Development of BRD_AL Prototype

Development of aluminium alloy hysteretic damping system for seismic retrofitting of pre-coded reinforced concrete buildings

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Outline of the Doctoral Programme

Introduction:

- The problem
- Objectives

An overview of the State of the art:

- Hysteretic yielding devices
- Aluminium Alloys
- BRD_AL prototype

Methodology:

- Assessment of aluminium alloys behaviour;
- Assessment of device behaviour (local analysis);
- Analysis of device behaviour (global analysis);
- Case study Analysis

The problem - Seismic risk of pre-coded buildings

Quantification of RC buildings in Lisboa (INE Census 2011)

Transition period 1958 –
Introduction of 1st regulation
RSCCS

Regulatory framework	Inexistent			RSEP(1961)		REBAP, RSAEP(1983)				
Year of construction	Until 1919	1919-1945	1946-1960	1961-1970	1971-1980	1981-1990	1991-1995	1996-200	2001-2005	2006-2011
Nº of existing RC buildings	0	7502	26405	39895	61042	55562	24930	28317	29088	20237

Estimate:

Nº of existing RC Buildings design without seismic provisions: > 26.000 buildings

Nº of existing RC Buildings designed with outdated seismic provisions: > 100.000 buildings

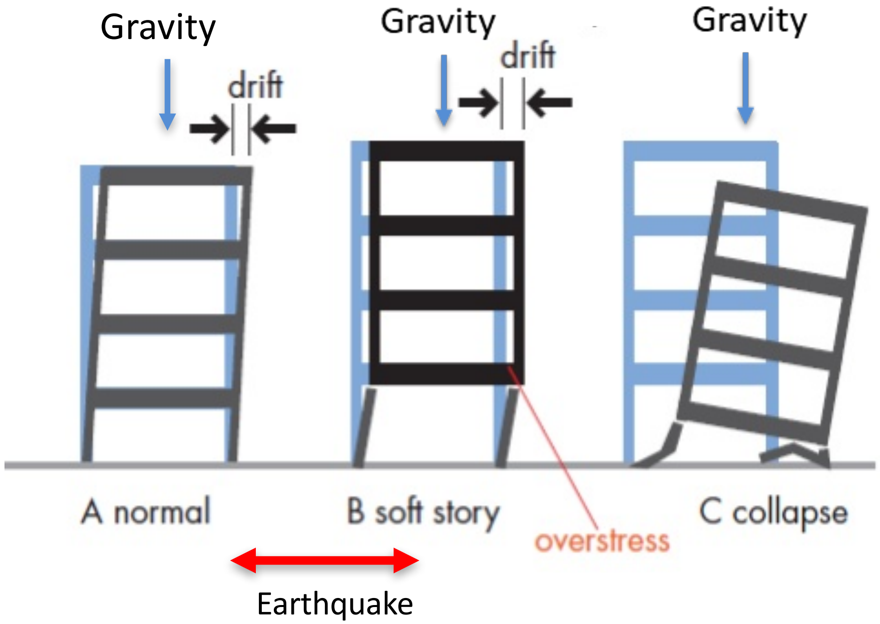
The problem - Pilotis Buildings

Construction of several buildings during the 50's and 60's, with particular characteristics:

- Commonly used in residential areas;
- Main volume + slender columns in transition to ground level;
- Seismic behaviour of this building typology – occurrence of soft-storey phenomena

The problem - Soft-storey phenomena

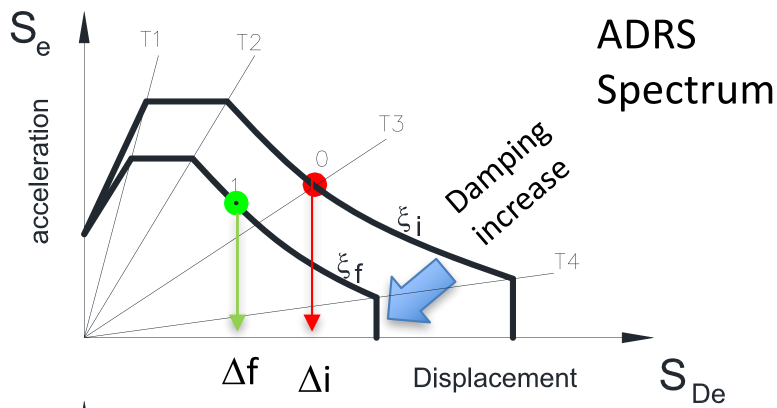
Soft storey failures in Golcuk, Turkey (Izmit and Düzce earthquakes). Source (AIR)

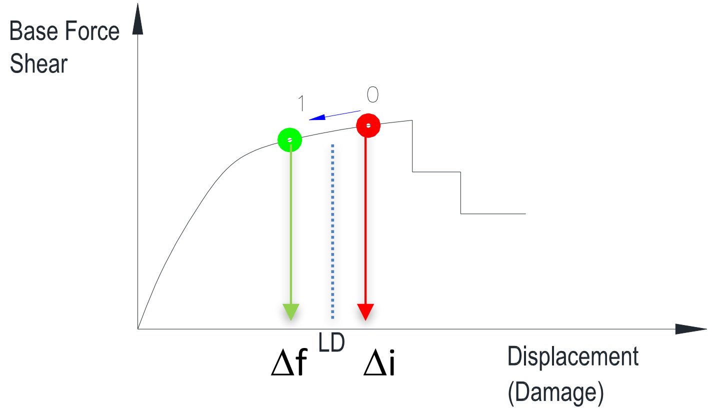


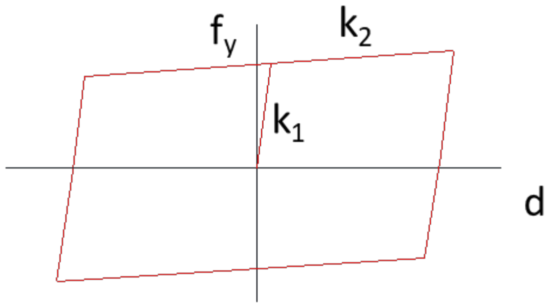
- Abrupt stiffness transition between building body and supporting slender columns, resulting in significant overstress on transition cross-sections of the supporting columns;
- Pilotis buildings constructed in Lisbon during the 50's and 60's of the last century where not designed for seismic action and are prone to this type of phenomena in case of a moderate to high seismic event.

The objective – Drift reduction Δ

- The reduction of drift Δ can be attained by the increase of structural damping;
- Hysteretic damper can be an efficient and economical way to increase damping (ξ), enabling the structure to comply to a certain limit damage (LD);
- Hysteretic dampers take advantage of the deformation capacity of metallic elements, usually steel;
- Damping provided by the device is determined by its dissipative capacity in each cycle;
- The hysteretic behaviour control parameters are K_1(initial stiffness), K_2(post-yield stiffness) and F_y(yield strength).







State of the Art – Dissipative devices – Brief overview

<table>
<tr><th colspan="3">Classification of devices</th></tr>
<tr><td rowspan="3">Displacement Dependent</td><td colspan="2">Linear(LD)</td></tr>
<tr><td rowspan="2">Non-Linear (NLD)/Hysteretic(HD)</td><td>Yielding metal (YMD)</td></tr>
<tr><td>Friction (FD)</td></tr>
<tr><td rowspan="2">Velocity Dependent/Viscous Dampers (VD)</td><td colspan="2">Fluid Viscous (FVD)</td></tr>
<tr><td colspan="2">Fluid Spring (FSD)</td></tr>
<tr><td colspan="3">Acceleration dependent</td></tr>
<tr><td colspan="3">Modified Input</td></tr>
<tr><td colspan="3">Combination</td></tr>
</table>

Source : Frederico Mazzolani, Luis Calado, *Introduction to reversible mixed technologies, FP6 PROHITEC project*

Hysteretic behaviour of Buckling Restrained Braces- as a principle for the development of new device

State of the Art – Aluminium Alloys overview

Classification of alloys
(Aluminium association and EN)

Constitutive elements:

Series	Alloying elements
1xxx	Pure Aluminium
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and silicon
7xxx	Zinc
8xxx	Other elements

Source: Mazzolani, 1995

Fabrication stage

F- Rough;
O-annealed;
H – Work-hardened;
W-Tempered non stabilized stage;
T-heat treated

Stages H and T can also be subdivided in terms of the stabilization stage, ageing processes and cooling processes

Heat-treatment

- Heat treatable alloys;
- Not heat treatable alloys

State of the Art – Aluminium Alloys overview

Properties	Aluminium	Steel
Average weight density γ (kg m^{-3})	2700	7850
Melting point T (ºC)	658	1450-1530
Linear thermal expansion, α (ºC^{-1})	24 x 10^{-6}	12 x 10^{-6}
Specific heat, C (cal g $^{-1}$)	0,255	0,12
Thermal conductivity λ, (cal cm^{-1} s^{-1} ºC^{-1})	0,52	0,062
Electrical resistivity ρ (μ Ω cm)	2,4	15,5
Young Modulus, E (N mm^{-1})	70 x 10^{3}	210 x 10^{3}

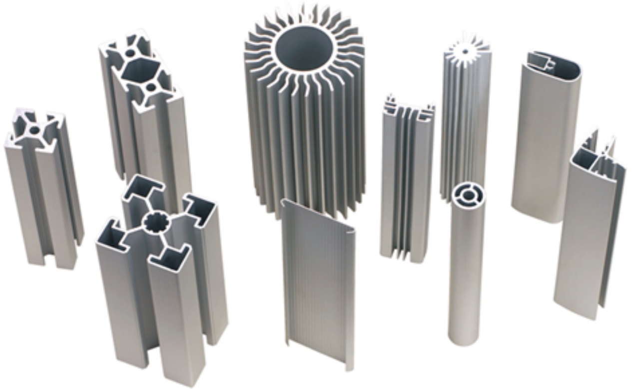
State of the Art – Aluminium Alloys overview

Mechanical Properties	Aluminium	Steel
Yield stress f_y ($N\ mm^{-2}$)	50-360	235-350
Ultimate stress f_t ($N\ mm^{-2}$)	80-410	360-510
Ultimate strain ε_t (%)	10-25	25-30

State of the Art- Aluminium alloys overview

Aluminium Alloys (advantages):

- Capability of production of elements with non conventional cross sections using alternative fabrication processes such extrusion or EDM;
- Ductility;
- Aesthetic appearance;
- Low weight (about 1/3 of the weight of steel);
- Corrosion resistance;
- Low maintenance;
- Recyclable

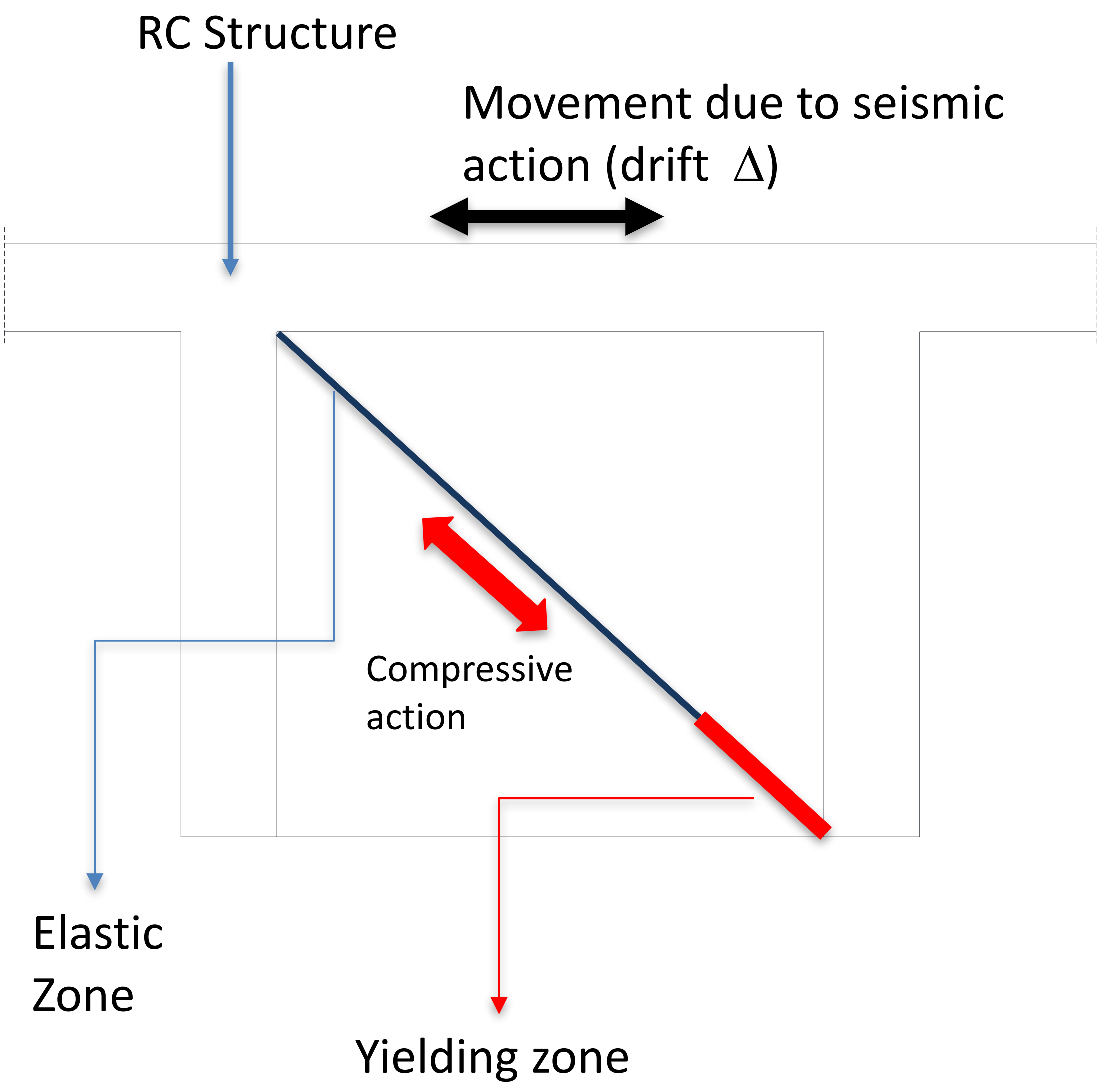


Source: World-Aluminium.org

Development BRD_AL Prototype

Objectives:

- Alternative to the dissipative bracing device paradigm: use an extruded aluminium alloy member without infill;
- Light-weight and easy to integrate in bracing system;
- Device that is simple to integrate both in new and existing buildings
- Device capable of withstanding significant plasticization, hence increasing structural damping due to hysteretic behaviour of the aluminium member;



Development BRD_AL Prototype - Methodology

Tasks:

1. State-of the art review, PhD curricular courses, contacts with national and International partners for the development of the device;
2. Definition of the aluminium alloy.
3. Cross section analysis.
4. Global Analysis;
5. Case study analysis;
6. Writing of the thesis

Task 2 – Aluminium Alloy analysis

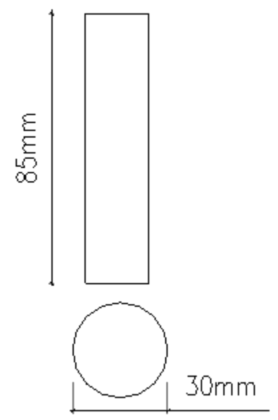
Experimental campaign of tension and compression tests will be carried out for the characterization of 3 different aluminium alloys.

A pre-determined set of aluminium alloys, based in the EN 1999 reference alloys, will be chosen for testing. The chosen aluminium alloys are:

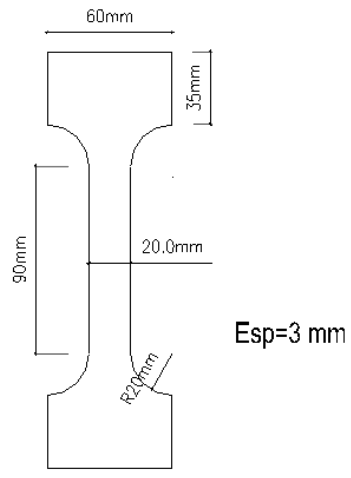
- EN AW 1050
- EN AW 5054 T6
- EN AW 6061 T6;

Standards to be used in compression and tension will be:

- EN 10002-1 – “Tensile testing -Part 1: Method of test at ambient temperature;
- ASTM E9-“Standard compression testing of metallic materials at room temperature”.



Compression test specimen



Tension test specimen

This will allow to have a consolidated comparison framework with test already performed by Prof. Mazzolani; and the normative values provided in the EN 1999-1 (EC9) and with analytical definitions like the Ramberg-Osgood formulation.

Task 2 – Aluminium Alloy analysis

Parameters analyses

- Yield stress;
- Ultimate stress
- Yield strain;
- Ultimate strain;

Main criteria for selection of the aluminium alloy

- Extrudability;
- Ductility;
- Price;

Objective

- Determine the best suited alloy to be used in BRD_AL production;

Task 3 – Cross section analysis

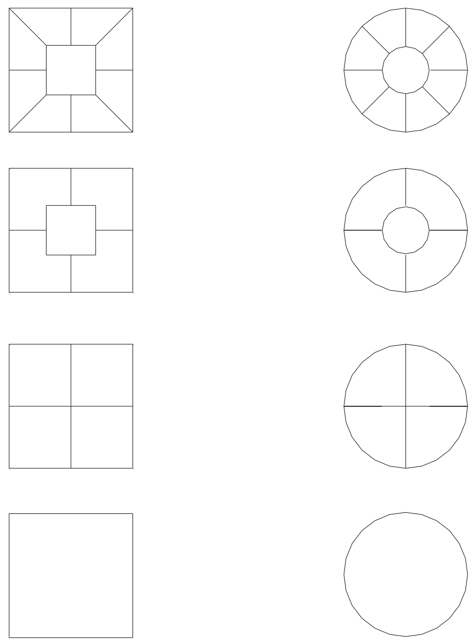
- Cyclic tests of extruded profiles fabricated using the aluminium alloy determined in the previous task ;

- Extruded profiles will be subjected to uniaxial cyclic loading with crescent amplitude until failure, following the recommendations :

  – EN 15129 “Anti-seismic devices”;

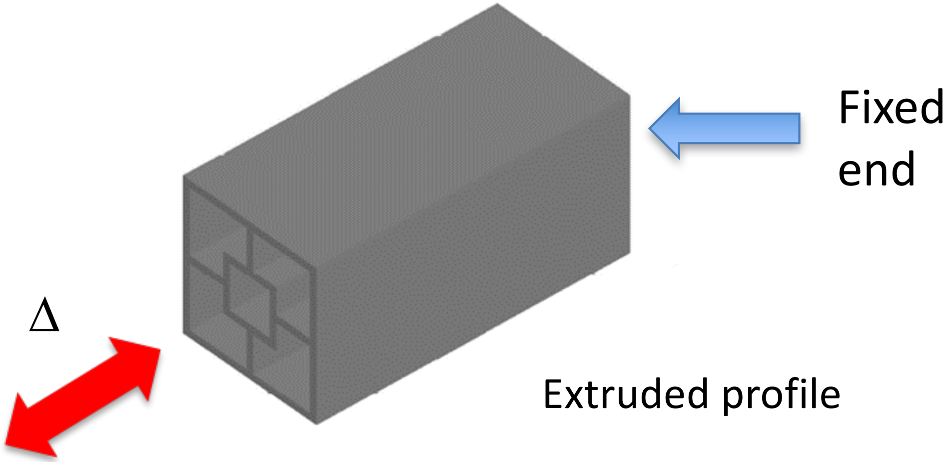
  – ATC 24 “Guidelines for the cyclic seismic testing of components of steel structures”;

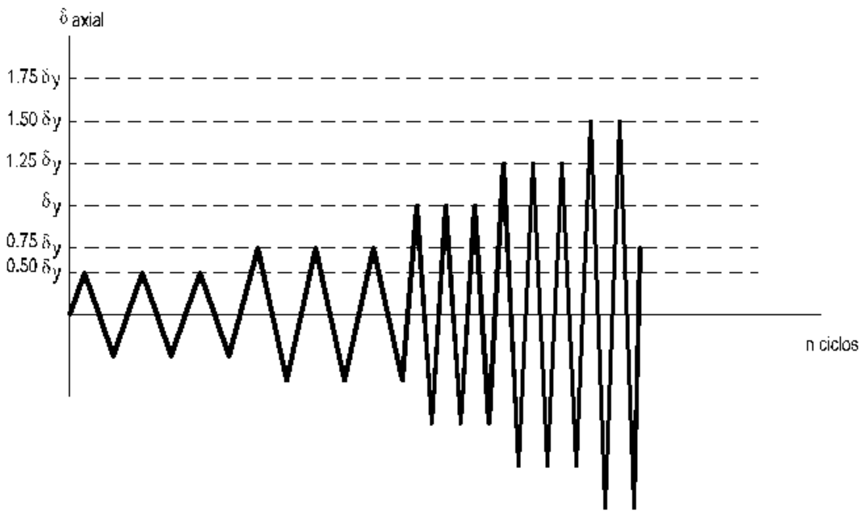
  – ECCS TGW 1.3 1985 “Recommended testing procedure for assessing the behaviour of structural steel elements under cyclic loads

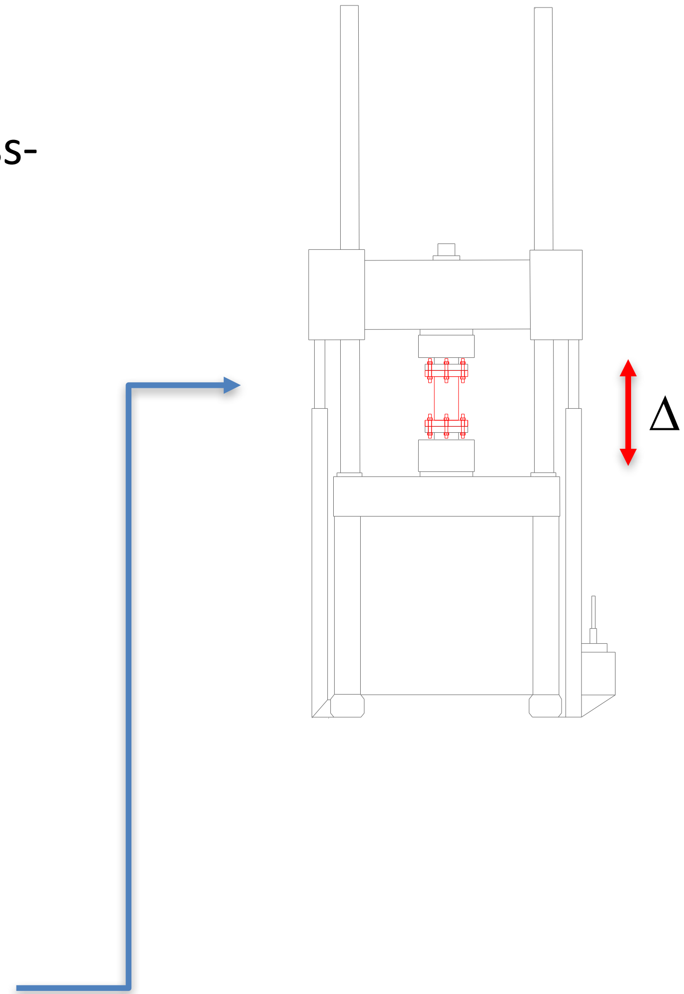


Task 3 – Cross section analysis

Loading to be applied to the centre element of the cross-section or to the whole cross-section (to be analysed);





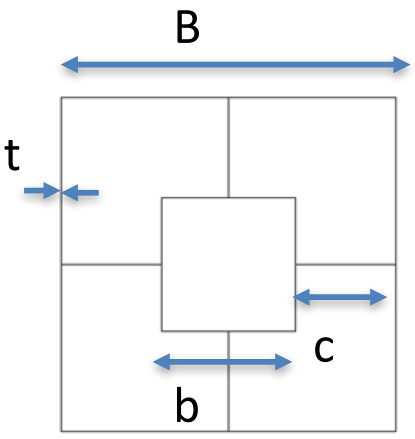


Uniaxial cyclic procedure using Universal machine Instron at LERM (IST)

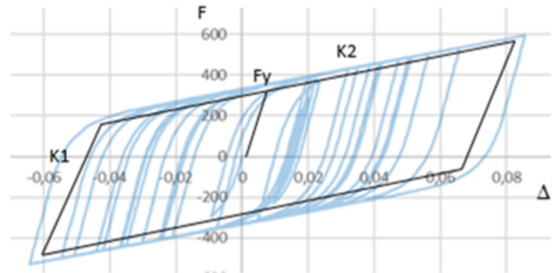
Task 3 – Cross section analysis

Objectives:

- Assessment of the influence on hysteretic behaviour of key parameters:
  - Influence of form;
  - Influence of geometric relationships between dimensions of the elements of the extruded profile;
  - Influence of existing geometric imperfections (w_0).
- Definition of most favourable cross section configuration;
- Definition of representative numeric model of the element, modelling the isotropic and kinematic hardening phenomena observed during the experimental tests;



Cross section example

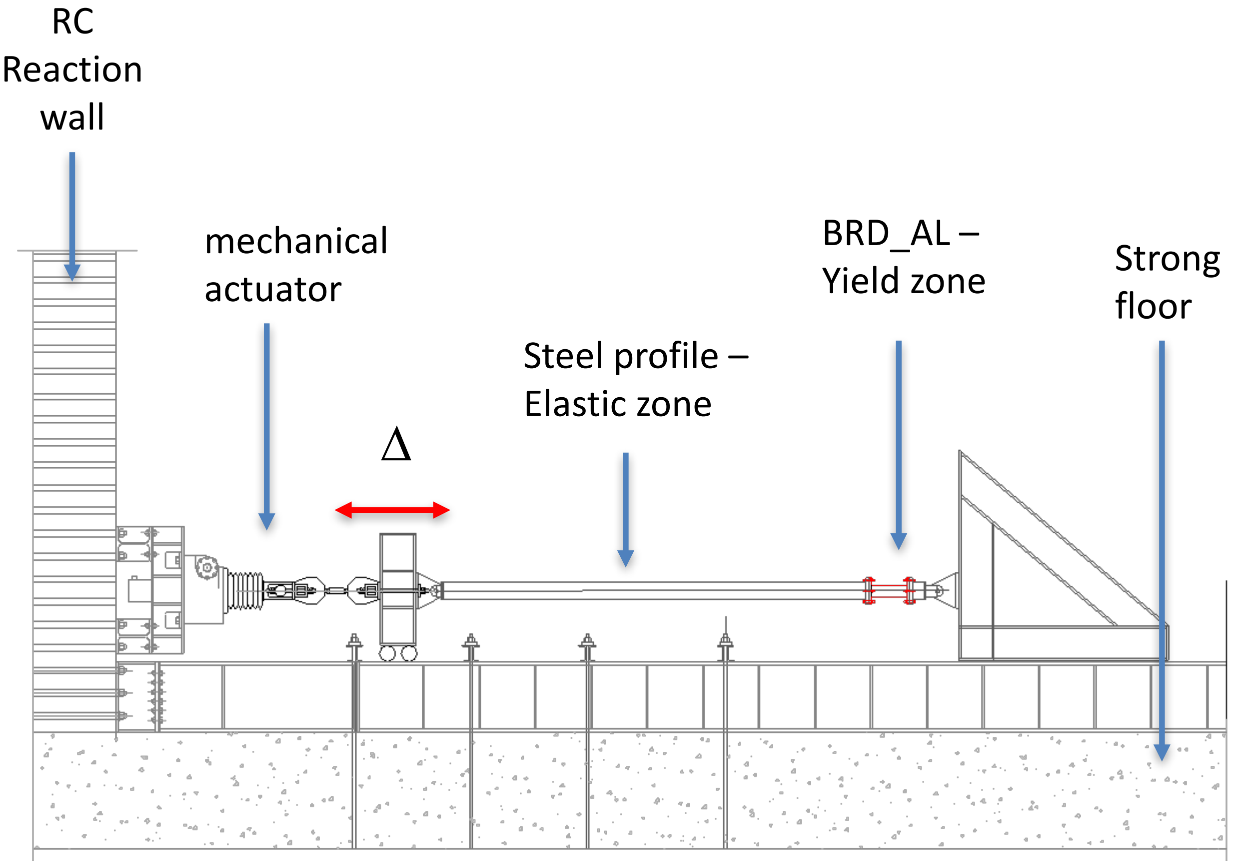


Parametrization of the non linear behaviour of BRD_AL

Task 4 – Global analysis - Experimental campaign to analyse the global hysteretic behaviour

Objectives:

- Analysis of the effects of boundary conditions and global in-plane and out-of-plane imperfections on the hysteretic behaviour of the assembly;
- Definition of numeric model global system duly calibrated from experimental results.
- Same loading programme has in task 3



Task 5 – Case study - Development of numerical analyses of an existing pre-code pilotis building in Lisbon;

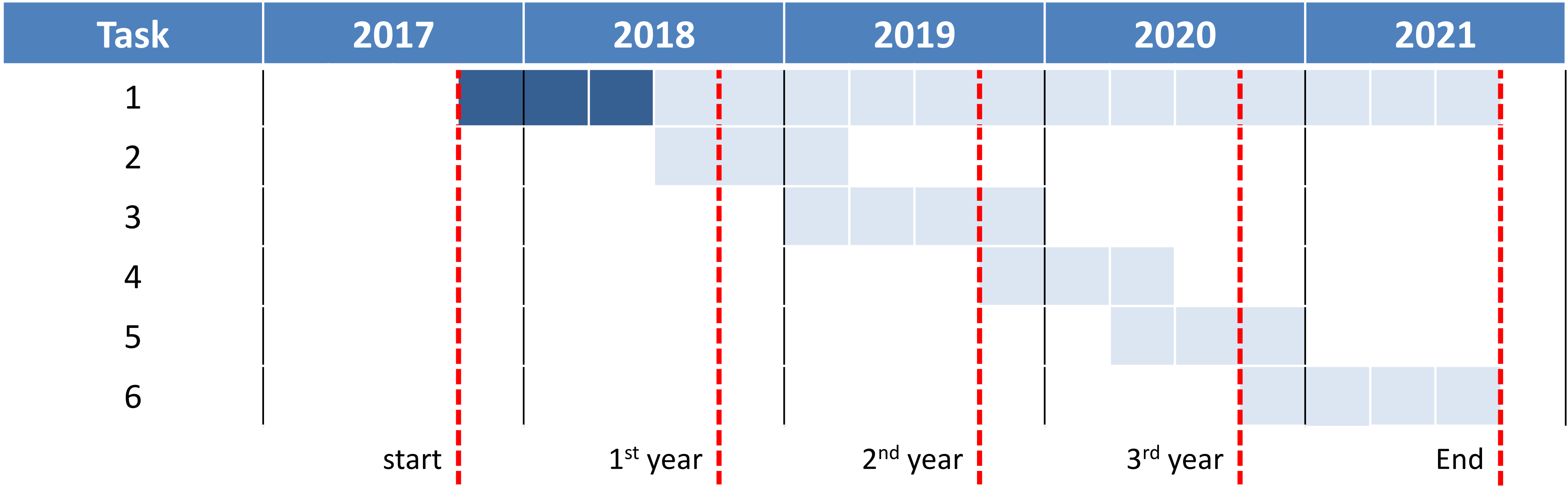
Objectives:

- Assessment of dynamic behaviour of the existing pre-code building considering the performance requirements and compliance criteria of EN NP 1998-1 and EN 1998-3;

- Assessment of dynamic behaviour of the case study building when BRD_AL is used has structural retrofitting technique;

- Numerical analyses on the case study building will performed using OpenSees and Built-X numerical software using the numerical model of the non-linear behaviour of BRD_AL duly calibrated during task 4;

Chronogram and tasks



Task 1 – State of the art review, PhD courses of host institution; Contacts with national and international partners for the development of BRD_AL;

Task 2 – Definition of the aluminium alloy. (Mechanical characterization of aluminium alloys);

Task 3 –Cross section analysis (Characterization of the hysteretic behaviour of the BRD_AL);

Task 4 – Global Analysis. (Characterization of the hysteretic of the global system;

Task 5 – Case study analysis;

Task 6 – Writing of thesis

References

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EN 10002-1 – "Tensile testing -Part 1: Method of test at ambient temperature;

EN 15129 - "Anti-seismic devices";

ATC 24 - "Guidelines for the cyclic seismic testing of components of steel structures";

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World Aluminium- http://www.world-aluminium.org/publications/

European Aluminium - https://www.european-aluminium.eu

Thank you for your attention.