Seismic Assessment of Irregular Bridges Equipped with Shape Memory Alloy

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Abstract

Concentration of seismic damage on shorter piers is a common problem for irregular bridges subjected to strong ground motion. This study investigates the effectiveness of shape memory alloy (SMA) restrainer bars to reduce the seismic vulnerability of irregular bridges. SMAs are a unique class of materials that have the ability to undergo large deformations, while reverting back to their undeformed shape through the removal of stress (superelastic effect). To evaluate the effectiveness of the devices, nonlinear time history analyses are performed on a reinforced concrete single column bent viaduct using a suite of representative ground motions. The results showed that superelastic restrainers can significantly reduce the bridge damage index ratio (BDIR) mean response in controlled bridge compared to as-built bridge due to alleviating damage concentration on short pier. It is also found that SMA devices can effectively participate in dissipating hysteretic energy.

Keywords: bridge, irregularity, shape memory alloy, damage index, superelasticity

1. INTRODUCTION

Earthquakes have resulted in considerable damage to highway bridges especially irregular bridges in events of past decades. Such damage to bridges can cause significant disruption to the transportation network. Because of rough topography of mountain valleys or urban transportation requirements, construction of irregular bridges with unequal height is often inevitable. The irregularity can cause excessive damage in shorter piers and increases the possibility of brittle shear failure due to concentration of shear force in such piers. While new seismic design strategies aim to moderate irregularity in new bridges, there are many existing bridges that may be susceptible to this mode of failure. Designers sometimes do use some techniques for balancing the stiffness of adjacent bents such as combination of monolithic and bearing deck to pier connections or adjusting stiffness characteristics of bearings placed at different bents. 'pre-shafts' (upward extensions of the foundation shaft that increase the effective height of shorter piers), also can be a choice in new designs. Although these techniques are effective in balancing stiffness of adjacent bents, but often tend to increase the overall cost of the bridge and require regular maintenance [1,2].

This study presents a new method for response modification of irregular bridges using Nitinol shape memory alloy. The proposed method can limit susceptibility of collapse and improves the seismic behavior of bridges.

2. SHAPE MEMORY ALLOY

Shape memory alloys are unique alloys that have the ability to undergo large deformations, but can return to their undeformed shape by heating (known as the shape memory effect) or through removal of the stress (known as the superelastic effect). The key behind such a unique feature lies in the ability of the SMA to transform from the parent phase (austenite), which is microstructurally symmetric to the less symmetric martensitic phase [3]. Among SMAs, Nitinol shape memory alloys (NiTi SMAs) possess several characteristics that make them desirable for use as restrainers in bridges. These characteristics include: (1) large elastic strain range; (2) hysteretic damping; (3) proper energy dissipation through repeated solid state phase transformation; (4) strain hardening at strain above 6%; (5) excellent low- and high-cycle fatigue