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# Behavior of structures equipped with variable friction dissipative systems


Liborio Cavaleri, Mario Di Paola, **Marco Filippo Ferrotto**, Vincenzo Sucato

dipartimento di ingegneria unipa

Department of Engineering, University of Palermo,
Viale delle Scienze 90128, Palermo, Italy

**THE NEED OF ENERGY DISSIPATION SYSTEMS………**

EARTHQUAKES

WIND LOADS

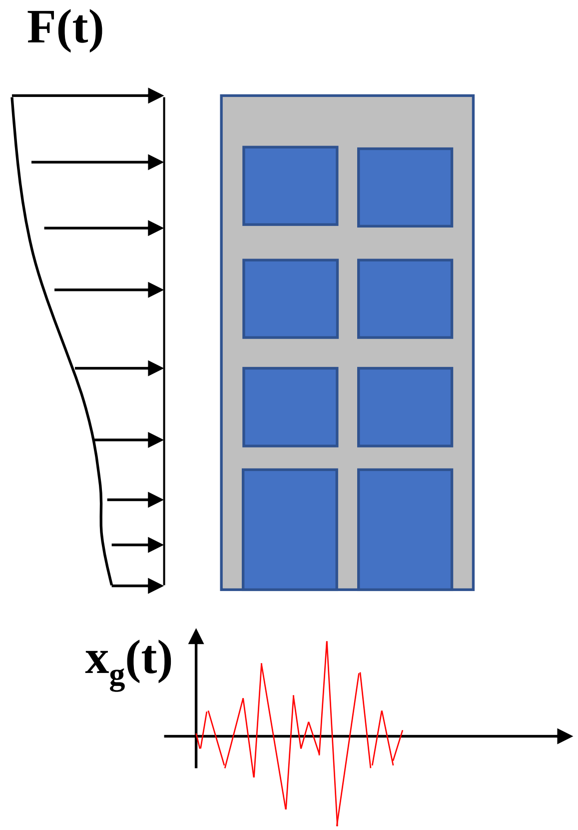
OTHER DYNAMIC ACTIONS

↓

MITIGATION/REDUCTION OF DISPLACEMENTS/VIBRATIONS

↓

NEW OR EXISTING STEEL/RC FRAMED STRUCTURES



# OUTLINE

1. MOST USED DISSIPATION DEVICES FOR PRACTICAL APPLICATIONS

2. COMPARISONS OF MECHANICAL PROPERTIES

3. A PROPOSAL FOR A VARIABLE FRICTION DISSIPATIVE DEVICE

4. NUMERICAL APPLICATIONS AND COMPARISONS WITH CLASSIC CONSTANT FRICTION DAMPER DEVICES

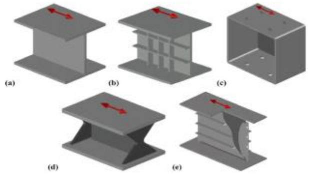
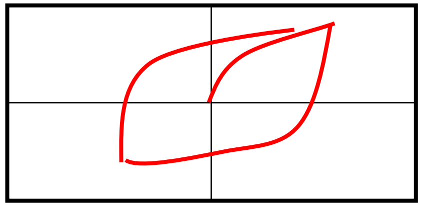
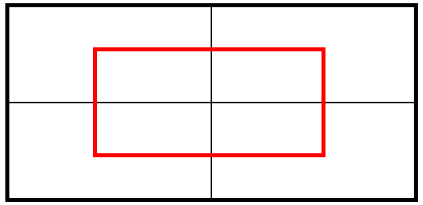
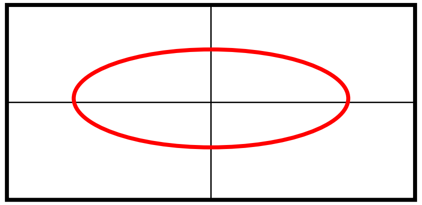
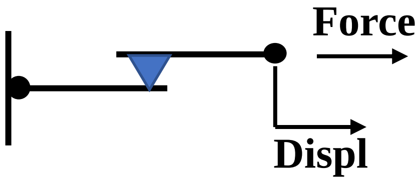
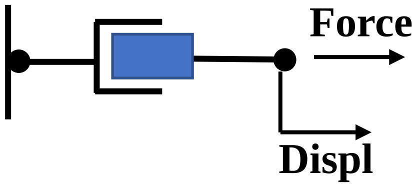
## SOME EXAMPLE……..

**HYSTERETIC DAMPERS**

**FRICTION DAMPERS**

**FLUID VISCOUS DAMPERS**

# MAIN FEATURES OF ENERGY DISSIPATION DEVICES

| | | | |
|---|---|---|---|
| **Device** | Metallic damper  | Friction damper  | Viscous damper  |
| **Constitutive behavior** |  |  |  |
| **Physical model** | / |   |   |
| **Advantages** | • Stable hysteretic behavior<br>• Long term reliability | Large energy dissipation per cycle | • Activated at low displacements<br>• Minimal restoring force |
| **Disadvantages** | Device may need replacement after the earthquake | Sliding interface conditions may change with time | • Properties are temperature dependent<br>• Very expensive |

## Dissipative force of the VFD

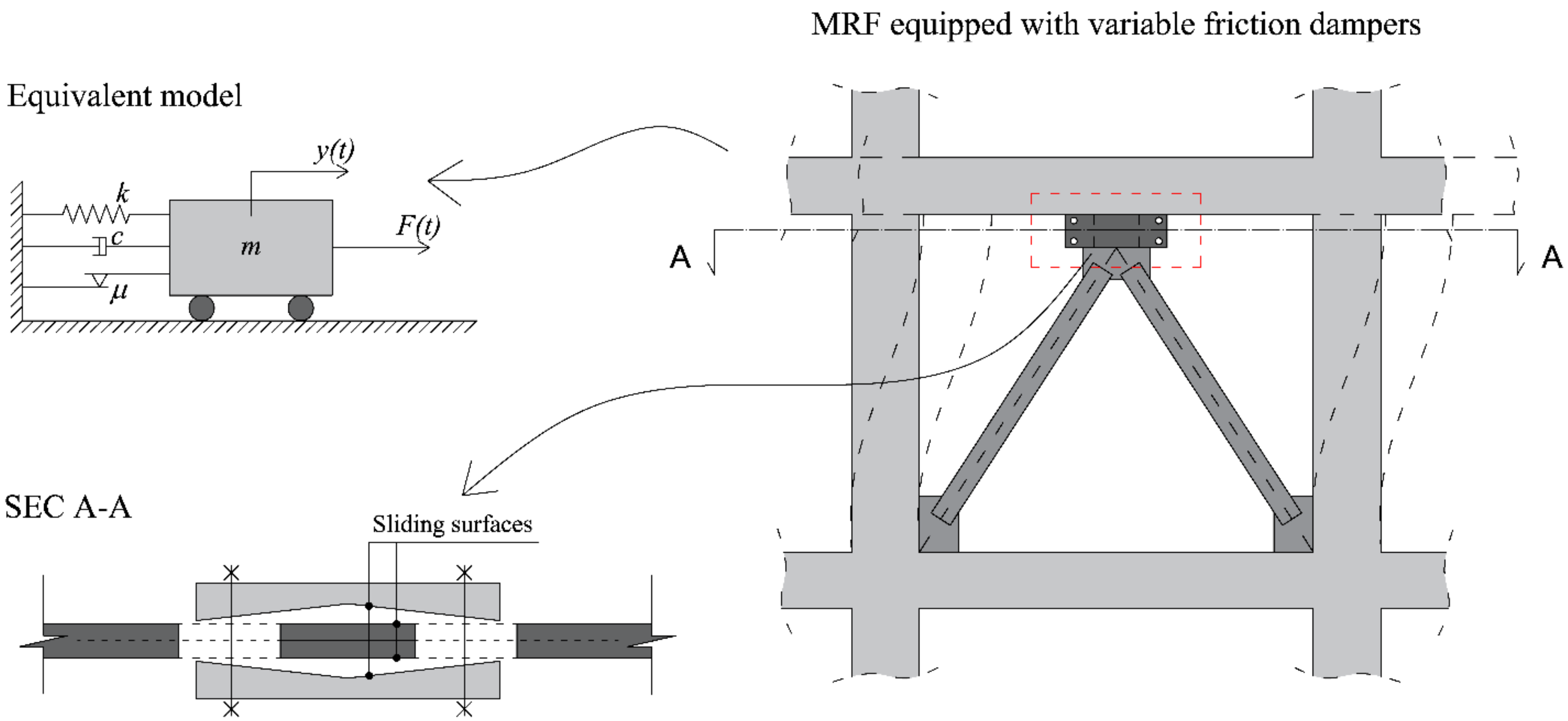
$$F = \underbrace{c_0 \cdot sign(\dot{x})}_{\text{Pure friction}} + \underbrace{c_1 \cdot |x| \cdot sign(\dot{x})}_{\text{Hardening component}}$$

## GEOMETRICAL DESCRIPTION

Two steel plates are fixed to the bottom of the beam at the upper floor, while an intermediate steel device is connected to the lower steel braces. The central device slides along the internal surfaces of the external plates that are bolted with a given prestressing induced by tightening (according to the classic friction damper devices).

## MECHANICAL EFFECTS

The **internal surfaces of the two plates are inclined by a certain angle**. This causes that **the central device is forced to a convex funnel-shaped surface**. This **geometrical configuration** generates **additional restoring forces** with the increasing of the relative outwards displacements. **The tightening level** of the bolts **acts for the constant friction component**, while **the convex funnel-shaped surface** provides an **additional restoring force**



# MECHANICAL MODEL FOR VARIABLE FRICTION DAMPER (VFD) DEVICE

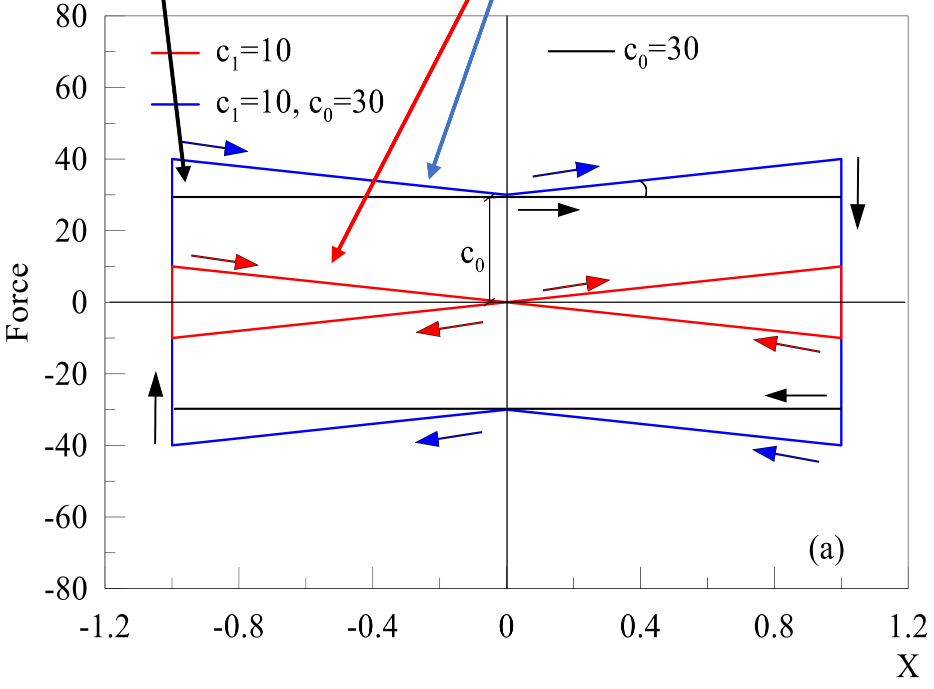


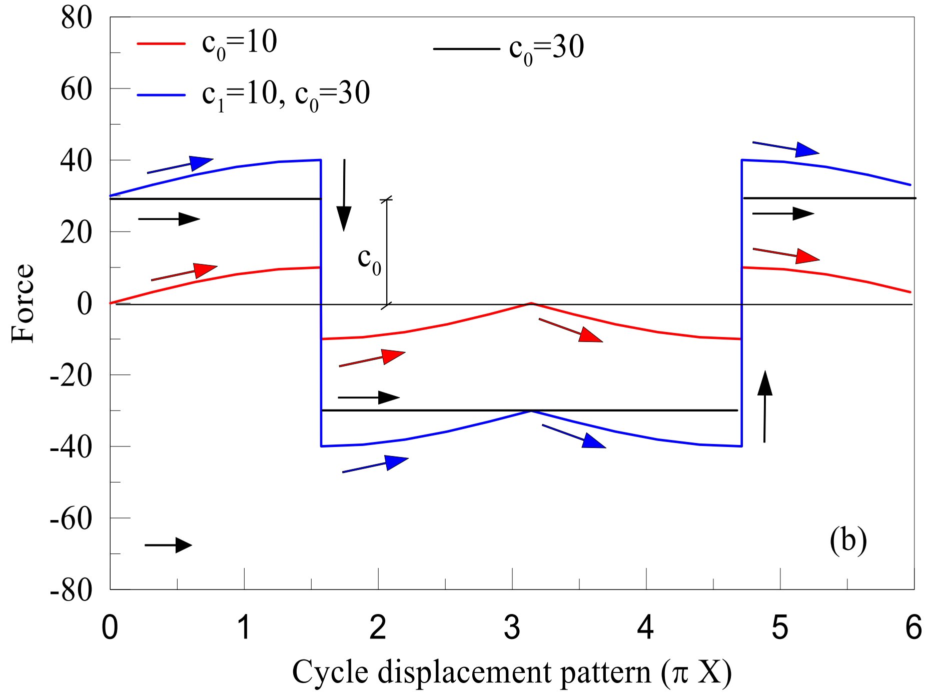
Dissipative force

$$F = \underbrace{c_0 \cdot sign\left(\dot{x}\right)}_{\text{Pure friction}} + \underbrace{c_1 \cdot \left|x\right| \cdot sign\left(\dot{x}\right)}_{\text{Hardening component}}$$

Linear law that increases the dissipative force as the displacement increases and decreases as the displacement decreases until it reaches zero for relative zero displacements

**CONSTITUTIVE LAW**



Equilibrium equation of the damped system

$$\ddot{x} + 2\varsigma\omega\dot{x} + \frac{F_d}{m} + \omega^2 x = -\ddot{x}_g$$

Generation of the seismic input

$$R(\tau) = E\left[\ddot{X}_g(t)\,\ddot{X}_g(t+\tau)\right] = 2\pi S_0 \delta(\tau)$$

Dynamic properties of the SDOF system

$$k = 0.5 \cdot 4 \frac{12\,EI}{H^3} = 35156.25\,k\text{N/m};$$

$$\omega = \sqrt{\frac{k}{m}} = 31.25\,\text{sec}^{-1};$$

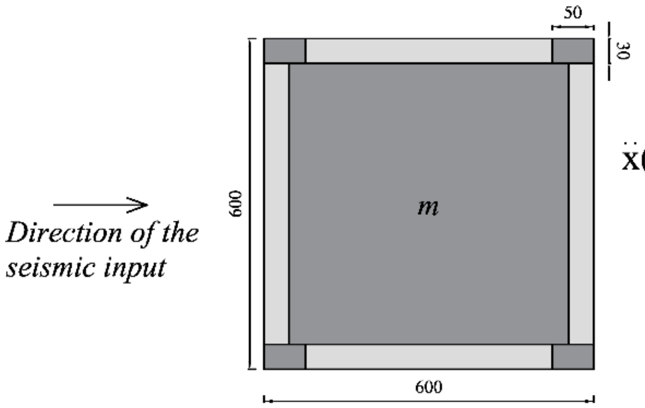
$$T = \frac{2\pi}{\omega} = 0.2\,\text{sec}$$

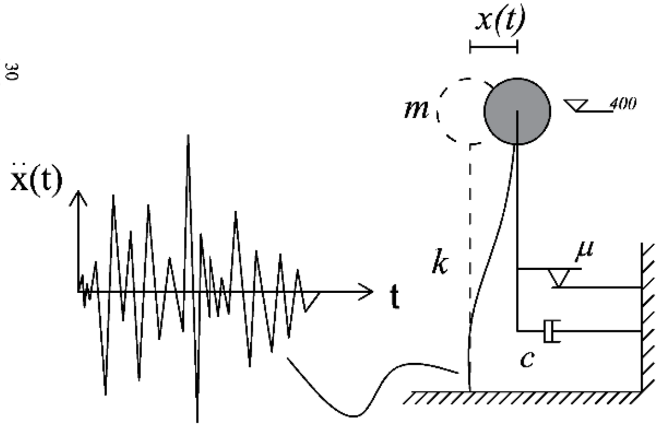
**Single-storey one-bay RC structure**

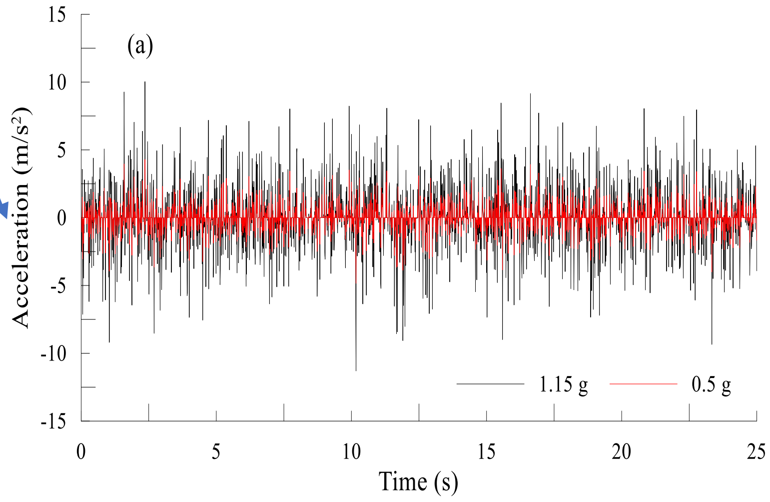
Interstorey heigth= 4m

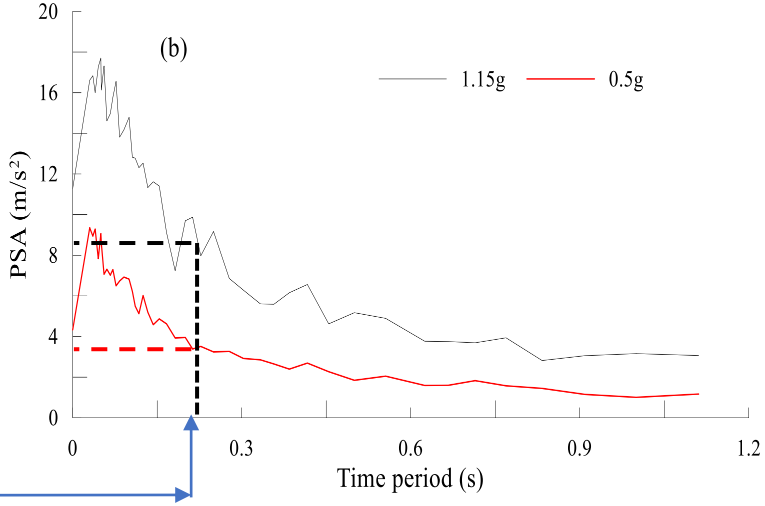
Dimensions= 6x6 m$^2$

Columns 0.3x0.5 m$^2$



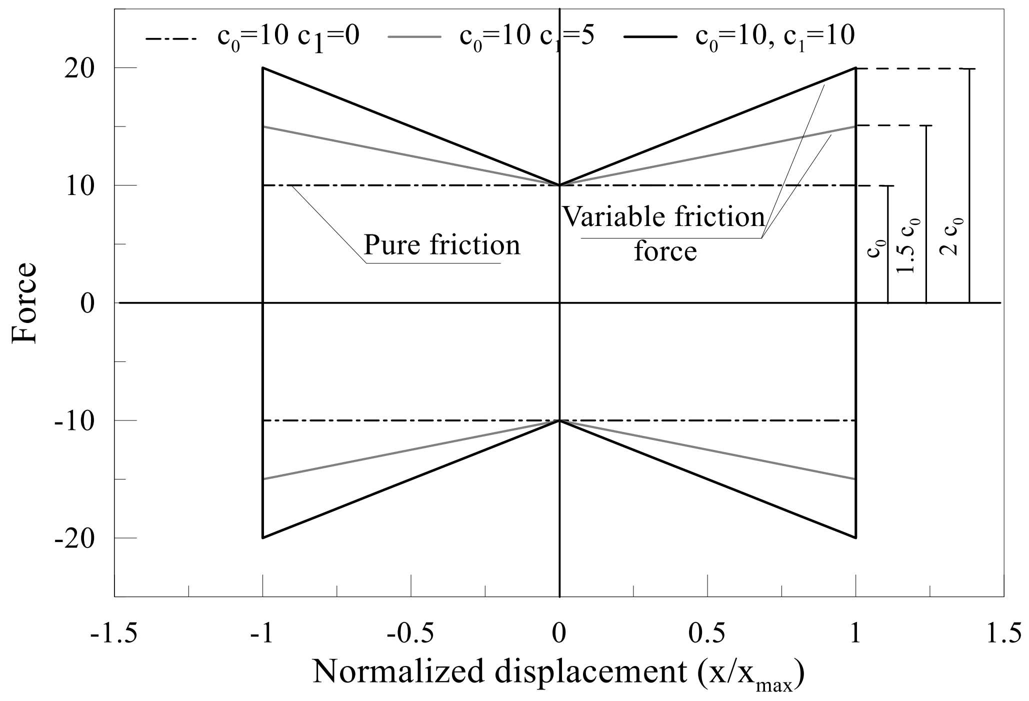



## Analysis and design procedure

1. **Defining of the maximum dissipative force** for the **constant friction damper (CFD)** (fixing $c_0$ ) as a ratio of the maximum elastic restoring force of the damped system;
2. Performing the analysis to **calculate the dynamic response** (displacement, velocity, restoring force);
3. **Defining the linear variable part** of the **friction dissipater (VFD)** (fixing $c_0$ as for the CFD and $c_1$ to reach the 50% and the 100% of the pure friction maximum force respectively;
4. **Performing the analysis** to observe the differences in the dynamic response compared with the case of constant friction.

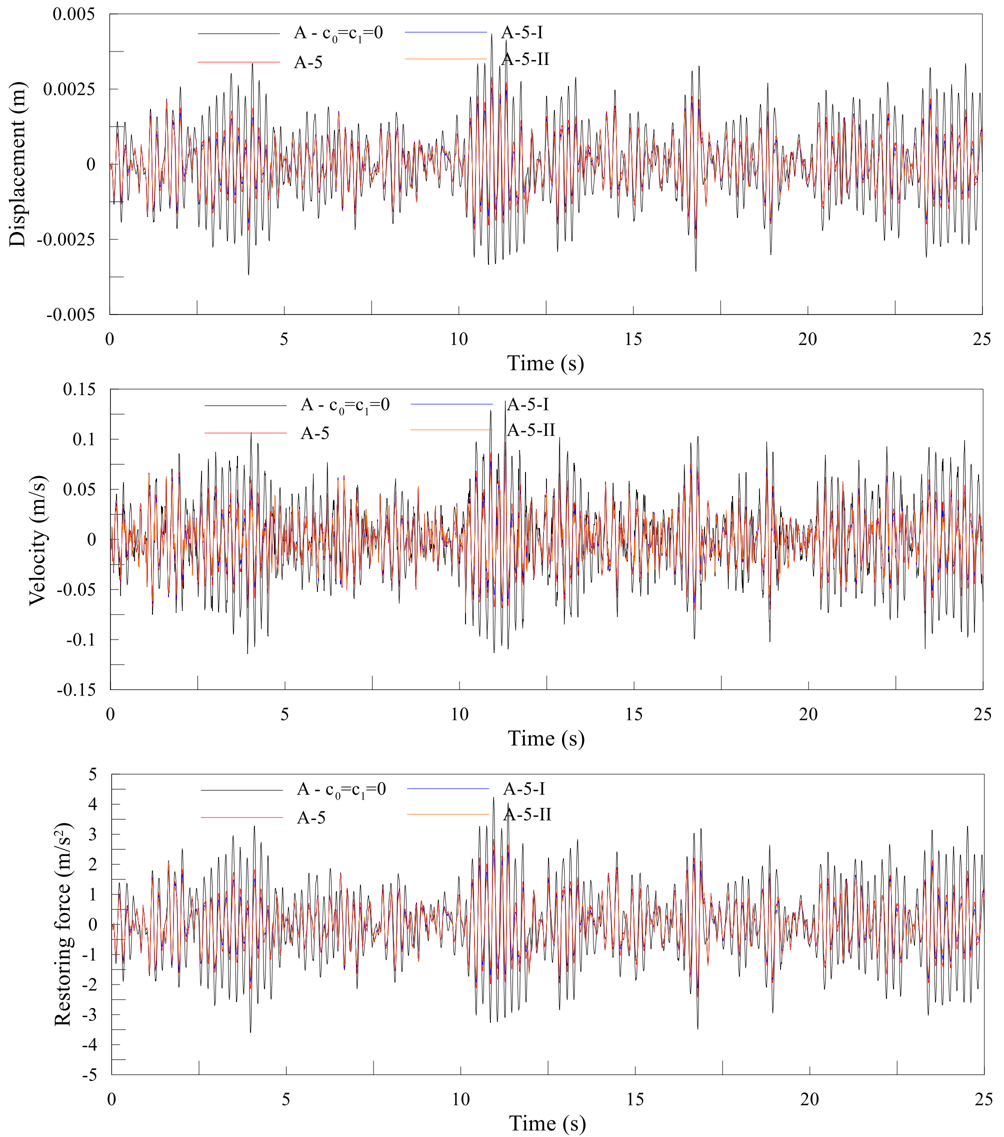
| | Restoring force RF | | Friction coefficients | | Friction force FF | | Dissipated energy | |
|---|---|---|---|---|---|---|---|---|
| CASE ANALYSIS | Maximum normalized (m/s$^2$) | Ratio "without VFD/ withVFD" | $c_0$ (m/s$^2$) | $c_1$ (1/s$^2$) | Maximum normalized (m/s$^2$) | FF/RF (%) | E | % |
| *A* | 4.230 | 1.000 | 0 | 0 | 0 | 0 | 0.272 | 1.000 |
| *A-5* | 2.830 | 0.669 | 0.145 | 0 | 0.145 | 0.05 | 0.341 | 1.253 |
| *A-5-I* | 2.470 | 0.584 | 0.145 | 50 | 0.266 | 0.11 | 0.373 | 1.371 |
| *A-5-II* | 2.180 | 0.515 | 0.145 | 100 | 0.361 | 0.17 | 0.401 | 1.475 |
| *A-10* | 2.194 | 0.519 | 0.225 | 0 | 0.225 | 0.10 | 0.362 | 1.332 |
| *A-10-I* | 2.070 | 0.489 | 0.225 | 50 | 0.324 | 0.16 | 0.385 | 1.417 |
| *A-10-II* | 1.899 | 0.449 | 0.225 | 100 | 0.42 | 0.22 | 0.408 | 1.499 |
| *A-20* | 1.850 | 0.437 | 0.370 | 0 | 0.37 | 0.20 | 0.405 | 1.490 |
| *A-20-I* | 1.740 | 0.411 | 0.370 | 50 | 0.463 | 0.27 | 0.418 | 1.536 |
| *A-20-II* | 1.720 | 0.407 | 0.370 | 100 | 0.552 | 0.32 | 0.439 | 1.613 |



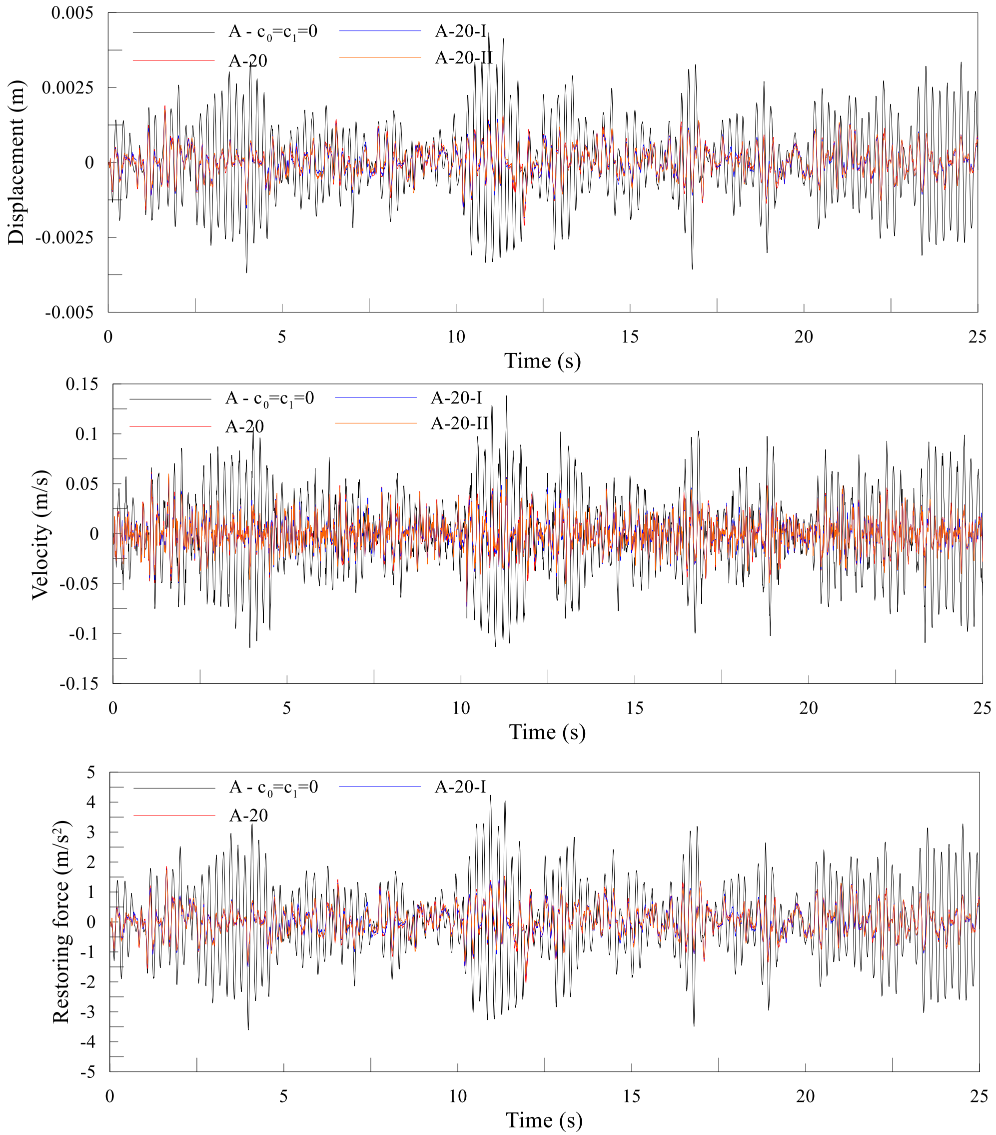
Behavior of structures equipped with variable friction dissipative devices

## Time-history results

CFD and VFD for the case analysis A, A-5, A-5-I and A-5-II.

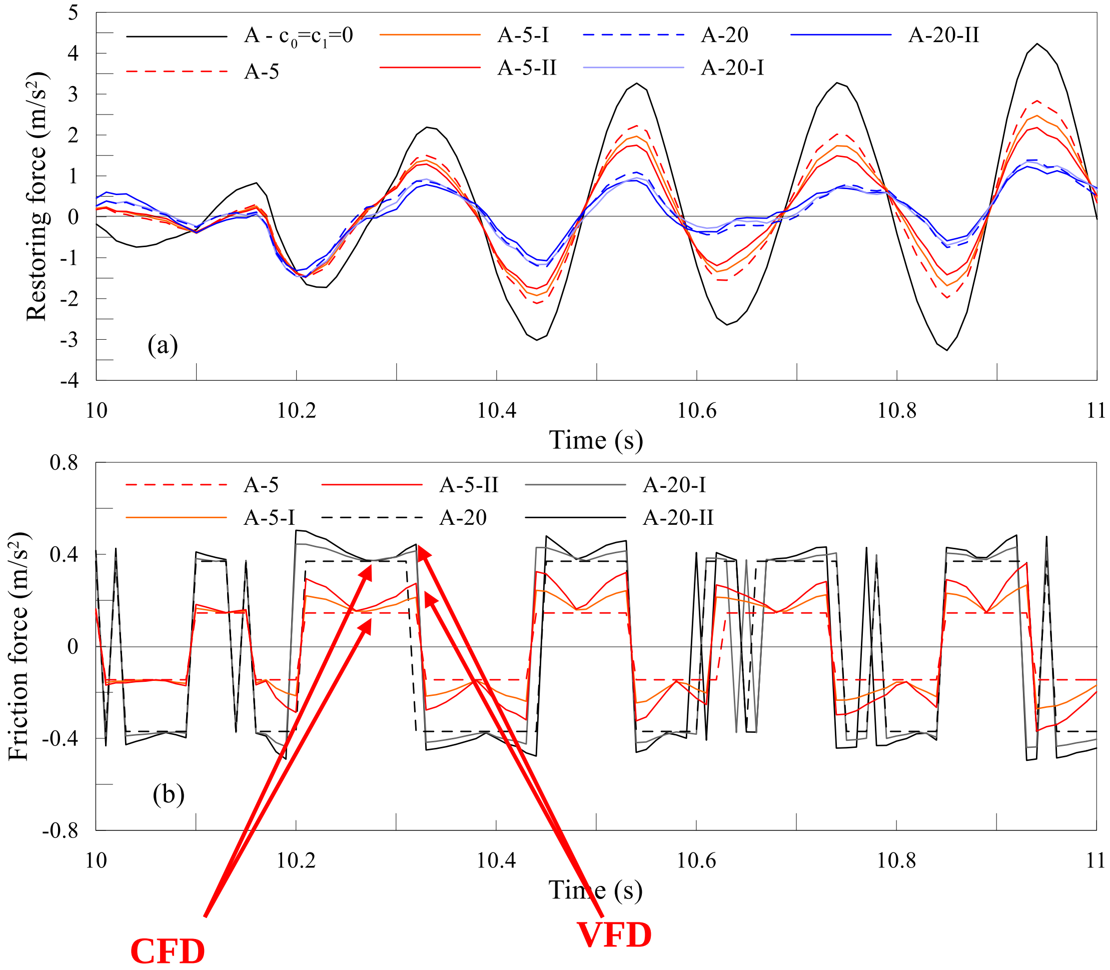



CFD and VFD for the case analysis A, A-20, A-20-I and A-20-II.

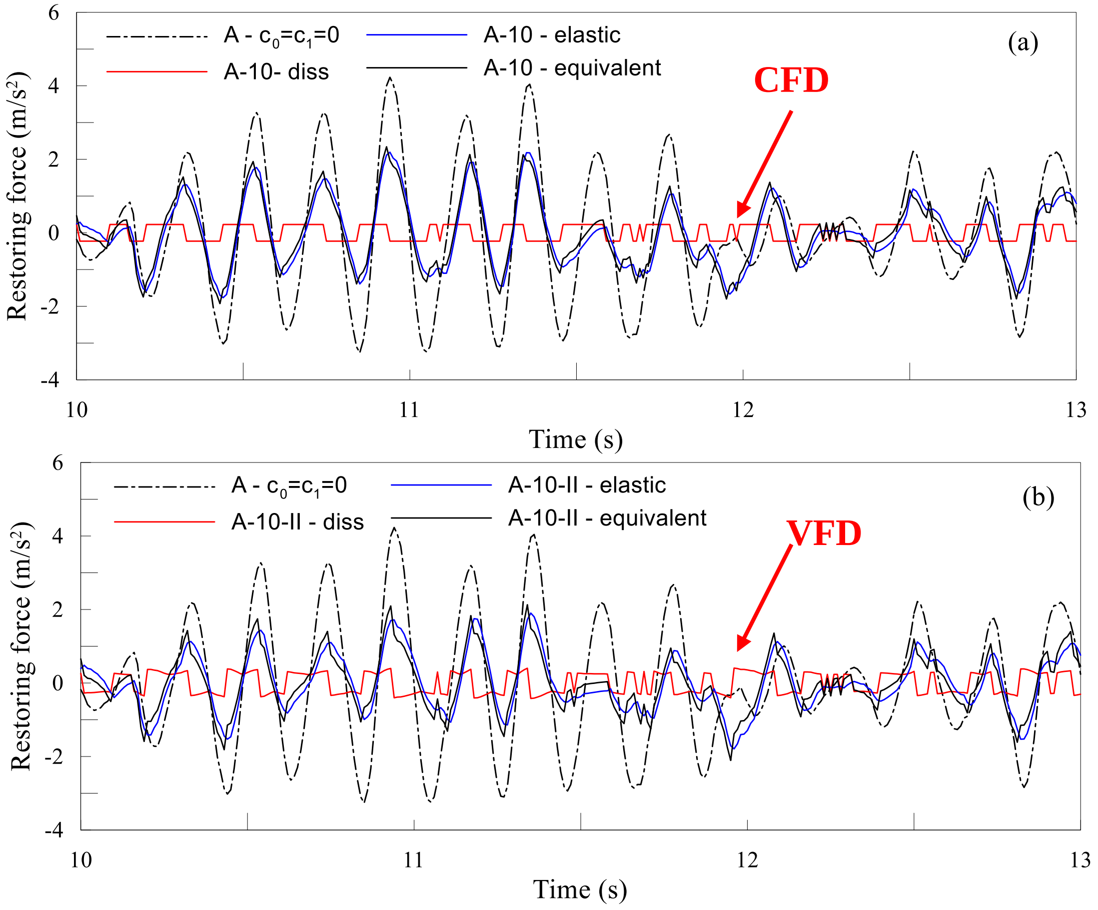


## Time-history results

Restoring force and friction forces for time interval of 10-11 seconds.



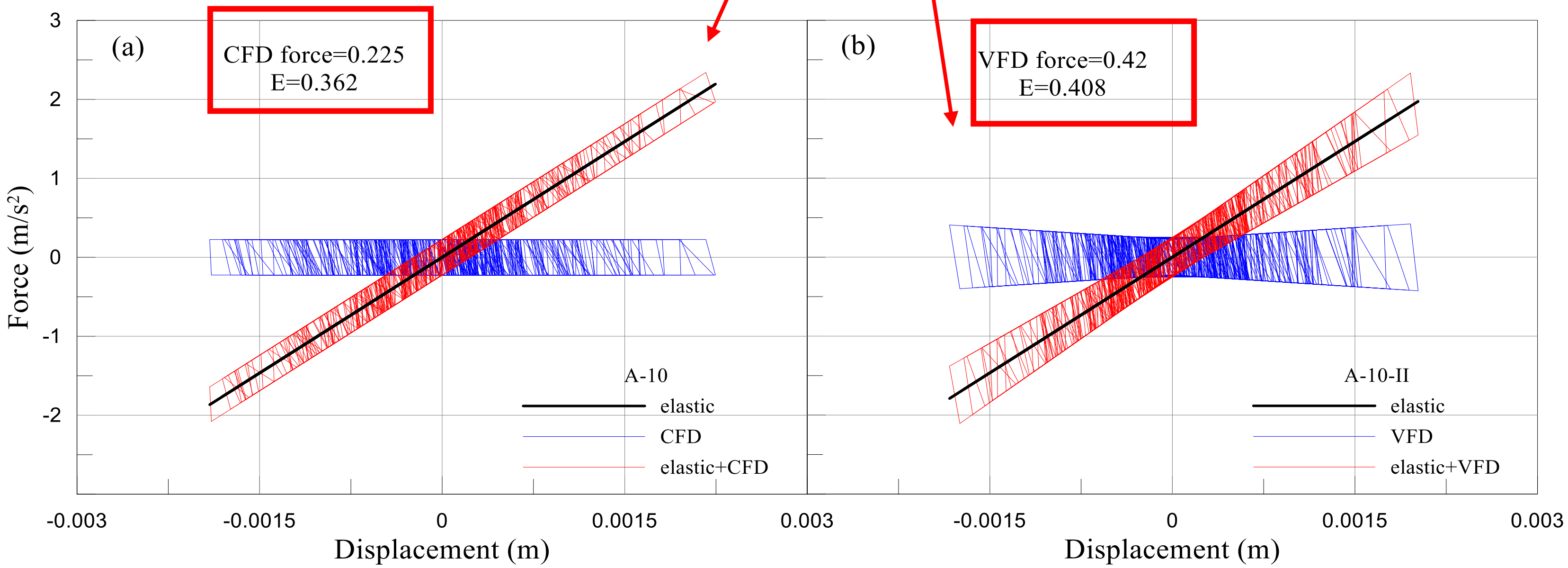

Force contributions for time interval of 10-13 seconds.



Behavior of structures equipped with variable friction dissipative devices

## Time-history results

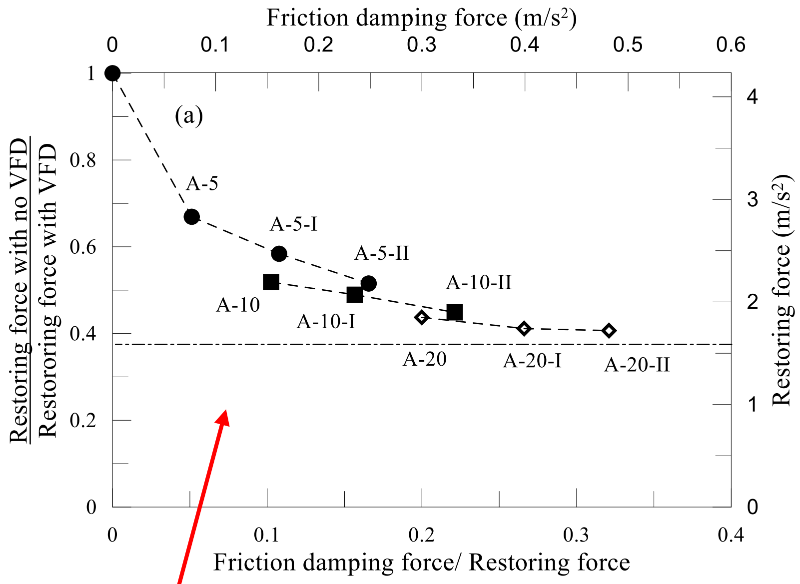
Force-displacement cycles:
CFD; VFD



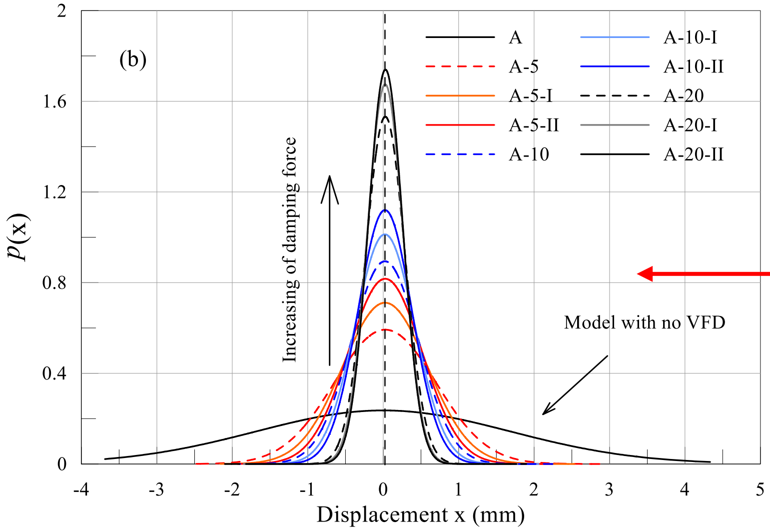

**Higher energy dissipation per cycle obtained for the same pure friction dissipation capacity by using the variable friction dissipative VFD device**

# NUMERICAL APPLICATION AND RESULTS

Behavior of structures equipped with variable friction dissipative devices

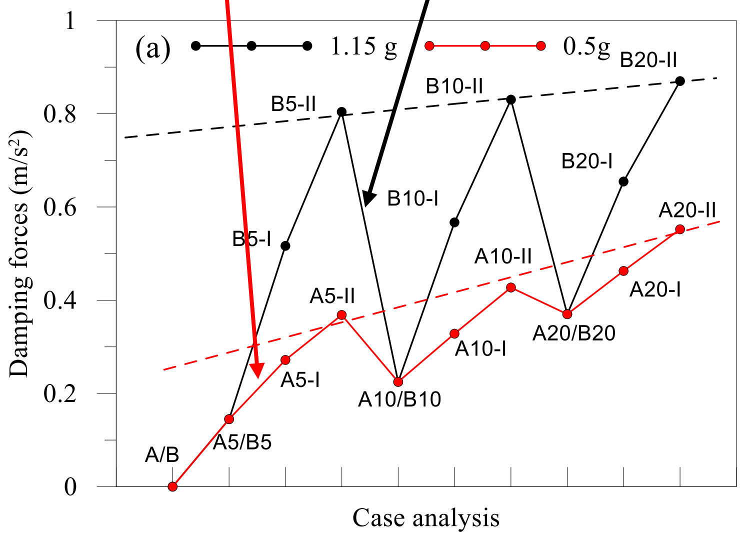



Reduction of the restoring force with the increasing of the damping force

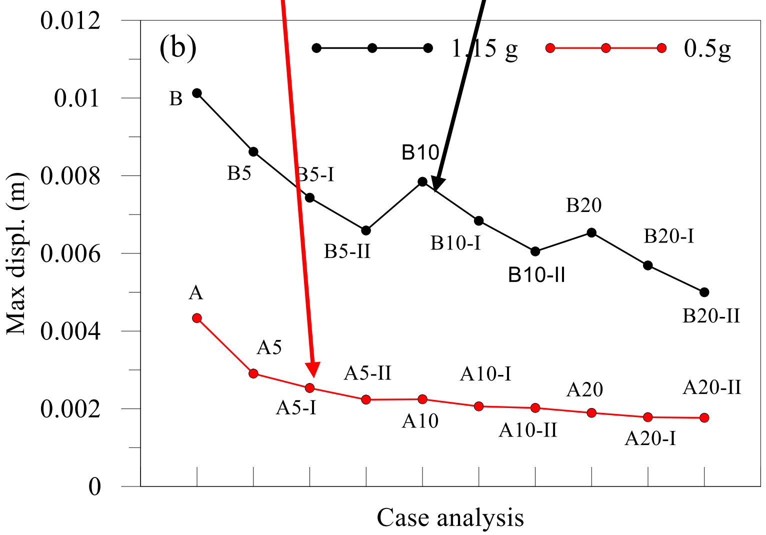



Distribution of the displacement history

Maximum friction forces seismic input A (0.5g) and B (1.15g)




Maximum displacements for seismic input A (0.5g) and B (1.15g)



# CONCLUSIONS

The system allows to reach greater dissipation forces than the classic friction dissipaters exploiting geometric effects

Reduction of displacements and velocity are observed with the increasing of the dissipation capacity of the device

By **keeping the same mechanical characteristics** of the **VFD** dissipater and **varying the seismic input** (stronger earthquake)………….

The constant friction damper (**CFD**) provides **always the same damping force** regardless the intensity of the seismic input

The variable friction damper (**VFD**) gives **high dissipating force as much as the structure experience high displacements**

THANK YOU FOR YOUR KIND ATTENTION