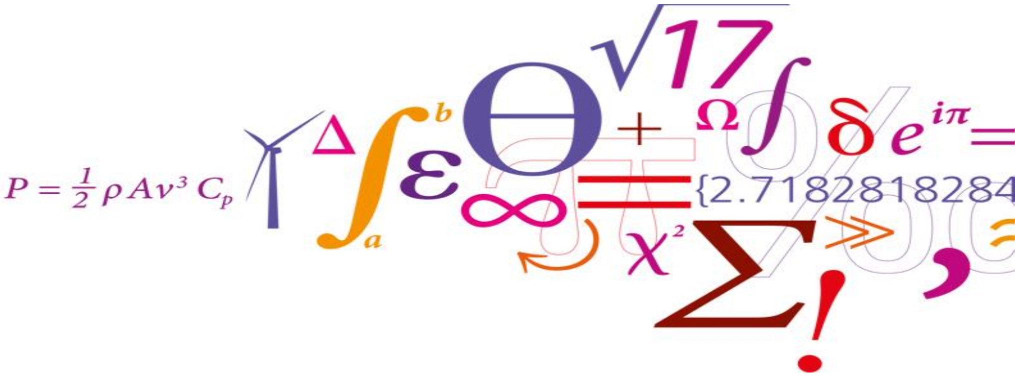
APPLICATION OF MAGNETO-RHEOLOGICAL DAMPERS TO ALLEVIATE FATIGUE DAMAGE OF JACKET SUBSTRUCTURES FOR 20 MW WIND TURBINES



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INTRODUCTION - Problematic

- Passive tuned vibration absorbers (TVAs) and passive tuned mass dampers (TMDs) have been successful as load mitigation techniques for the DTU 10 MW reference wind turbine
- However, it has been noted that these load mitigation techniques affect only a **narrow frequency range**, which is non-optimal for a system with multiple excitation frequencies.
- Moreover, disturbances and changes in natural frequencies can lead to the **de-tuning of the damper system**.
- Requiring **space** at component level, they may necessitate an **integrated design** for acceptable performance

INTRODUCTION – Proposed Solution

- Semi-active magneto-rheological (MR) dampers are been proposed as an alternative to the passive systems

- MR dampers can have a **local effect** and can be used in **multiple units to accommodate various exciting frequencies**.

- They are **moderate in size** and may not require extra space. They can be **assembled as a scaling strategy**.

- They can be put in place at the substructure level, eliminating the necessity of **integrated design** of the couple made of the support structure and the rotor-and-nacelle assembly.

- The objective of this study is to mitigate fatigue loads on jacket substructure using MR dampers

DESIGN PARAMETERS – INNWIND 20 MW

Parameters	Values
Wind regime	(see table 1)
Rotor type, orientation	3 bladed - Clockwise rotation – Upwind
Control	Variable speed – Collective pitch
Cut-in, rated, cut-out wind speed	4 m/s, 11.4 m/s, 25 m/s
Rated power	20 MW
Rotor, hub diameter	252.2 m, 7.9 m
Hub height	167.9 m
Drivetrain	Medium speed, Multiple-stage Gearbox
Minimum, maximum rotor speed	4.45 rpm, 7.13 rpm
Maximum generator speed	339.4 rpm
Gearbox ratio	47.6
Maximum tip speed	90.0 m/s
Hub overhang	10.0 m
Shaft tilt, coning angle	5.0°, -2.5°
Blade prebend	4.7 m
Rotor mass including hub	632,016 kg
Nacelle mass	1,098,270 kg

DESIGN PARAMETERS – Air, Sea, Jacket

Atmospheric Conditions

- Wind speed range: from 4 m/s to 25 m/s divided into 11 bins of 2 m/s width
- Wind speed distribution: Rayleigh distribution with 9.25 as parameter
- Wind turbulence: similar to the IEC Class 1C

Sea Conditions

- Wave spectrum: JONSWAP
- 50 m water depth
- Expected sea states (peak spectral period and significant wave height) are associated to each mean wind speed.

Jacket description

- Upscaled from a model optimized for DTU 10 MW RWT (factor 1.3)
- Four legs of about 1000 mm diameter and 60 – 100 mm wall thickness
- Braces have OD of ca 700 – 900 mm.

MR DAMPER – Device

Characteristic for 200 kN

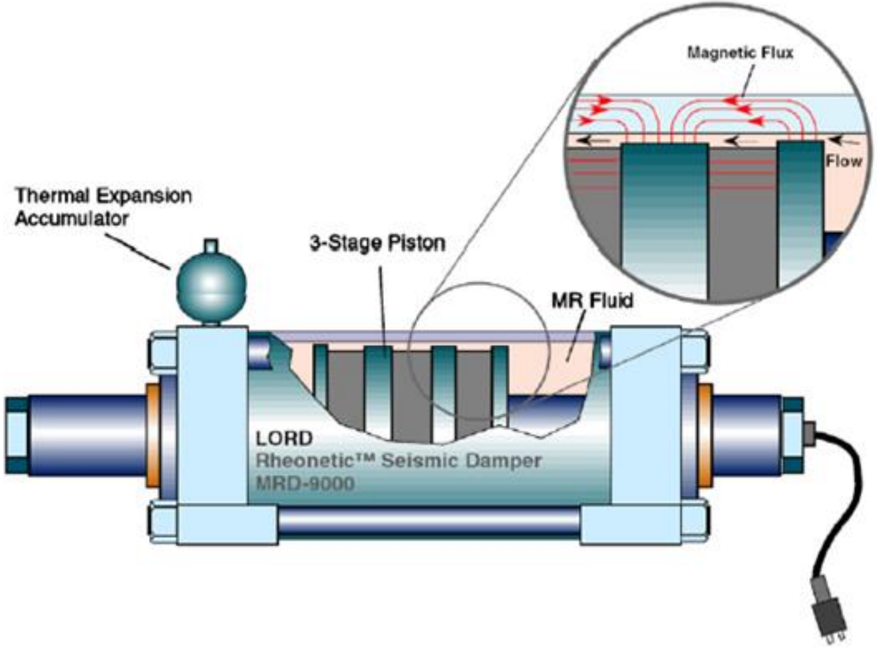
Mass: 250 kg.

Dimensions: 1000 mm long, 300 mm wide with 203 mm inside diameter.

Piston: stroke of ±80 mm.

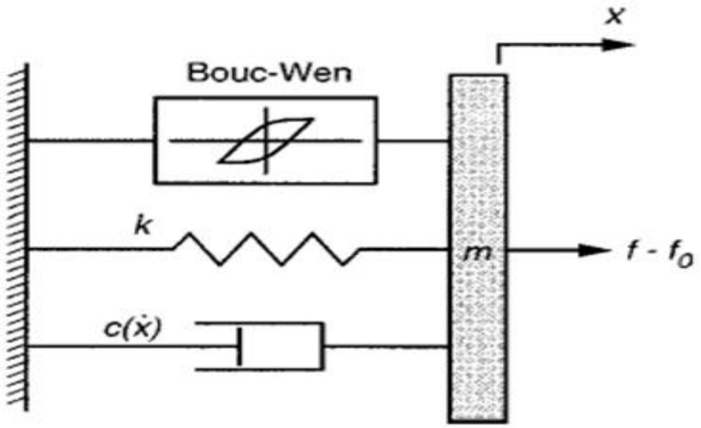
MR Fluid: 5.0 litres.

Coil wires: 1.5 km long, induction of 6.6 H, resistance of 21.9 Ω.



Kim Y, Langari R , Hurlebaus S. Semi active nonlinear control of a building with a magnetorheological damper system, Mechanical Systems and Signal Processing 23 (2009) 300–315.

MR DAMPER – Phenomenology



The force equilibrium along the x-axis gives the damper force:

$$f = m\ddot{x} + c(\dot{x})\dot{x} + kx + \alpha z + f_0$$

with the evolutionary variable z from the Bouc-Wen model

$$\dot{z} = -\gamma|\dot{x}|z|z|^{n-1} - \beta\dot{x}|z|^n + A\dot{x}$$

and the variable damping coefficient:

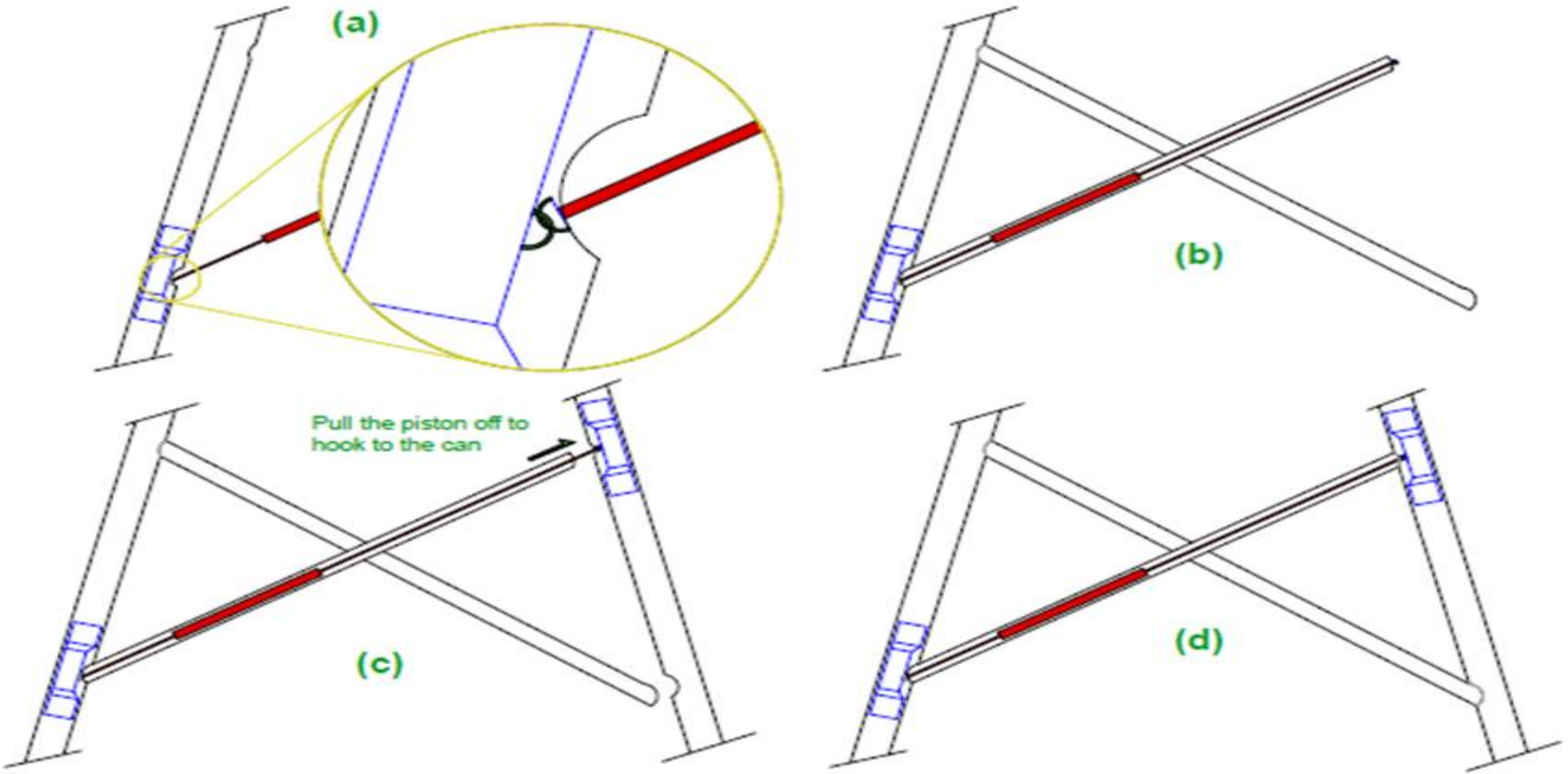
$$c(\dot{x}) = a_1 e^{-(a_2|\dot{x}|)^p}$$

Yang G, Spencer Jr. B F, Jung H-J, Carlson J D. Dynamic Modeling of Large-Scale Magnetorheological Damper Systems for Civil Engineering Applications, Journal of Engineering Mechanics 130:9 (2004) 1107–1114.

MR DAMPER – Parameters for 200 kN

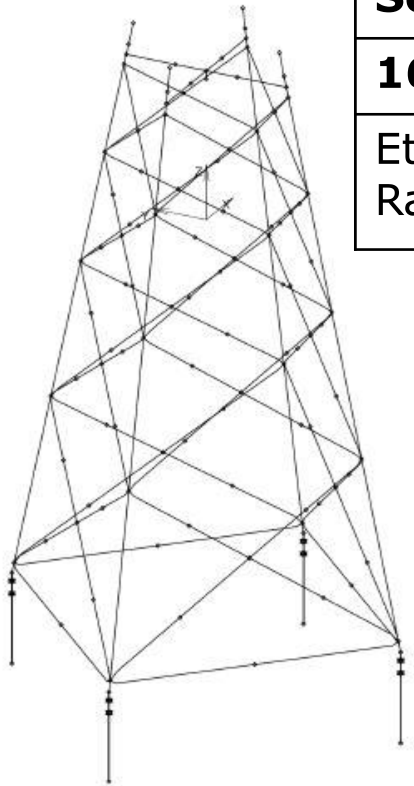
Symbols	Unit	Description	Values
γ	m^{-1}	Bouc-Wen constant	25 179.04
β	m^{-1}	Bouc-Wen constant	27.1603
A	m^{-1}	Bouc-Wen constant	1 377.9788
$\boldsymbol{k}$	**N/m**	**Accumulator stiffness and MR fluid compressibility**	**20.1595**
p	-	Positive constant	0.2442
α	N	Positive constant	2.3000 E 5
a_1	N s/m	Positive constant	35.000 E 6
a_2	s/m	Positive constant	4 335.00
$\boldsymbol{m}$	**kg**	**Equivalent mass which represents the MR fluid stiction phenomenon and inertia effect**	**22 000**
n	-	Bouc-Wen constant	6.7300
$\boldsymbol{f_0}$	**N**	**Damper friction force due to seals and measurement bias**	**5 126.00**

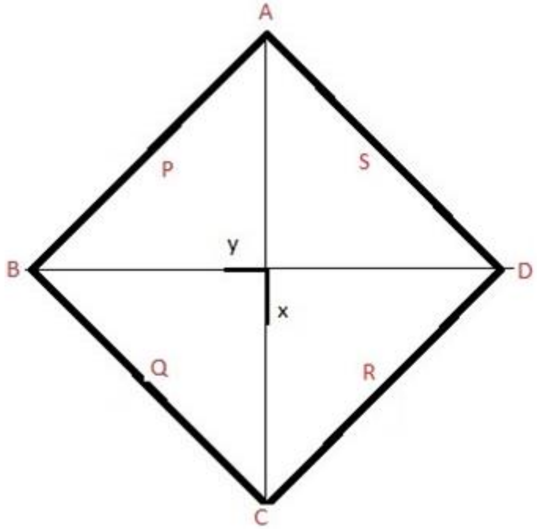
MR DAMPER – Installation

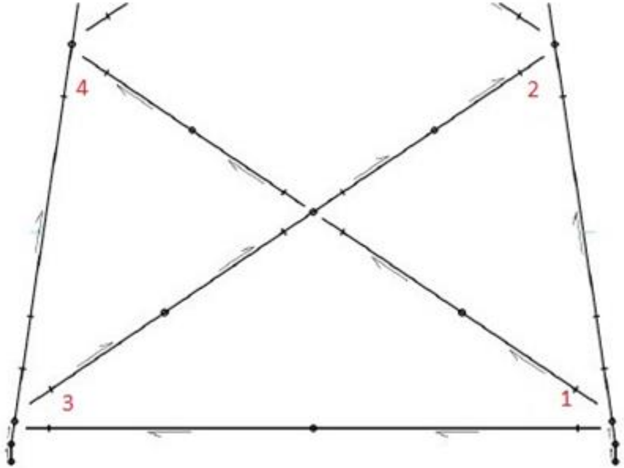


MODELLING – Load, Stress, and Damage

Software Package: HAWC2	**Design load case**: IEC DLC 1.2
16 hotspots: critical Q2	**Node nomenclature**: P1, P2, P3…
Ethymiou Equations for SCFs Rainflow counting for cycles	T-curve with cathodic protection Miner rule for damage summation

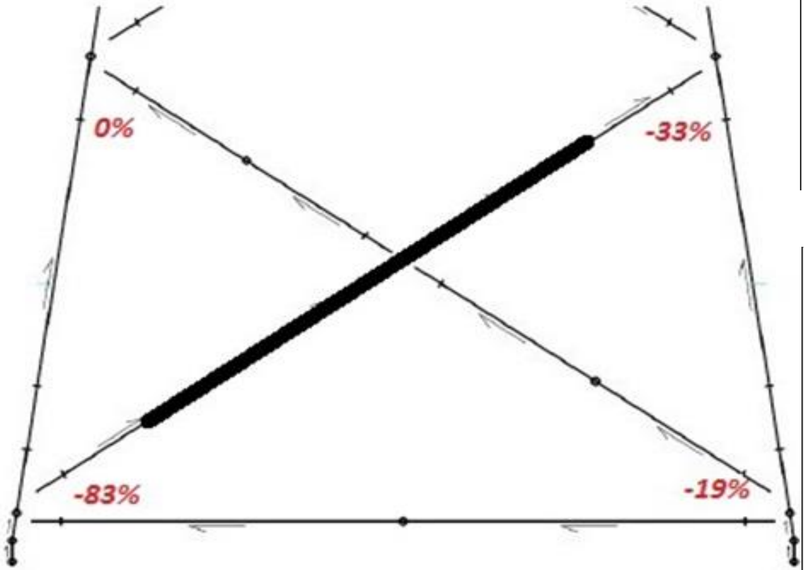


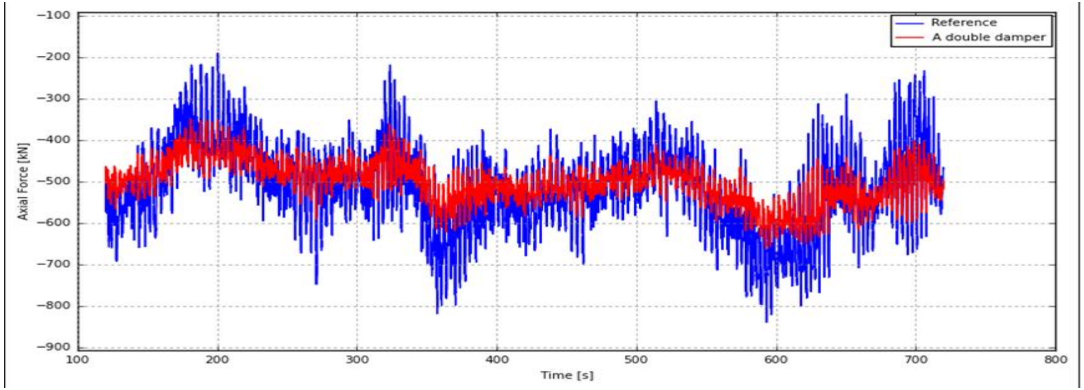


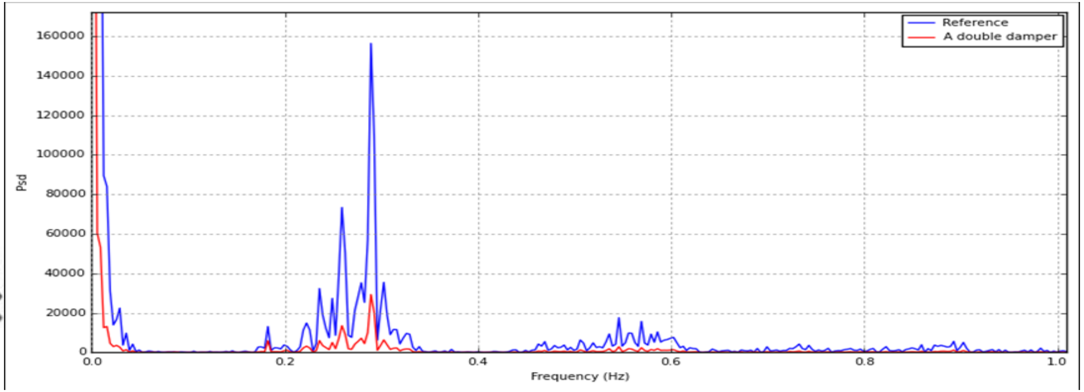


RESULTS – Axial Load

Brace equipped with one device

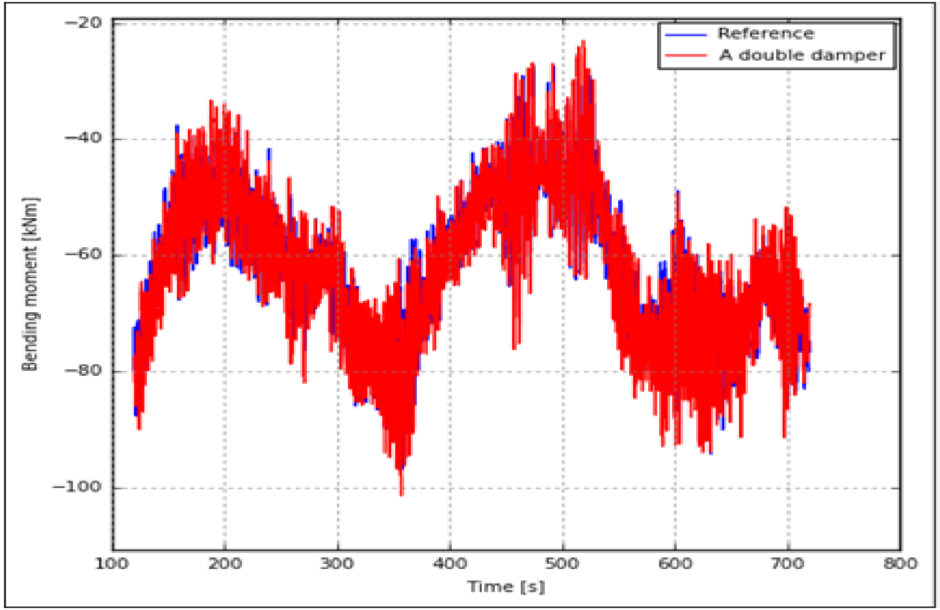


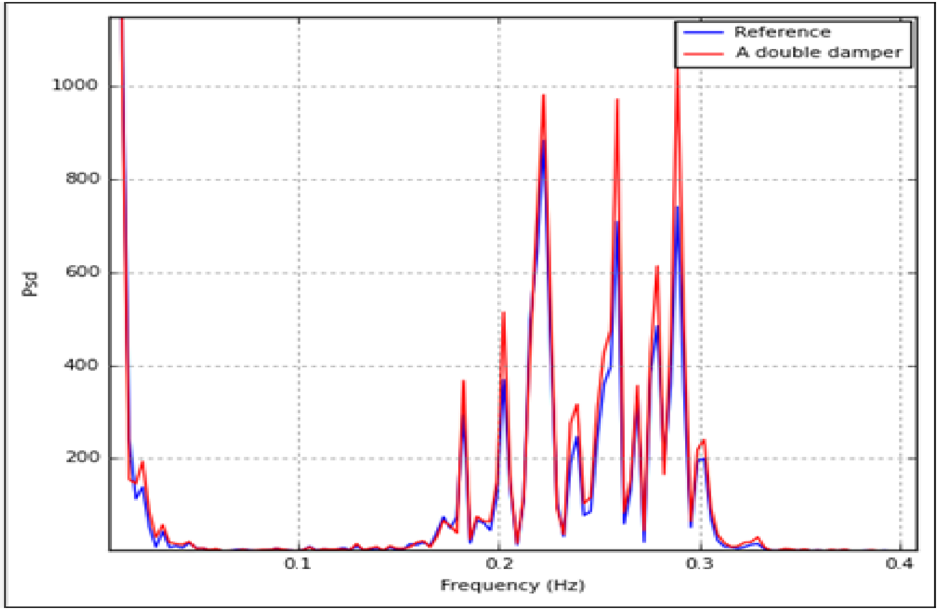




RESULTS – Bending Moments

Out-of-plane bending moment





RESULTS – Shortage and Solutions

1- **Shortage**: Increase of the fatigue damage at other hotspots, between 2% and 102%.

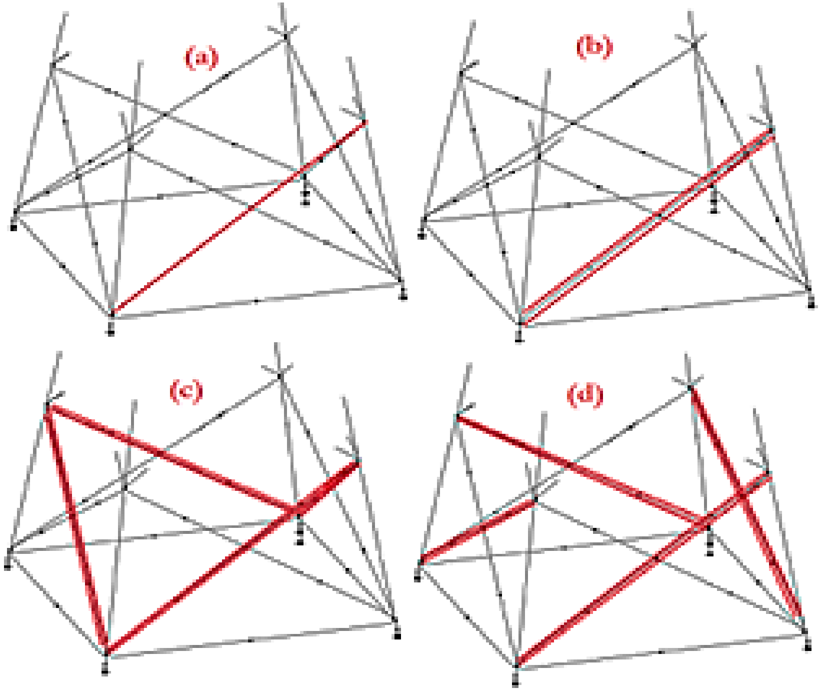
2- Investigation of other **configurations**:

a) **Unique damper**

b) **Double damper**

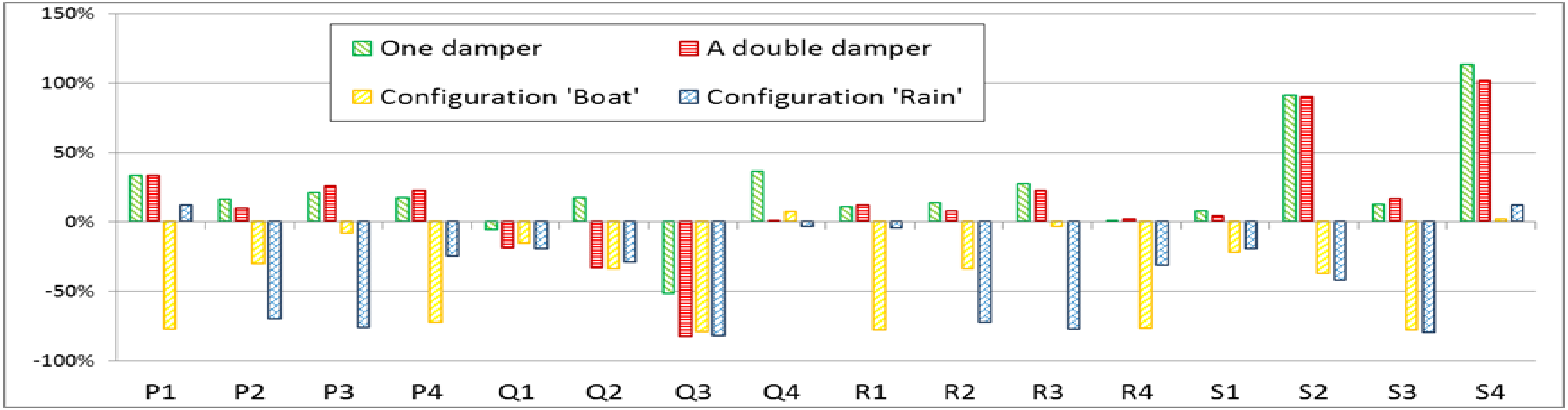
c) **Configuration 'Boat'**

d) **Configuration 'Rain'**



RESULTS – Performance Comparison

Positive relative change indicates increase of fatigue damage.



CONCLUSION AND FUTURE DEVELOPMENTS

- The study reveals the potential of MR dampers to **alleviate fatigue damage**. Indeed, up to 77% of fatigue damage reduction at a critical joint can be obtained

- By considering various configurations, results show the necessity of selecting **appropriate configurations** in order to maximize the benefits of the fatigue reduction strategy at specific links, without causing any increased damage at other sections.

- Further studies may be required to propose a procedure of **smart distribution** of the devices around the jacket.

- The **robustness of the system** with respect to external actions and manufacturing tolerances may also be investigated, as well as the effect of the **additional mass** on the equipped brace.

- The MR damper used in this study is developed for civil engineering applications; it is encouraged to design **dedicated MR devices for jacket** (geometry and sensibility).

THANK YOU FOR YOUR ATTENTION