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Songye Zhu

The Hong Kong Polytechnic University, Hong Kong

Using superelastic shape memory alloys to achieve earthquake resilience

Modern seismic design philosophy allows buildings to experience significant plastic responses to dissipate energy at plastic hinge regions when subjected to moderate-to-strong earthquakes. Even though the performance target (e.g., Collapse Prevention) of these buildings can be successfully met, such a design philosophy may result in permanent damage concentrated in the selected "sacrificial" regions after earthquakes. The damaged buildings are often demolished because too large residual deformation makes the repair economically unviable. For example, approximately 60% of RC buildings after 2011 New Zealand Christchurch earthquake were demolished because of forbidden repair cost, although most of them did not collapse during the earthquake. The government estimated the total losses would be as much as NZ$40 billion. Furthermore, the central business district was closed for over 2 years and some tall buildings underwent a long-demolished period. A recent study concluded that residual drift ratio greater than 0.5% makes rebuilding a new structure more economical rather than retrofitting the damaged structure. For this reason, new seismic protection concepts, such as resilience-based design (RBD) have recently emerged to minimize structural damage through new technologies or high-performance materials.

As a high-performance metallic material, shape memory alloys (SMAs) can undergo large strains and recover their initial shape through heating (shape memory effect) or unloading (superelastic effect). The schematic of stress-strain responses of superelastic and shape memory behaviors. The stress-strain behavior of SMA is similar to the conventional steel with fat hysteresis loop and remarkable residual strain at a temperature below the martensite finish temperature $T < Mf$; however, residual strain can be recovered through temperature increase. When the temperature above the austenite finish temperature $T > Af$, SMA exhibits superelastic behavior with little or no residual strain caused by a stress-induced phase transformation from austenite to martensite. Moreover, excellent corrosion resistance performance and high fatigue resistance of NiTi SMAs can overcome the aging, durability, and maintenance issues in a life-cycle design of civil infrastructures. The superelasticity of SMA is appealing to the earthquake engineering research community because flag-shaped hysteresis is associated with minimal residual deformation under cyclic loading.

The lecture highlights the research on seismic applications of superelastic SMAs, from material level, structural member level, to structural system level. The major content includes the thermomechanical constitutive model of SMA, SMA-based dampers and braces, self-centering reinforced concrete walls, high-performance steel rocking columns, shake table test study of a steel frame with SMA braces, and performance-based seismic design method. From the perspective of seismic design, SMA-based structural members and systems exhibit satisfactory and stable flag-shaped hysteretic loops with excellent self-centering capability and sufficient energy dissipation capability. Detailed experimental studies and numerical analyses show superelastic SMAs can provide a promising solution to high-performance structural systems to achieve modern resilient and sustainable civil infrastructure.

Biography

Songye Zhu received his B.Eng. and M.Sc. degrees in Structural Engineering from Tongji University, China in 2000 and 2003, respectively, and his Ph.D. degree in Civil Engineering from Lehigh University, USA in 2007. He is currently an Associate Professor in the Department of Civil and Environmental Engineering and the Hong Kong Branch of National Rail Transit Electrification and Automation Engineering Technology Research Center at The Hong Kong Polytechnic University. He also serves as Editor of Advances in Structural Engineering (an international journal), Associate Editor of International Journal of Nano and Smart Materials, and Immediate Past President of American Society of Civil Engineers – Hong Kong Section (2018-2019).

e: songye.zhu@polyu.edu.hk