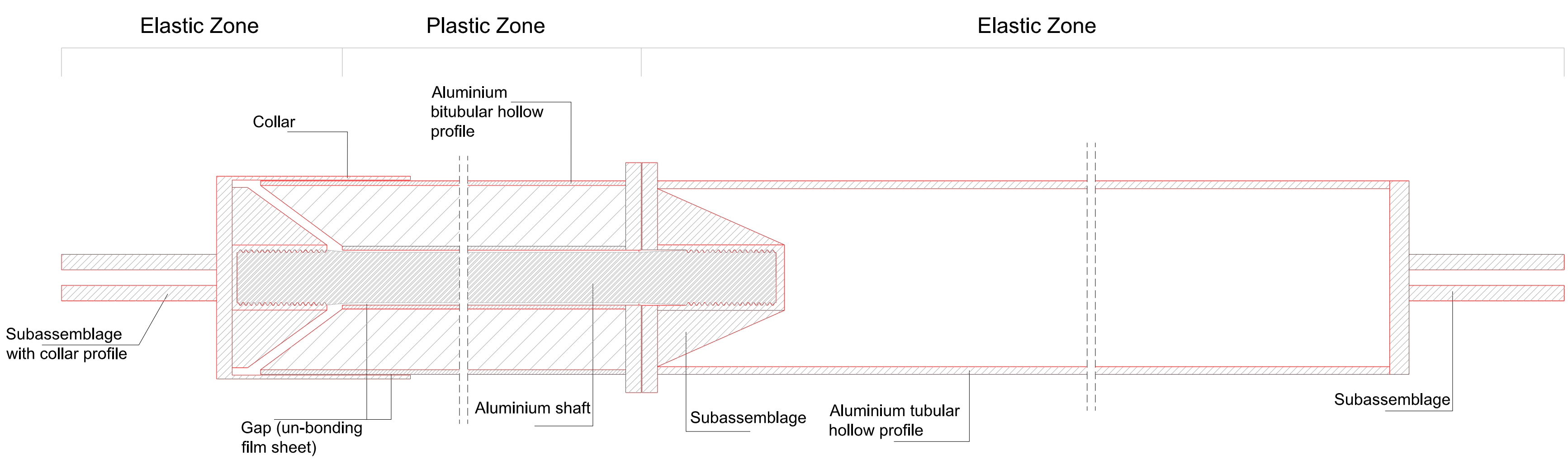
Main assessments:

- The effects of geometric imperfections on the cyclic behaviour of the bracing;
- The effects of the length of the elastic and dissipative components in l cyclic behaviour of the bracing



Cross section of the BRD-Al device

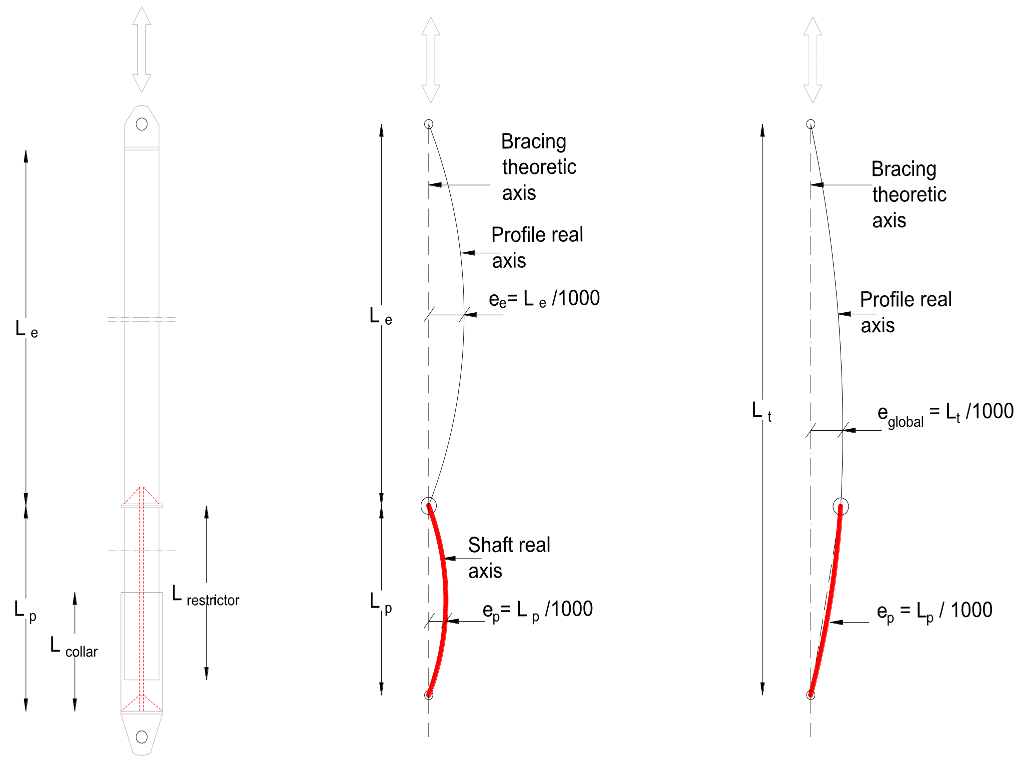




Bracing analyses – Assessment of the global behavior of the bracing system

Assumptions:

- **Pinned connection**: Application of additional restraining element - Collar profile (formulation proposed by Jing-Zhong et al.)
- Two possible cases of geometric imperfections - Case A (local imperfections) and Case B (global imperfection);



Case A

Case B

Assessment of the global behavior of the bracing system

Numeric simulation of cyclic tests on the bracing system (software ABAQUS)

⇩

Bracing Test scenarios:

1. Different lengths for the plastic component (**L_e**) and for the dissipative components (**L_p**);
2. Overall size of the bracing in the L= 6400 mm of length is maintained (reference size for the bracing);
3. Application geometric imperfections (Cases A and B)

⇩

Assessment of the cyclic performance of each scenario considering a cyclic history of increasing displacement amplitude

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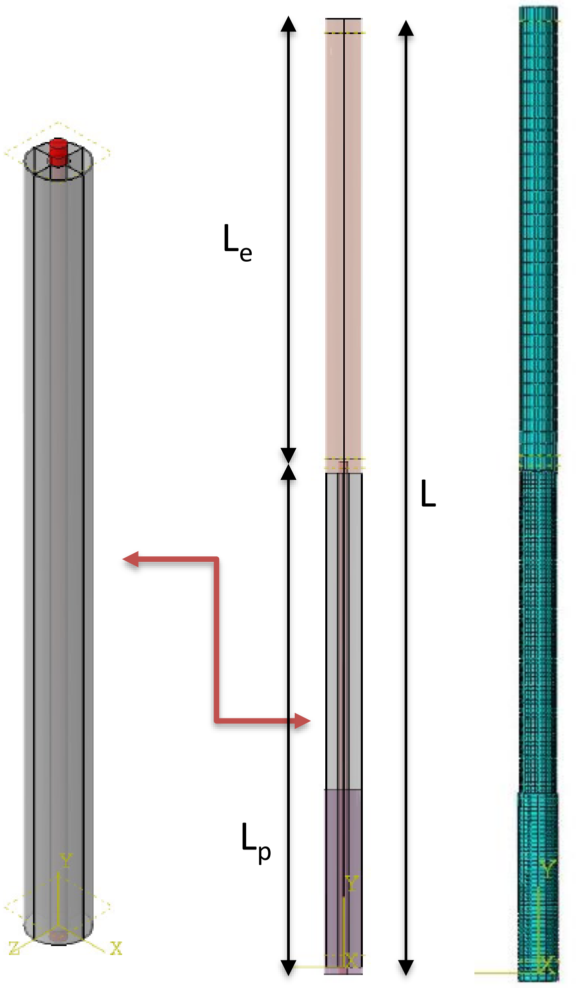
Observation of the maximum axial deformation achieved in each scenario during stable cyclic behaviour



Bracing analyses – Assessment of the global behavior of the bracing system

Case A and B – General dimensions

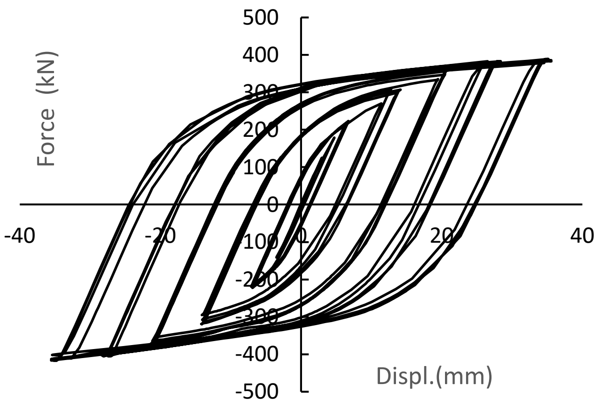
L_t mm	L_p mm	L_e mm	L_{collar} mm
6400	300	6100	1280
	500	5900	
	1000	5400	
	5000	1400	

Case A – Initial imperfections

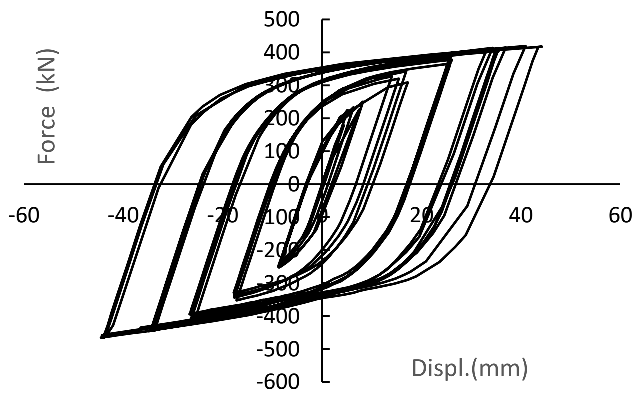
L_p mm	(e_p) mm	(e_e) mm
300	0,3	6,1
500	0,5	5,9
1000	1	5,4
5000	2,49*	1,4

Case B – Initial imperfections

L_p mm	(e_{global}) mm
300	6,4
500	
1000	
5000	



Example of the cyclic behaviour of case A with L_P=1000 mm

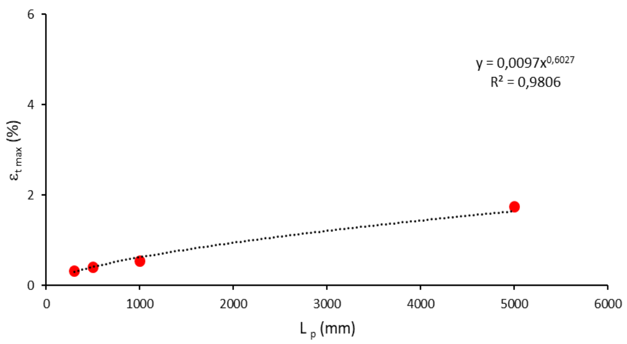


Example of the cyclic behaviour of case B with L_P=1000 mm

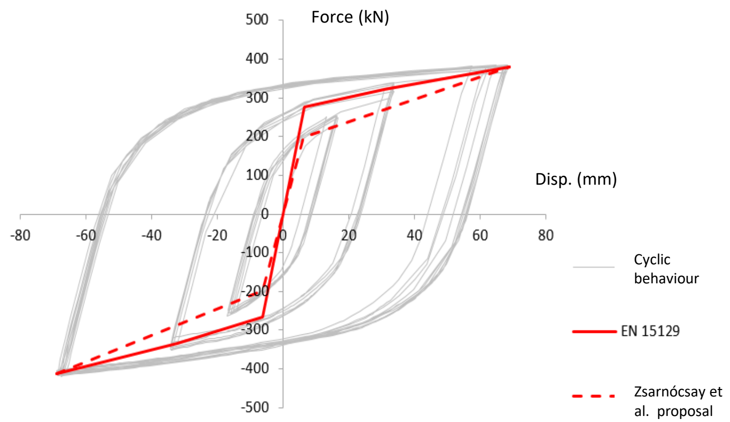
Bracing analyses – Assessment of the global behavior of the bracing system

Results were used for:

1) Definition of expressions to determine the optimum length of dissipative component L_p in relation to the maximum imposed displacement d_{bd} and the maximum strain of the bracing $\varepsilon_{t\ max}$



2) Parametrization of the cyclic behaviour of the bracing system – Theoretic Bilinear Model proposed by Zsarnócsay et al., instead of the model proposed in the EN 15129



Allowed :

1. The definition of the length of the components of the bracing;
2. The determination of the gap Δ_{axial} necessary to prevent contact between the bicylindrical profile and the connection cone when in compression

Allowed :

1. A more accurate approximation of the transition between the elastic and the plastic domain;
2. A more accurate approximation of the hardening process

Analysis of a case study

Case study → Existing building in Lisboa, typical example of the "Pilotis building" →

Objective → Seismic assessment of 2 Scenarios →

1. The structure in its present condition;

2. The braced structure (and the effects of the bracing system in the reduction of the seismic response)

Case study analyses

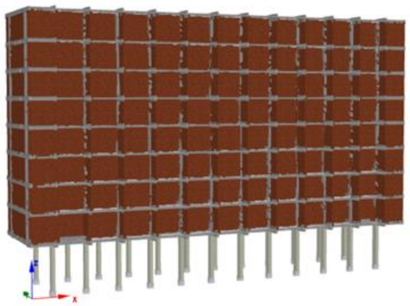
Numerical model of the building using the SeismoStruct software.

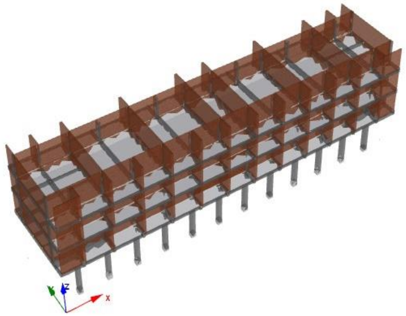
Definition of R/C members based on the project information and the design codes used at the time of construction;

Structural elements simulated using fine elements considering distributed plasticity;

Simulation of infill elements using macro-elements;

Bracing elements were simulated using frame elements





Non linear behaviour models of materials :

Rebar (Menegotto-Pinto model);

Concrete (Mander et al. model , considering the Martinez-Rueda e Elnashai for cyclic behaviour);

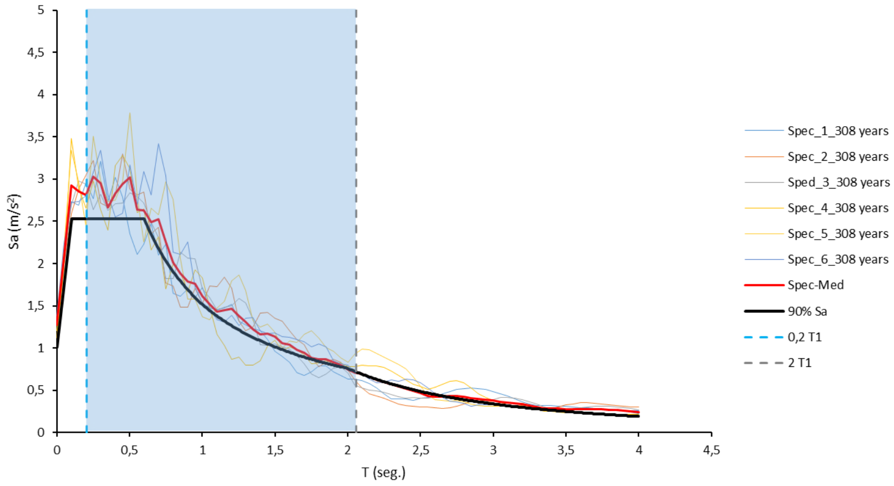
Infill elements: Crisafulli model

Dissipative bracing : Bilinear model proposed by Zsarnócsay et al.

Case study - Evaluation of seismic performance – EN 1998-1 and EN 1998-3 specifications

Non Linear Static Analyses (AENL)

Response specters of seismic actions type 1 and 2, considering the return periods correspondent to Damage levels DL (damage limitation) and SD (Significant damage) (T_R=73 e 308 years, respectively) as defined in the EN1998-3

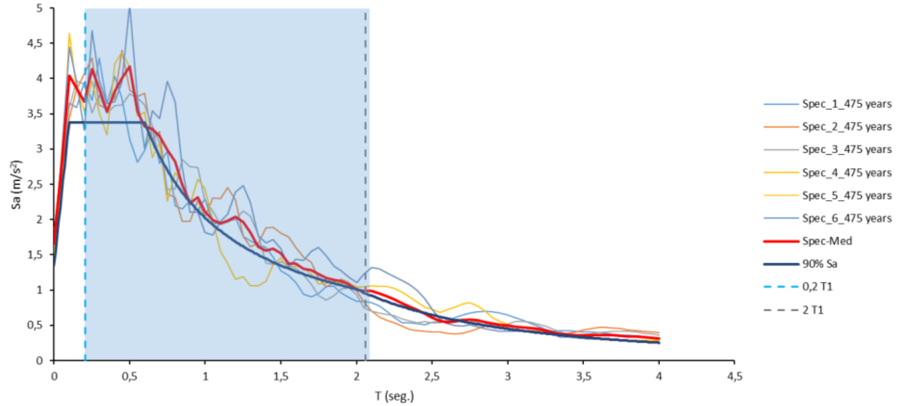


Also

Additional performance requirement: compliance with the Significant Damage level SD for the relevant seismic action (Type 1) with T_R=475 years.

Dynamic analyses (AT)

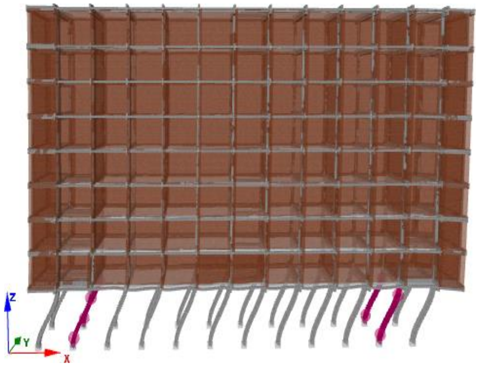
Compatible artificial accelerograms of relevant seismic action (Type 1) for T_R=308 e T_R=475 years :



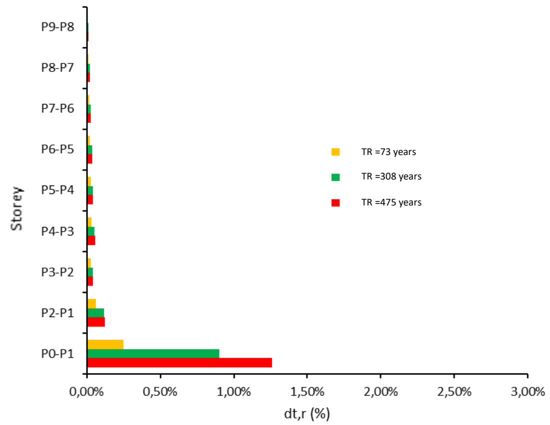
Case study analyses

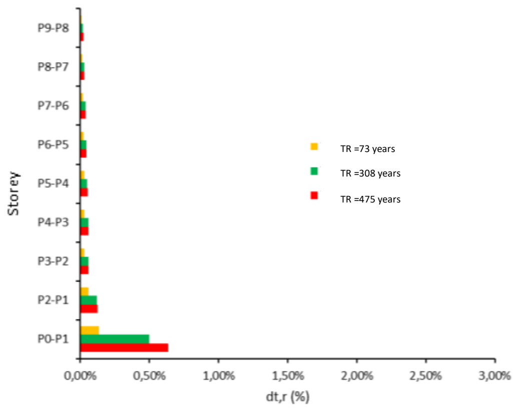
Assessment of the seismic performance - Scenario 1

Results:



- Concentration of interstorey drift on the first floor;
- Insufficient shear capacity of columns in the transition between the ground and first floor to comply with SD damage level;

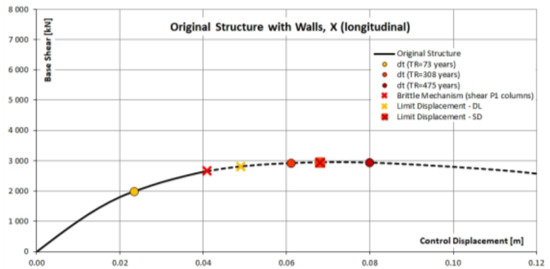


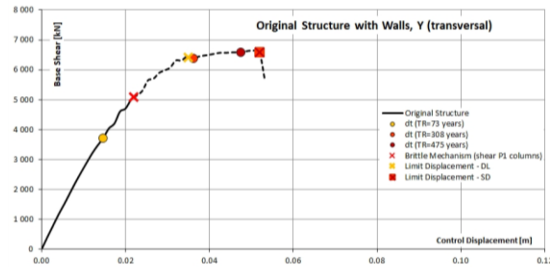


<u>Ductile mechanisms</u>:

- Acceptable performance relatively to LD and SD damage levels (relevant seismic action type with T_R=73 e 308 years);

- Unacceptable performance relatively to SD damage level (relevant seismic action type with T_R=475 years;





Analysis of a case study

Intervention strategy

- Increase of columns shear capacity ;
- Take advantage of the structure's seismic response configuration;
- Apply the bracing system between the ground floor and the first floor.

Objectives

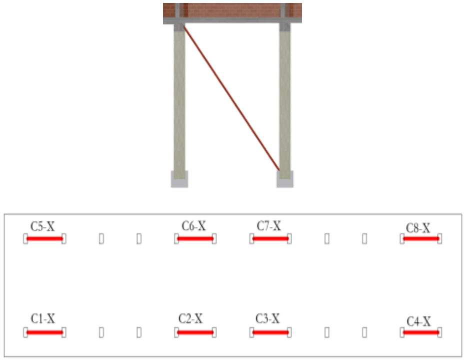
- Reduce the first floor displacement;
- Not increase (excessively) the interstorey drift of the upper storeys;
- Comply with the damage level SD when the structure is subjected to the reference seismic action with T_R=475 years.

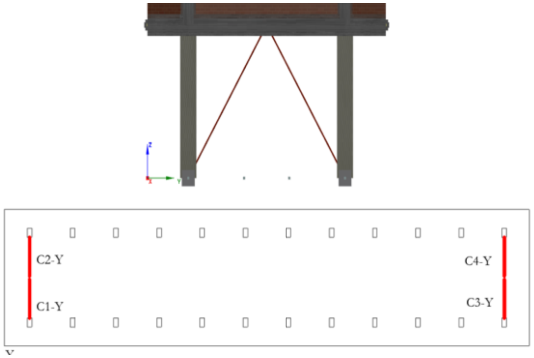
<u>Definition of the elastic and dissipative components lengths</u> (expressions defined previously and considering the maximum drift of the 1st floor

<u>Application of Kasai 's methodology</u>
Determination of the necessary global stiffness of the bracing K_d to achieve the required displacement reduction

Quantification of the number of necessary bracings

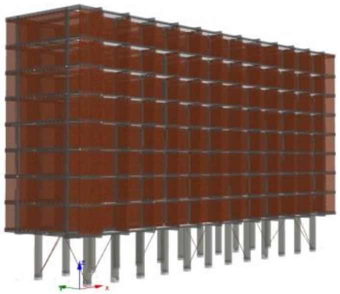
Application of the bracing elements between columns between the ground and the first floors (X and Y direction)



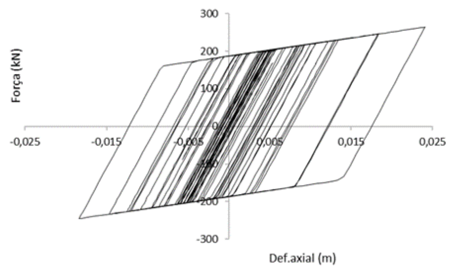


Case study analyses

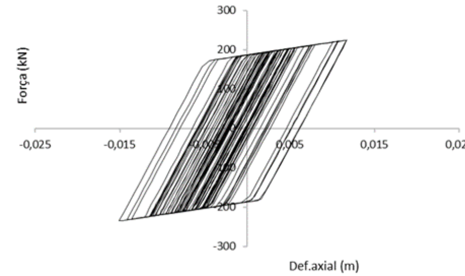
Assessment of the seismic performance - Scenario 2



Numerical model of the structure with bracings (Scenario 2)

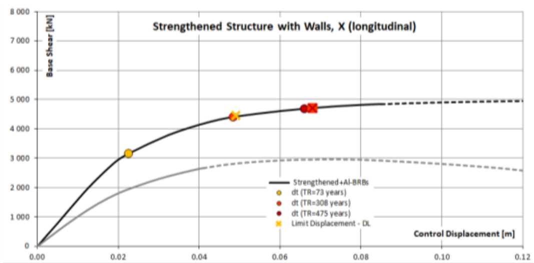


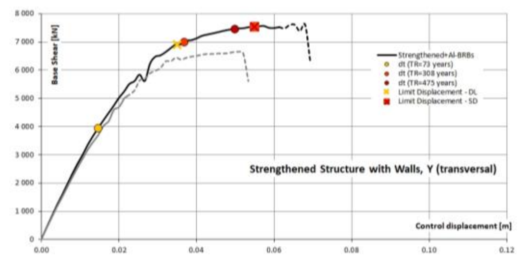
Bracing cyclic behaviour–dir. X – T_R=475 years



Bracing cyclic behaviour –dir. Y – T_R=475 years

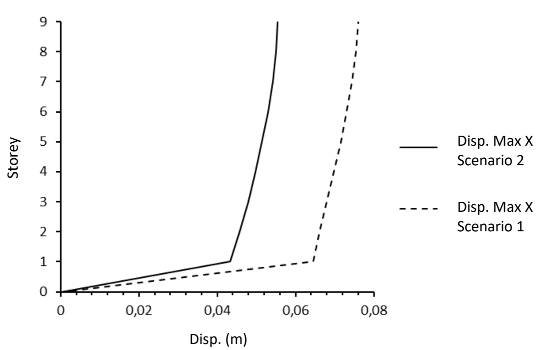
Non Linear Static Analyses (AENL)

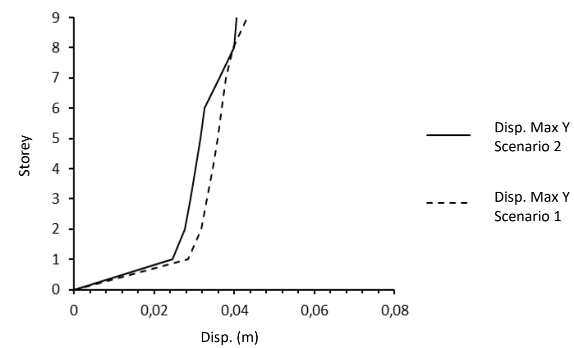




Damaged level SD is verified for the reference seismic action with return period TR = 475 years.

Dynamic Analyses (AT)





Case study

Partial conclusions (resume):

- **Current building:** When the infill elements are considered in the numeric model, the soft-storey mechanism is observed for seismic action lower than those required for the SD damage level.

- **In AT e AENL analyses** :

1. Deformation results obtained for the first and last floors, in both scenarios, are similar;

2. Interstorey drift results for intermediate floors were slightly different. Correction of results obtained from AENL is recommended , for example, considering the extended N2 method proposed by Fajfar;

- **Bracing behaviour** : Maximum deformation values observed in the bracings were within the limits of stability of its cyclic behavior and, therefore, the expected behavior was confirmed;

- **Kasai's methodology :** Since the pre-established reduction of the horizontal displacements was verified, it can be considered as effective method to estimate the number of bracings to a achieve a pre-determinate displacement reduction;

- **Structural intervention Stategy** : Although there was an increase of the interstorey drifts of the upper storeys, the main objectives of this structural intervention strategy were achieved;

Recommendations for future studies (in brief)

Development of experimental tests → Assessment

- **Low cyclic fatigue capacity** of the BRD_Al device, considering different imposed displacement cycles;
- **Cyclic behavior of the BRD_Al design**, possibly considering different dimensions of the cross section of both the bicylidrical profile and the dissipative core;
- **Cyclic behavior of the complete bracing system**
- **Cyclic behaviour of connection elements** :

  1. Between the elastic and plastic components;
  2. Between the bracing and the structure;

- **Development of an incremental dynamic analysis**, considering different levels of seismic actions, different lengths of each of the bracing's components and different distributions of the bracing within the structure **to assess the variability of the seismic response of R/C buildings with this type of bracing**;
- **Application of this bracing system** in the reduction of the seismic response of **other types of R/C buildings** and **other types of structures such as metallic or R/C bridges**.

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Thank you for your attention.