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Negative Stiffness Elements in Seismic Isolation of Bridges[1]

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1 INTRODUCTION & SCOPE OF WORK

Throughout the last decades, seismic isolation of bridge structures has attracted the attention of civil engineers and scientists, since bridges belong to the category of structures whose functionality needs to be preserved after an earthquake event. Research around this field has progressed tremendously, starting from the use of simple elastomeric bearings for the decoupling of the bridge's deck from the abutments and moving towards the invention of more complex devices (characteristic examples being the Tuned Mass Dampers – TMDs or the Quasi-Zero Stiffness oscillators – QZSs) aiming to enhance structural dynamic behavior. In this context, the implementation of novel passive seismic isolation devices incorporating negative stiffness elements to bridge structures is introduced and proposed in this effort. The design of these devices follows the scope of a general vibration isolation and damping concept, entitled KDamper concept based on Antoniadis et al. (2016). The realization of negative stiffness elements includes two different approaches regarding the type of bridge structure considered, namely pre-stressed springs in proper geometric arrangements for bridges with solid-sectioned piers and a specialized inverted pendulum mechanism for bridges with hollow-sectioned piers. The proposed systems are compared to the initial undamped models as well as with similar structures employing other seismic isolation techniques. Comparative results prove the efficiency of the proposed KDamper system.

2 METHODOLOGY

In order to optimally design the proposed devices, a parametric study of frequency dependent characteristics has been carried out, demonstrating that seismic isolation systems with frequencies in the range of 0,8-1,2Hz manage to improve the structural dynamic behavior in both terms of absolute acceleration and relative displacement of the bridge's deck. It is hereby reminded, that considering the EC8 response spectrum while frequency becomes lower, acceleration becomes lower, too, whereas displacement is increased. The aforementioned study limits the frequency range between 0,8-1,2Hz, creating a window of optimal solutions. Furthermore, artificial earthquake records based on the EC8 response and excitation spectra are created in an effort to initially estimate the dynamic response of a bridge structure.

Two different implementations of the KDamper concept are examined in this effort according to the specific characteristics of each bridge structure. Specifically, for bridges with solid-sectioned piers, a mechanical configuration consisting of pre-stressed springs (Figure 1a) is employed to realize the desired negative stiffness system. On the other hand, an inverted pendulum based I-shaped mass (Figure 1b) is placed inside a hollow-sectioned pier, considering a different type of bridge structure where the free space in the hollow pier's section can be exploited.

[1] In case the material presented has been published elsewhere, appropriate reference should be made here.

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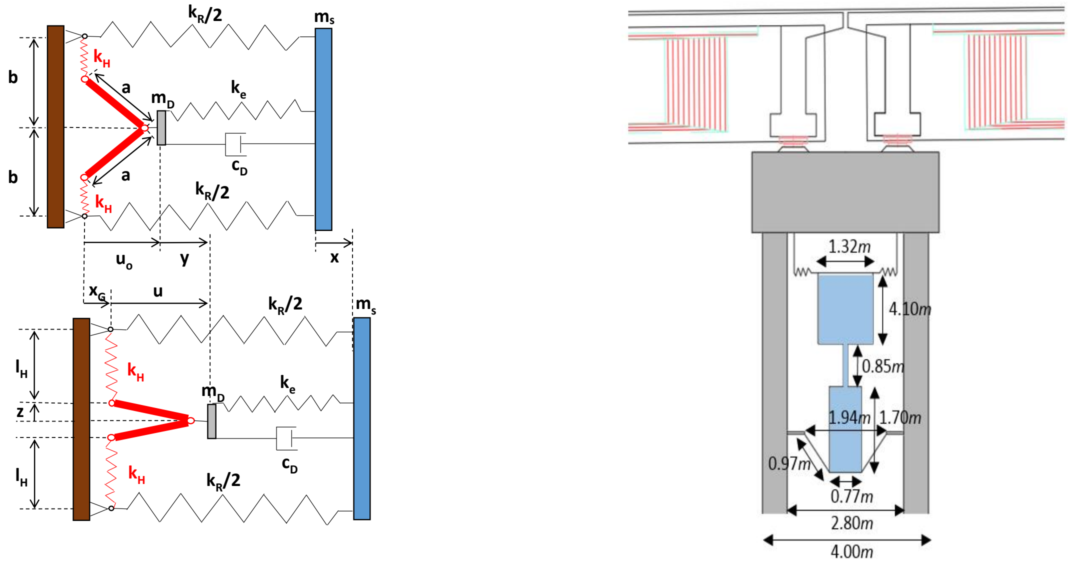

Figure 1. *a) Mechanical arrangement with pre-stressed springs (bridges with solid-sectioned piers). b) Inverted pendulum based I-shaped mass (bridges with hollow-sectioned piers).*

3 RESEARCH OUTCOMES

The proposed systems are subjected to various dynamic loadings, for instance, artificial and real earthquake records or sinusoidal excitation. Comparative results between the initial undamped model, bridge structures with different types of seismic isolation devices and the proposed system, prove the accuracy and efficiency of the KDamper concept.

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