Improving Bridge Performance Using Fiber Reinforced Polymer (FRP), Shape Memory Alloy (SMA), and Engineered Cementitious Composites (ECC)

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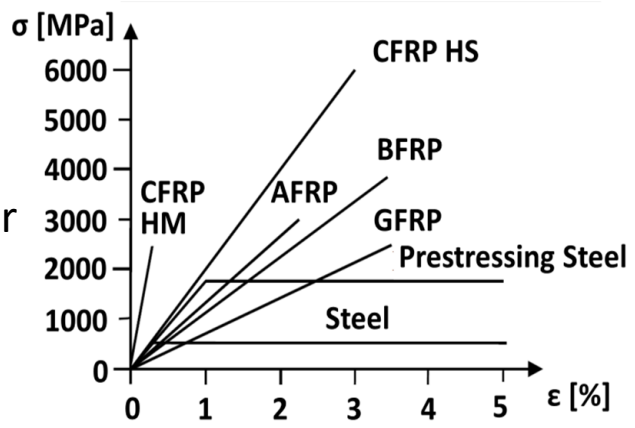
Outline

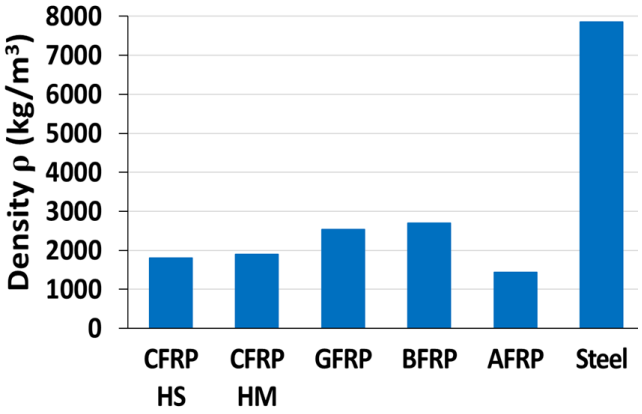
- My research aims to improve bridge performance through using innovative materials.
- This research addresses the following contents:
  - Advantages of FRP, SMA and ECC;
  - Applications in highway bridges;
  - On-going research;
  - Conclusions.

Fiber reinforced polymers

- Combination of fibers in polymer matrix:
  - Most loading is carried by the fibers
  - Matrix provides support and keeps the fibers together
  - Different types of fibers are used
    - ✓ *Glass, Carbon, Kevlar49, Boron, Silicon Carbide, etc.*

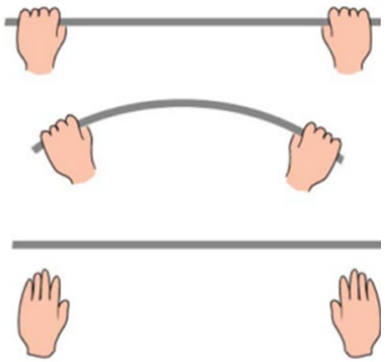


- Has many advantages
  - **High strength**
  - **Lightweight**
  - Fatigue & corrosion resistance
  - Low thermal conductivity & life-cycle cost

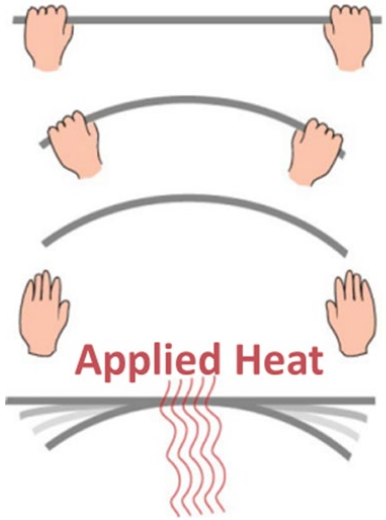


Shape memory alloys are smart materials

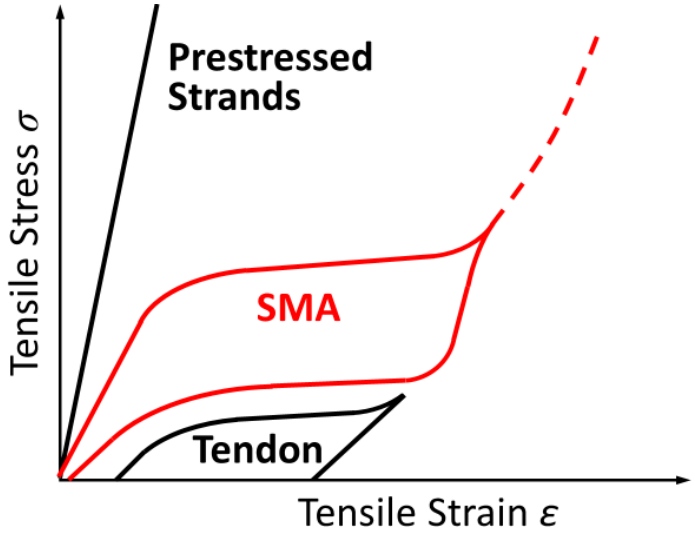
- With unique capability to “remember” the original shape:
  - **Super-elasticity**: Return to the original shape (6%~8% strain)
  - **Shape memory effect**: Recover from large deformations after heating



Super-elasticity



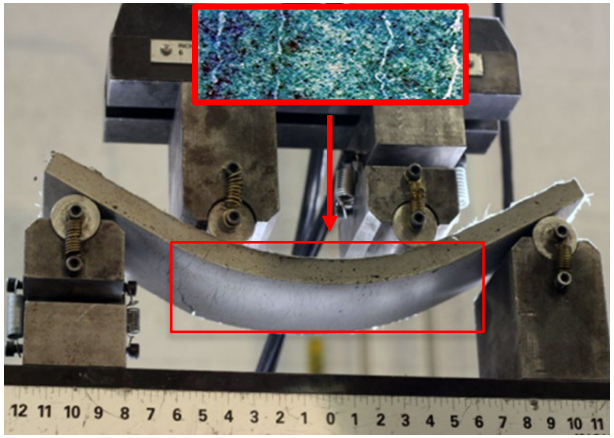
Shape memory effect



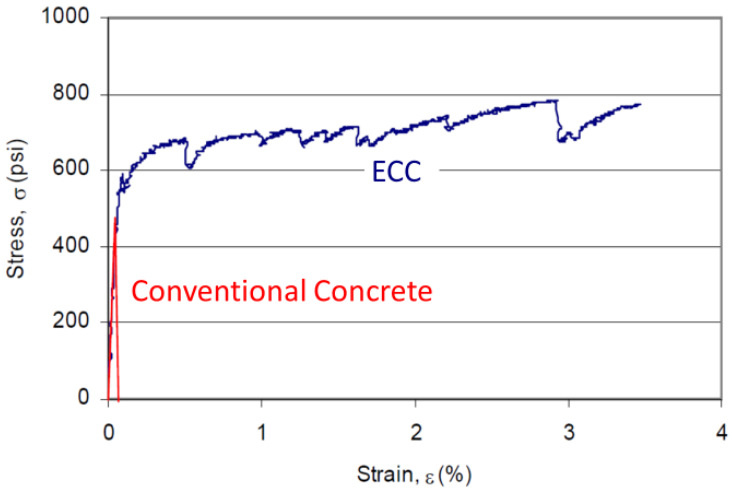
Tensile behavior of steels and SMA

Engineered cementitious composites (ECC)

- ECC is a smart material with multiple unique properties and functions:
  - ➢ Unique mechanical properties
    - ✓ **Tensile strain-hardening**, high tensile ductility (4% strain)
  - ➢ Excellent **durability**
    - ✓ Controlled crack width, self-healing of cracks
  - ➢ Superior temperature resistance
    - ✓ High-temperature, low-temperature
  - ➢ Multi-functionality (smart functions)
    - ✓ Self-sensing, self-cleaning, air-purifying, etc.



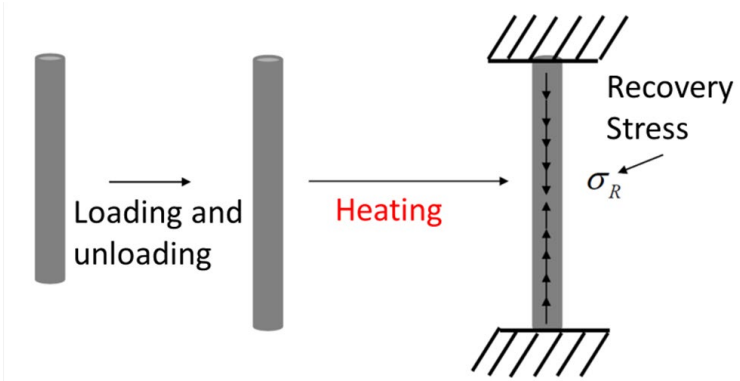
Flexural test of ECC



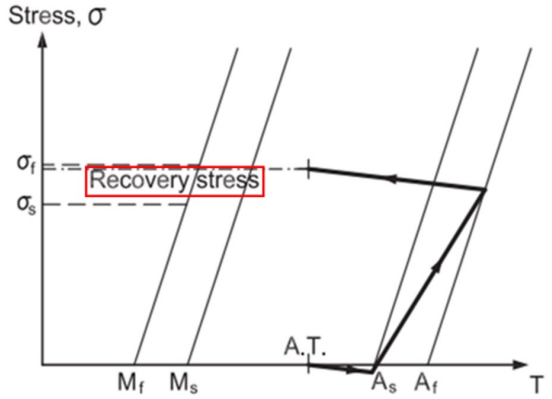
Applications in Highway Bridges

- **Lateral confinement of bridge piers**
  - Active confinement of concrete bridge piers with NiTiNb SMA spirals and FRPs
- **Innovative connection**
  - Column-footing connections in seismic zones with SMA bars and ECC
- **Bridge vibration control**
  - SMA devices for vibration isolation
  - Cable damping devices

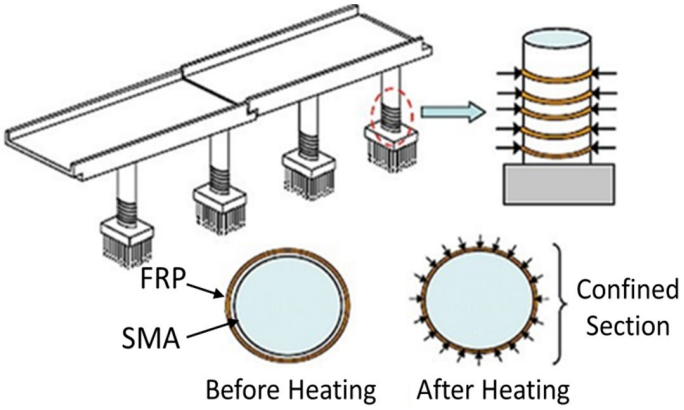
Lateral confinement of bridge piers



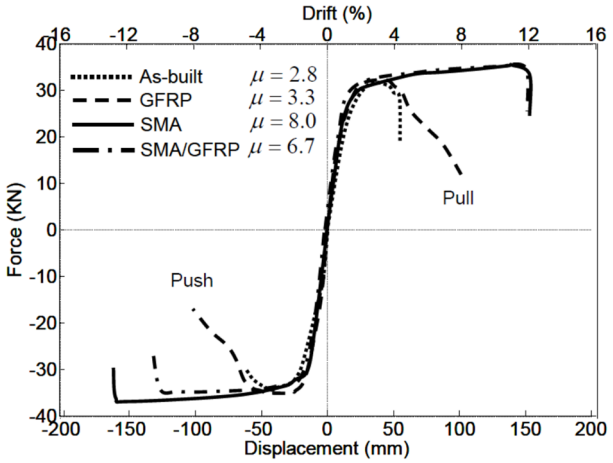
SEM in constrained recovery



Permanent prestressing after heating

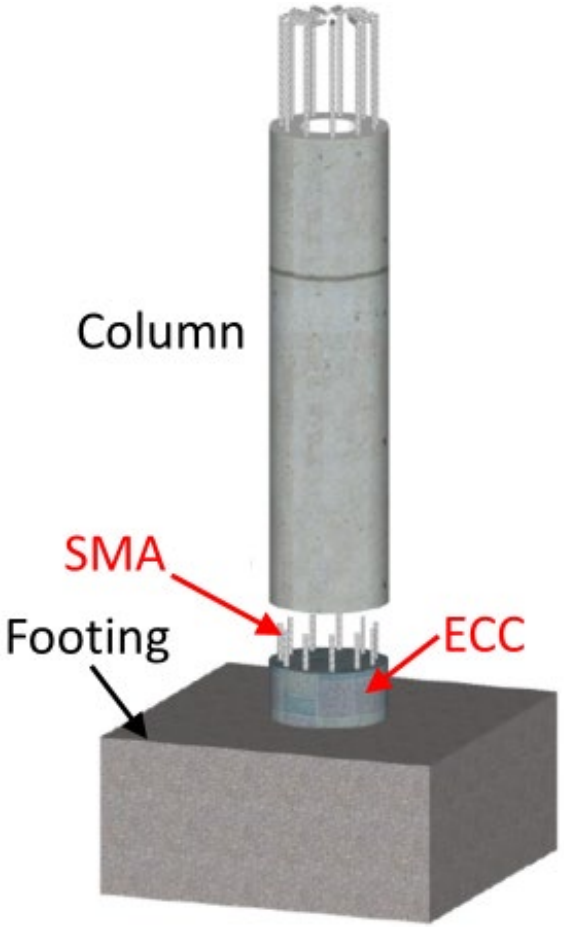


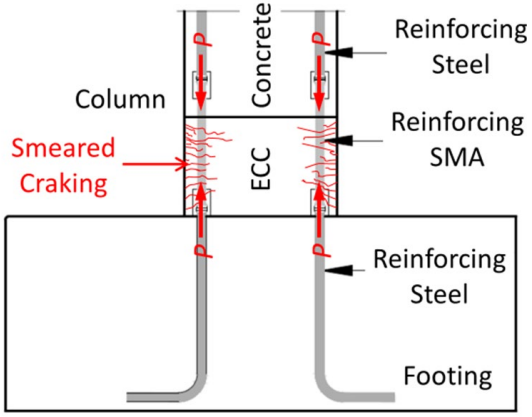
Lateral **active** confinement of bridge piers



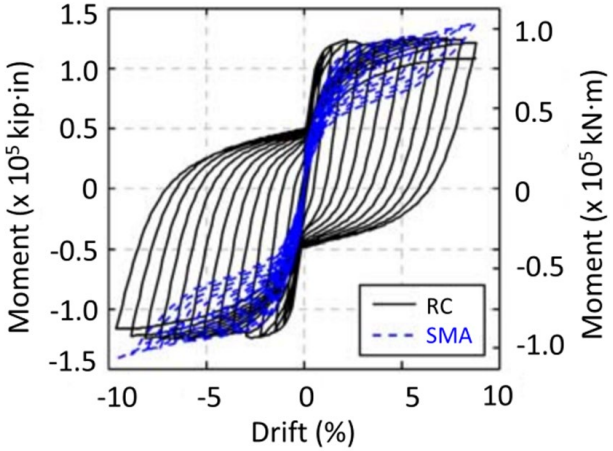
Comparison of force-displacement backbone curves of the four columns

Innovative connection



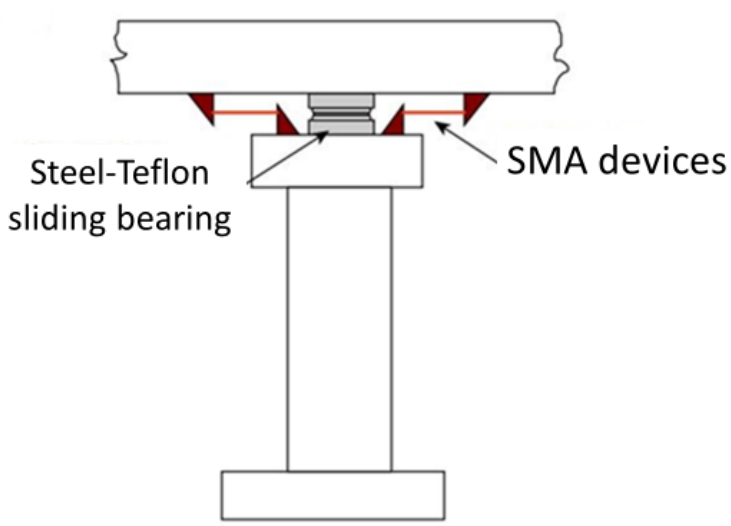


Self-centering & self-healing of cracks



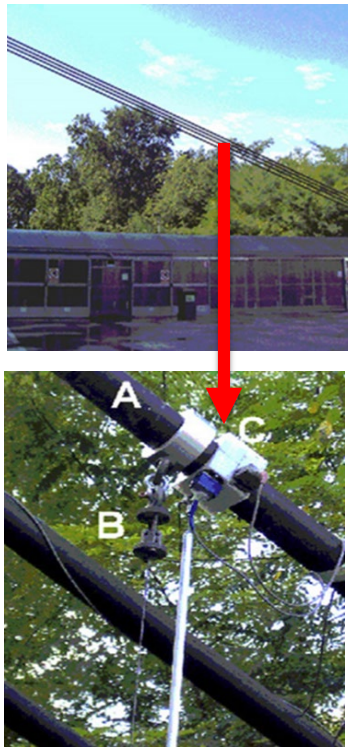
Isolate vibration with SMA devices

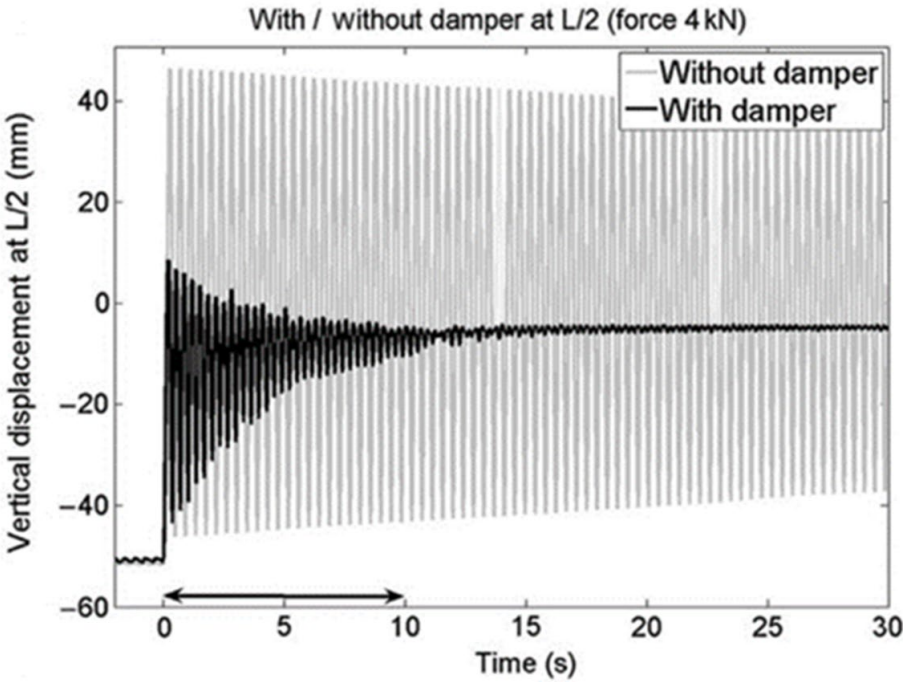
- Improving the **position stability** of bridges
- Benefits
  - Improving safety and resilience under dynamic loadings
  - Convenient installation and replacement



Cable vibration control with damping devices

- The **vibration amplitude** of cables and hangers are **reduced** by 50% using SMA dampers, increasing the service life of the cables/hangers.



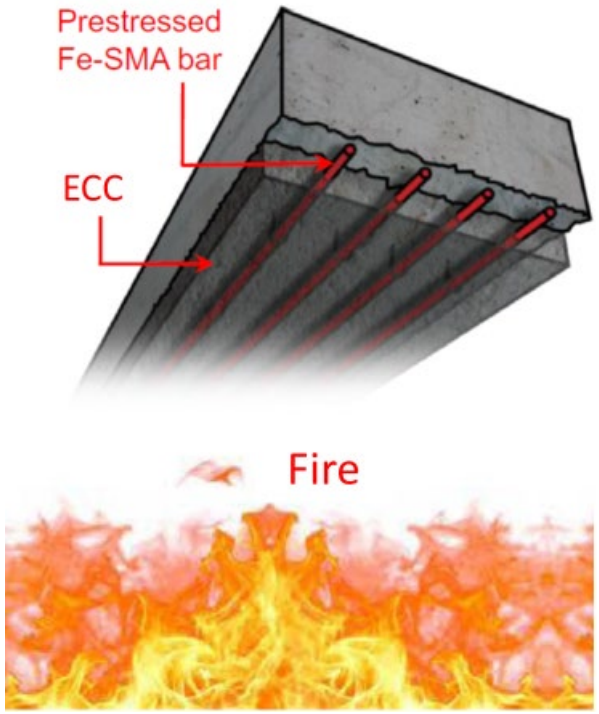


A = structural cable, B = SMA damper, and
C = accelerometer

On-going research 1:

Improve fire resistance of highway bridges

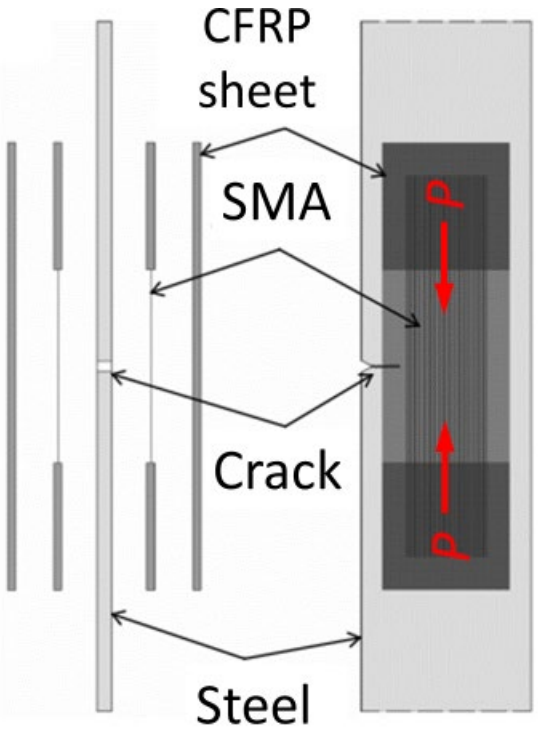
- Fire may result in permanent damage or even collapse of the bridge
- We improve the **fire resistance** using prestressed Fe-SMAs and fire-resistive ECC



On-going research 2:

Improve fatigue life of bridges Using SMAs and CFRP

- An **active retrofitting** technique using SMA/CFRP composite
- Crack-closing capability of SMA and fatigue resistance of FRP



Conclusions

- The combination of FRPs, SMAs, and ECC demonstrated advantages in bridge engineering, especially in earthquake resistance design.
- **Active confinement** delivered better performance of the bridge piers compared with the passive confinement strategy.
- The piers with SMA/ECC connection recovered the position and demonstrated the minimal permanent drifts.
- The SMAs are promising to **control structural vibration**, **improve fire resistance**, and **enhance the fatigue resistance** of bridges.