Future of PBE for Community Resiliency-Transportation Systems

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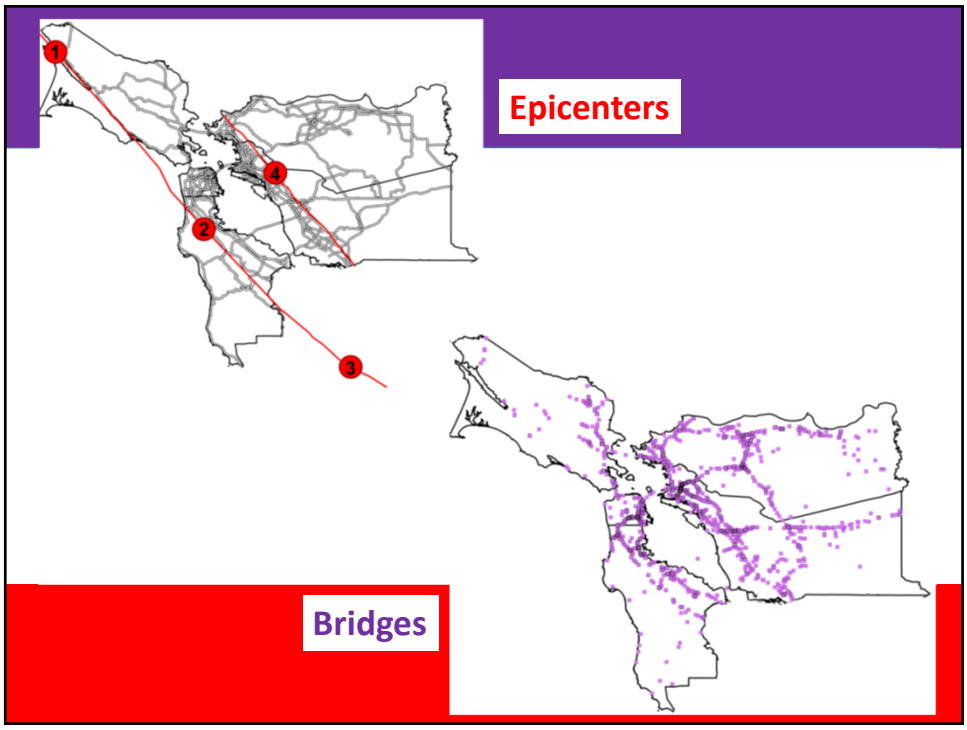


Seismic Performance Objective for Standard Structures:

No collapse under strong earthquakes

Failure and Success

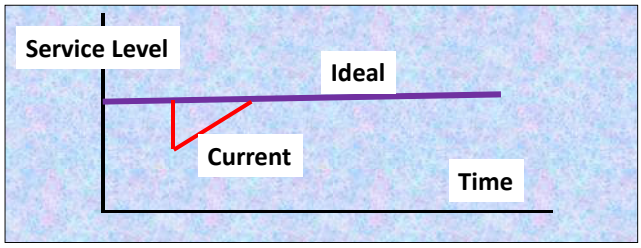
Failure

Success

New thinking: "No Collapse" is only partial success

- **Serviceability after earthquake:**
  Minimize permanent drift and damage (Bridges need to be sustainable)
- **Performance-based design**
- **Base isolation**
- **Advanced materials/details**

  Shape memory alloys/ductile concrete
  Post-tensioned members
  Members w/ built-in elastomeric pads
  FRP composites

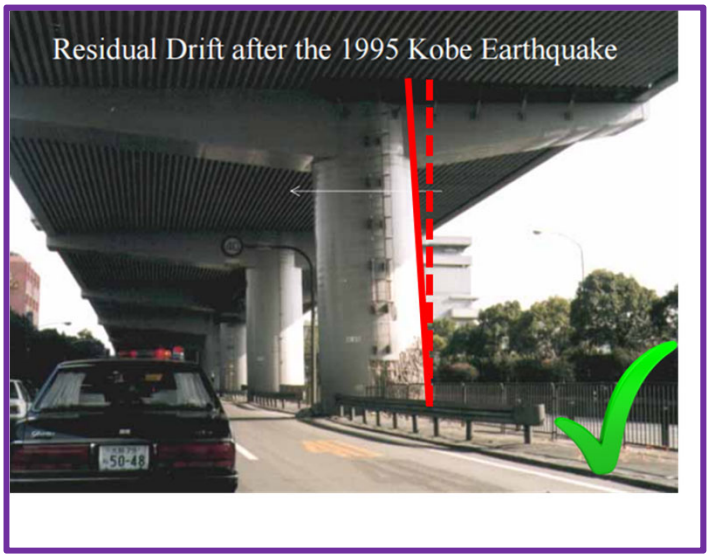


Earthquake Damage in New Bridges:

Plastic Hinge Damage and Permanent Drift

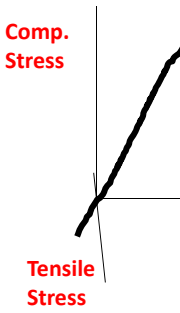
Plastic Hinge Damage

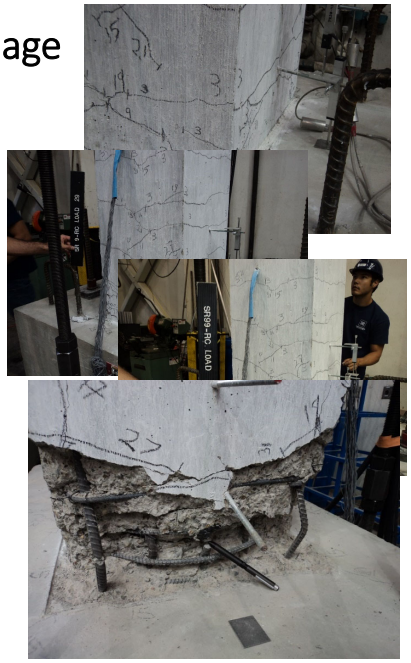
Residual Lateral Displacement



Cause of Plastic Hinge Damage

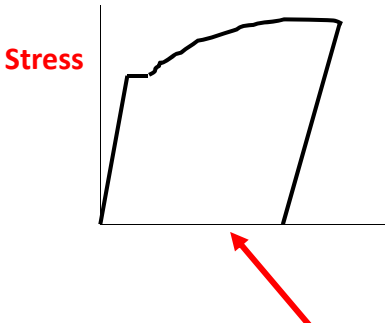
- **Low ductility of concrete**





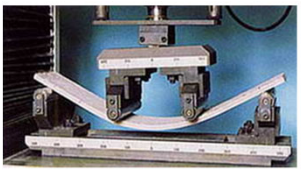
Main Cause of Permanent Drift

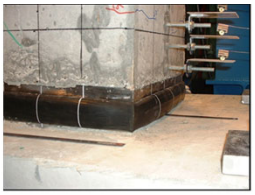
- **Residual steel strain after yielding**

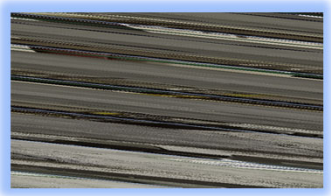


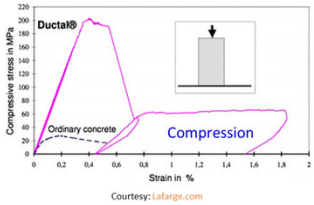
Reducing Plastic Hinge Damage

- **Engineered cementitious composite (ECC)**
- **Ultra high performance concrete (UHPC)**
- **Elastomeric rubber elements**
- **Fiber-reinforced polymer composites (FRP)**





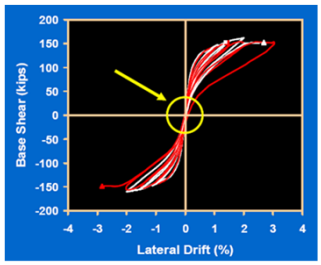


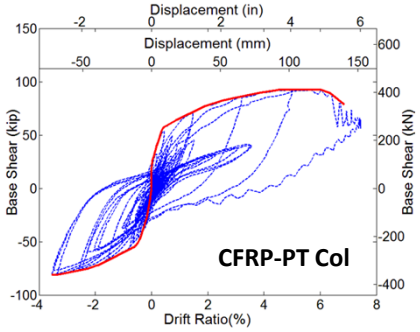


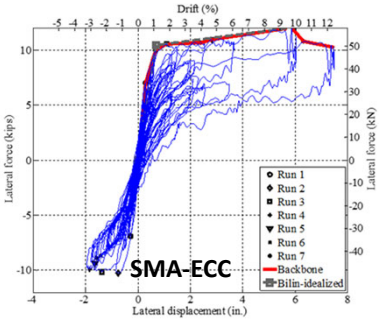
Courtesy: Lafarge.com

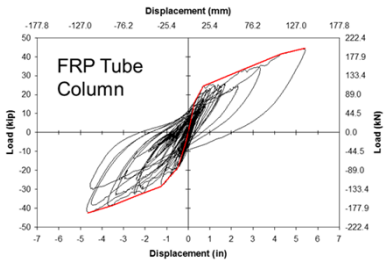
Reducing Permanent Drift

- Post-tensioned columns (Steel; CFRP)
- Superelastic shape memory alloys (Nickel-Titanium NiTi; Copper-Aluminum-Manganese; Iron based)
- Fiber-reinforced polymer composites (FRP)







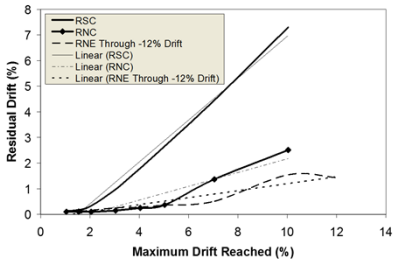


Examples of Resilient Columns w/ Novel Materials/Details

NiTi SMA/ECC Combination

10% Drift

Conventional SMA/ECC

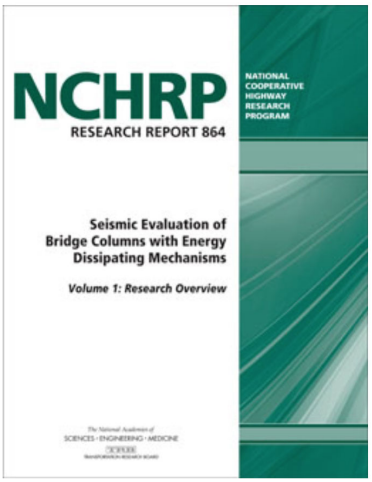


Conventional PT-RC w/ Steel Rod

UHPC w/ PT w/ CFRP Tendons

Dream or Reality- Advanced Materials Design Tools?

Evaluation and Design Guidelines for Columns w/ Novel Materials and Details (Published December 2017)



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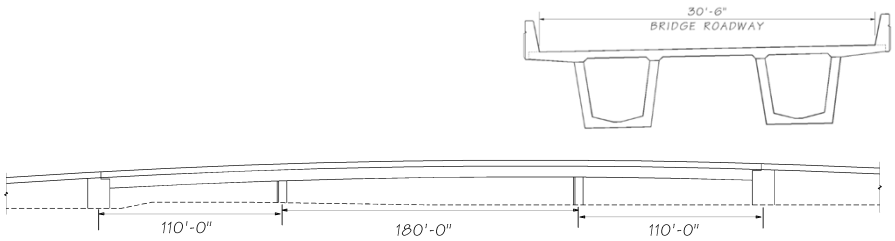
Implementation of SMA/ECC in Showcase Bridge (SR-99 Off Ramp)

- Alaska Way Viaduct Replacement, Seattle, WA
- Three Spans (33 m; 54 m, 33 m)
- Single, Square Columns (1.5 m x 1.5m) w/ Circular Core

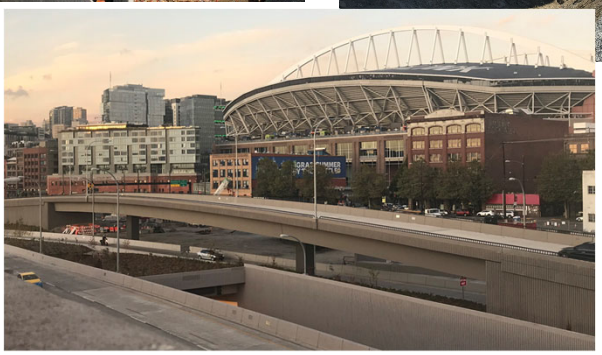


Washington State Department of Transportation

Damage at End of Testing

SR99-RC (8% Drift) **SR99-LSE (12% Drift)** **SR99-SSE (10% Drift)**

HRC Couplers in Seattle Alaska Way Viaduct
SR-99 Off Ramp



AWARDS (*Selected by Practicing Engineers!)

- *Outstanding Civil Engineering Achievement Award, ASCE, Seattle Section, 2018
- Lyman Award by the Precast Prestressed Concrete Institute for journal paper:

Baker, T., M. Saiidi, B. Nakashoji, J. Bingle, T. Moore, and B. Khaleghi, "Precast Spliced Girder Bridge in Washington State using Superelastic Materials in Bridge Columns to Improve Seismic Resiliency - From Research to Practice," PCI Journal, Precast/Prestressed Concrete Institute, January-February 2018, pp. 57-71.

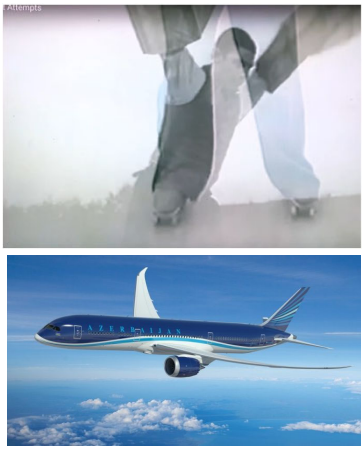
- *SR-99 Bridge: Top 5 Outstanding Civil Engineering Achievement (OCEA) in the United States, Washington DC, ASCE, March 2019
- *SR-99 Bridge: Award of Merit for Bridge Research, International Bridge Conference, Maryland, June 2019

What does the future hold?

- Prediction ability of human specie?

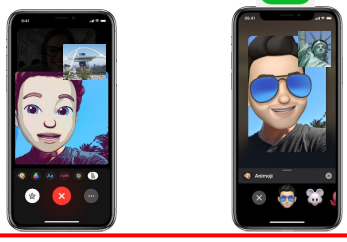
-- OK in predicting **WHAT**; Terrible in predicting **HOW**!

Someday human being will fly!



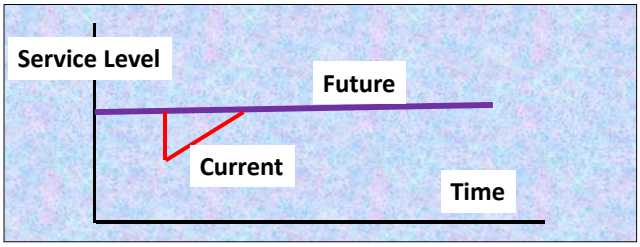
Someday we will see NY while standing in LA

Facetime!



Resilient Bridges of the Future!

The WHAT part:



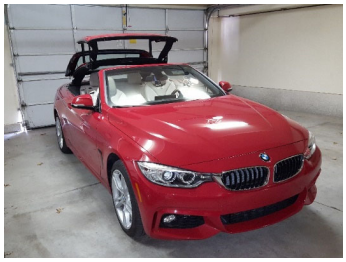
Resilient Bridges of the Future!

The HOW part:

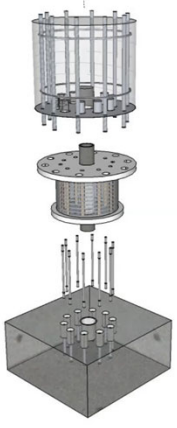
- **Evolution of emerging technologies**
- **Trial deployments here and there**
- **Big bang in adoption of these or other technologies in routine bridge design?**

No one predicted wide spread use of fiber reinforced polymer composites in civil structures 50 years ago!

CONCEPT CAR – CONCEPT BRIDGE



Resilient Design for Deconstruction



Lessons from Recent Research

- Achieving seismic resiliency with novel materials and details is feasible.
- Barriers toward implementing novel materials are not insurmountable.
- For successful commercialization of novel materials life cycle cost should be considered.
- Design guidelines should evolve faster than those for RC.

Move Toward Resilient Bridges-- New Era for Structural Engineering Research

- **Structural and materials engineers should talk!**
- **Substantial research aimed at adapting novel materials to structural engineering use**
- **Experimental studies: Materials; components; systems**
- **Constitutive models supported by extensive data base**
- **Extensive analytical modeling methods for resilient structures**