

# THE SMA: AN EFFECTIVE DAMPER IN CIVIL ENGINEERING THAT SMOOTHES OSCILLATIONS.

V. Torra.<sup>1</sup>, A. Isalgue<sup>2</sup>, C. Auguet<sup>1</sup>, G. Carreras.<sup>1</sup>

<sup>1</sup>Dep. Applied Physics. ETSECCPB, vtorra@fa.upc.edu, <sup>2</sup>Dep. Applied Physics. Fac. Nautica  
aisalgué@fnb.upc.edu

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**Abstract:** *The properties of SMA (Shape Memory Alloys, that are smart materials) are associated to a first order phase transition named martensitic transformation that occurs between metastable phases: austenite and martensite. At upper temperature or at lower stress the austenite is the metastable phase. The martensite appears at lower temperature or higher stresses. The hysteresis of the transformation permits different levels of applications, i.e., in their use as a damper. Two types of applications can be considered in damping of structures in Civil Engineering. The first one is related to diminishing the damage induced by earthquakes. The second one is a reduction of oscillation amplitude associate to an increase of the lifetime for the stayed cables in bridges.*

## 1. INTRODUCTION

The characteristic patterns in an earthquake and replicas relate sets of some minutes of intense oscillations after a number of years or decades without any action. The earthquake engineering would require an excellent performance during one or two minutes, i.e., nearly 200 – 1000 working oscillations, after a lot of years at rest. Large numbers of oscillations per day (at least  $10^5$  for a frequency of one Hz) with pauses for good weather of several hours or days could be the typical dynamic of stayed cables in bridges.

This work is focused into the realistic analysis of the behavior of a SMA alloy damper used in a “facility”: one steel portico (2.5 x 3.5 m) for a family house working as a shaking table in one dimension. The results establish the excellent damping effect of the SMA (in CuAlBe and in NiTi). Furthermore, the requirements corresponding to stayed cables for bridges were analyzed: the number of expected oscillations per each event that easily overcomes one million of oscillations. In particular, the fatigue - life behavior for the NiTi alloy and the suitable thermo-mechanical training treatment was studied avoiding the parasitic effects of SMA creep on cycling. At the end, three examples show the application of SMA damper to reduce the oscillation amplitudes in the portico and in two facilities using two “similar” and realistic cables built with steel wires. One with a length of 45 m (four sets of steel wire of 15 mm of diameter) and stressed by 250 kN. The second one, with a length of 50 m, uses one multilayer steel wire of 57 mm diameter stressed by 1000 kN.

## 2. CYCLING EFFECTS: THE FATIGUE/FRACTURE LIFE SMA

The first parameter required in damping to reduce the oscillation amplitude is that the fracture life overcomes the number of required working cycles. The use of SMA for stayed cables

requires a long lifetime of the alloy i.e., more than one million of cycles in comparison with 1000 working cycles for mitigation of earthquakes. The maximal stress ( $\sigma_{MAX}$ ) is a function of the maximal working cycles ( $N_f$ ) by the Basquin law:

$$\sigma_{MAX} (\text{MPa}) = 170 + 7920.9 * (N_f)^{-0.398}. \quad (1)$$

The approximate fit is in Fig. 1 left. For instance, the fatigue-fracture process was controlled by the martensitic phase transition not by the dislocation glides as in classical materials.

### 3. THE SMA CREEP, TRAINING AND TEMPERATURE EFFECTS

In the “as furnished” wire the initial transformation stress (for instance via sinusoidal cycles at 0.01 Hz) usually was close to 3 kN or 630 MPa. Series of 20 or 100 sinusoidal cycles at 0.01 Hz and 8 % of deformation reduces the initial maximal stress and, also increases the permanent initial deformation. Moreover, the retransformation was submitted to minor changes. Use of SMA in dampers requires an “invariant” length of the SMA wires when works. In general, the length increases progressively in the initial sets of cycles. Supplementary increase appears with an increase of cycling frequency, oscillation amplitude or the external temperature. An appropriate training is always necessary for satisfactory work. The hysteresis energy is a function of the cycling frequency as indicates the figure 1 right.

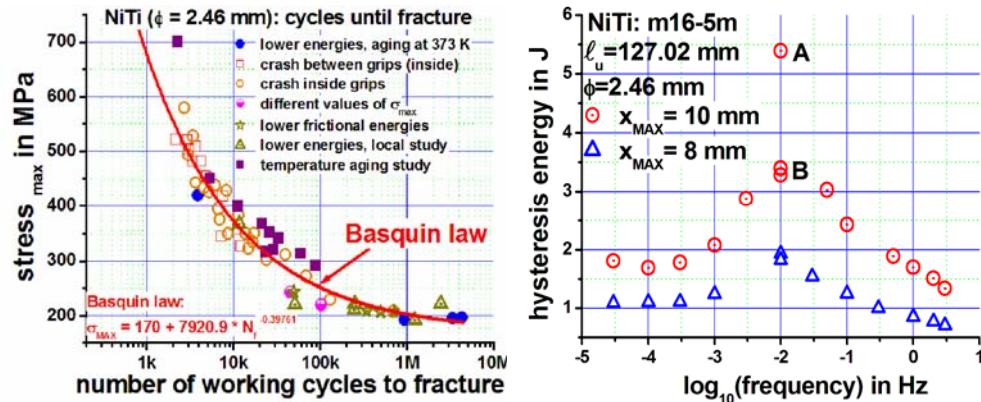


Figure 1. Left: The stress against the fracture life for NiTi. For fracture overcoming 500k cycles the used deformation remains under 1.5 %. Right: Evolution of hysteresis energy against the cycling frequency

The experimental values show relevant changes in the hysteresis cycle induced by the air currents (i.e., in laboratory measurements by the fan effects). To reduce the uncertainty in the numeric results of simulation was convenient the use of hysteretic cycles determined at frequencies near the particular frequencies of the application. In fact, in dampers situated in a bridge in free contact with the external weather, the numeric results are semi-quantitative.

### 4. EXPERIMENTAL RESULTS IN “FACILITIES”

The test of the SMA behavior was carried out in a “shaking table” in 1-dimension (see Fig. 2 left). The portico in steel [1] is mounted over a chariot with 10 wheels moving inside two U-

shape guidelines and was protected by supplementary reinforced walls for “out-of-plane” oscillations [2]. The SMA dampers (near 700 mm length) were installed in the portico diagonals and joined to the frame with steel cables. In the outlined example, Fig. 2 left, the four boxes (global load near 2120 kg) are situated on the top of the portico beam and the actuator realizes 40 sinusoidal oscillations at one Hz and  $\pm 15$  mm. When SMA damper (CuAlBe) was introduced with a pre-stress force of 1.38 kN, the oscillation amplitude reduces to near the 40 %, and the frequency spectrum is extremely reduced (Fig. 3 left).

The study of SMA in damping for stayed cables several measurements were carried out in the cable no 1 of the ELSA - JRC - EU laboratory facility. The cable no.1 (Fig. 2 center) with length of 45 m and four sets of steel wires is filled with wax that produces an intrinsic and relevant “self damping”. Only one trained wire (by 100 cycles) of NiTi SMA was used (2.46 mm of diameter and 4.14 m of length). The analysis was devoted to determine the oscillations induced by external periodical forces (roughly 49, 98 and 196 N) at the resonance frequencies of 1.8 Hz (free) and 2.05 Hz (SMA). When the SMA is included, several values of pre-stress are studied. The maximal cable oscillations, for instance  $\pm 80$  mm, are equivalent to deformations below 3.9 % in the SMA wire system. When the oscillations produce a deformation below 0.5 % in the SMA system the working point remains in the elastic part without energy dissipation in the SMA. In this case, only the intrinsic effect of wax reduces the oscillation amplitude. The analysis is performed without and with the SMA as shows the Fig. 3 center. The action of SMA reduces the maximal amplitude to 1/3.

The experimental equipment in IFSTTAR, Nantes, France (Fig. 2 right) permits a vertical displacement (up) of the cable by a measured force. The excitation is realized by the sudden release of the stress. The action (a Heaviside return) induces oscillations on the steel cable. Some results obtained in the 50 m length ( $\ell$ ) steel cable with 57 mm of diameter are shown in the Fig. 3 right. The experimental observations were realized inducing oscillations in the middle of the cable without (free cable) or with the SMA damper by two NiTi wires of 1260 mm long. Other tests were realized situating the actuator or the damper in cable lengths as  $\ell/4$ ,  $\ell/6$ ,  $\ell/8$  and  $\ell/16$ .

The vertical position of the cable (the oscillation amplitude) is detected by a laser, and the results are stored at a sampling of 300 Hz. The Fig. 3 right shows the time evolution of the oscillation amplitude without the SMA after a return of Heaviside signal of 4 kN. The spontaneous damping in the free cable was extremely low (25 % in one minute). The same figure includes the effect of a damper with two wires of NiTi SMA. The effect of the SMA induces one reduction of the oscillation amplitude to near “zero” in less than “ten” seconds. Simulations have been made with ANSYS with good agreement between experiment and simulation [3].

## 5. CONCLUSIONS

Guaranteed behavior of the SMA in damping requires a deep study of the alloy behavior according to the requirements of the application. Their application to portico or cable oscillations in realistic systems shows an excellent damping effect. Available technical solutions for immediate applications are available.

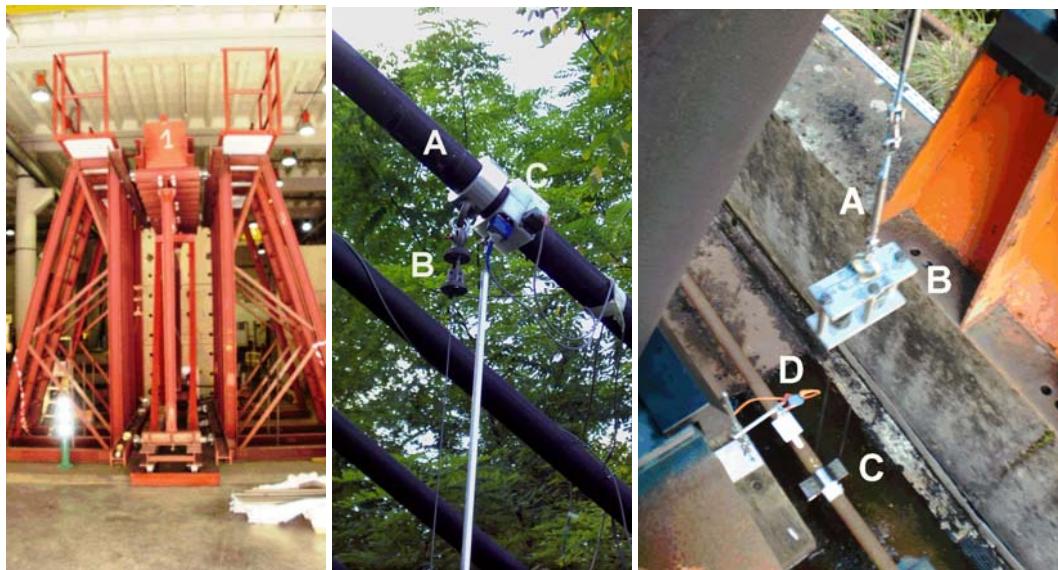


Figure 2. Left: Overview of the portico and their “out of plane” protections situated in the C1-ETSECCPB. Center: ELSA cables 1, 2 and 3. A: cable No. 1; B: SMA damper (1 wire of trained NiTi); C: accelerometers. Right: IFSTTAR cable: position near the center of the cable of the SMA damper with two SMA wires. A: shortened. B: fixation device up to 3 wires. C: fixation of wires in the cable. D: laser sensor.

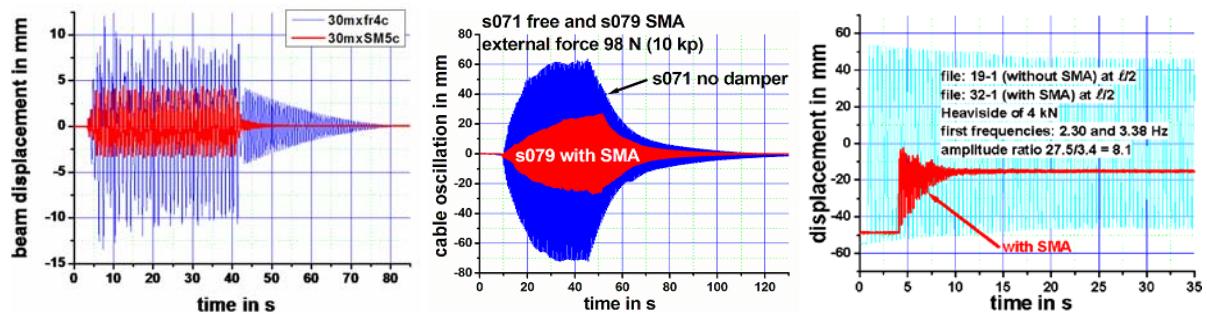


Figure 3. Left: Portico results (actuator frequency of 1 Hz and full available load): free oscillations (amplitude 20 mm) and damper (CuAlBe) amplitude (7 mm). Center: The displacements of ELSA cable no. 1 without and with one wire of NiTi. Right: oscillations in the cable of IFSTTAR without and with two wires of NiTi.

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## REFERENCES

- [1] M. L. Perea Ibáñez (Juliol-2010), “Estudi d’una casa familiar sismo-resistent”, Tesina ETSECCPB
- [2] V. Torra, A. Isalgue, F. Martorell, F. C. Lovey and P. Terriault (2010): Can. Metall. Quart., 49(2), pp. 179-190
- [3] V. Torra, F.C. Lovey & P. Terriault (2010), “Experimental study of damping in civil engineering structures using smart materials (Cu-Al-Be – NiTi SMA). Applications to steel portico and to stayed cables for bridges (The SMARTeR project)”, School and Symposium on Smart Structural Systems Technologies, 6-9 April, 2010, a FEUP, Porto, Portugal (S3T-ESF Meeting). Published in S(3)T 2010, R. Barros, A. Preumont Eds., Facultade de Engenharia da Universidade do Porto, ISBN: 978-989-96697-0-3, pp. 369-399