Sustainable UHPC with Recycled Steel Tire Fibers for Structural Columns

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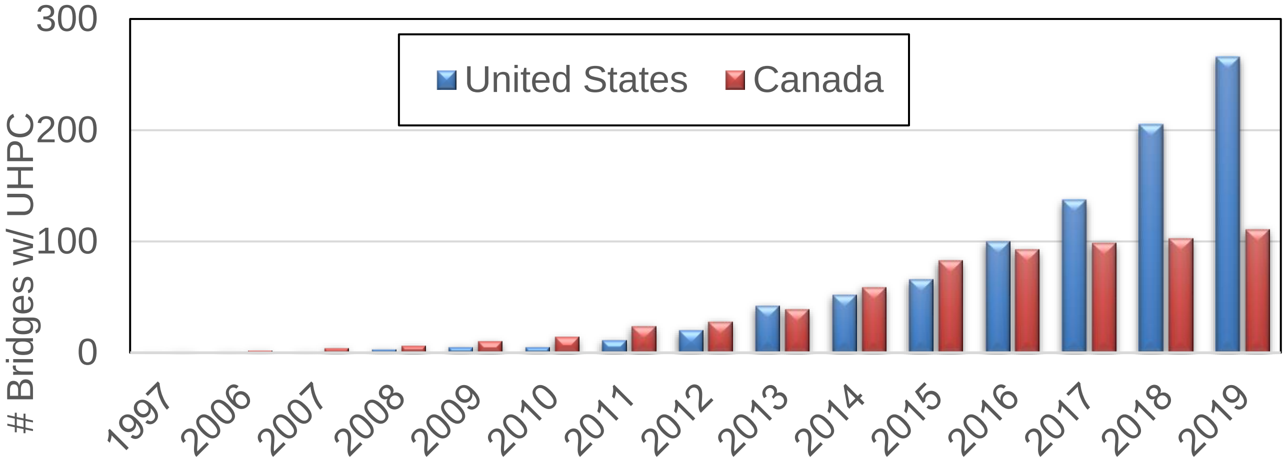
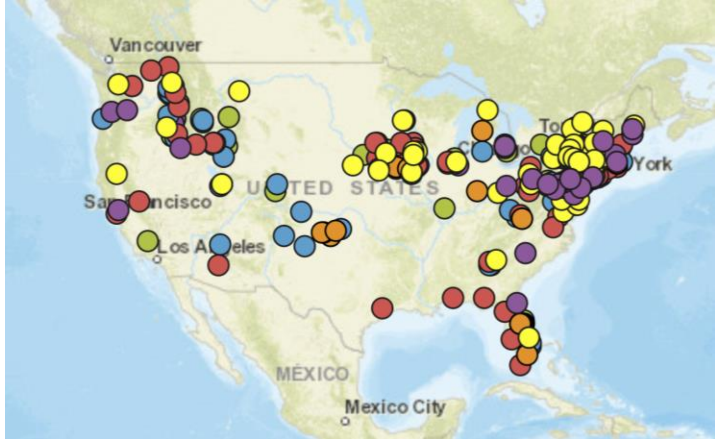
UHPC Market Growth

(Photo courtesy from "*Verified Market Research*)"





Field-cast bridge deck slab joints

Thin-bonded overlays on bridge decks

Current Issues

- UHPC is promising! However, UHPC still has limitations, such as:
  - ❑ Cost for large-scale application
  - ❑ Limited studies and codes exist up to date (does UHPC behave the same way in bridges?)
  - ❑ Lack of research on incorporating sustainable materials

Recycled Steel Tire Fibers in UHPC

- Production of steel-related products accounts for 7% of the CO_2 emissions
- 12-21% of the overall composition of tires are steel fibers, and almost 1 billion waste tires are disposed of in landfills every year
- Introducing recycled steel fibers from waste tires in UHPC can lower carbon footprint, consciously good for the environment, and sustainable in the long run

Knowledge Gaps

- Will recycled fibers work as an alternative to manufactured fibers?
  - Material Level
    - Effect of different types of recycled steel fibers (aspect ratio) in mixing
    - Effect of mixer type
    - Effect on mechanical properties, specifically for tensile and flexural strength
  - Structural Level
    - Axial full-scale precast UHPC columns
    - Accelerated bridge construction: both columns & connections

Mechanical Characterization

- Samples from 14 batches varying fiber type, fiber volume, and mixer type
  - ✓ ~1500 cylinders tested for compression
  - ✓ ~500 dog bones for direct tensile test
  - ✓ ~150 prisms tested for flexure

Key Findings

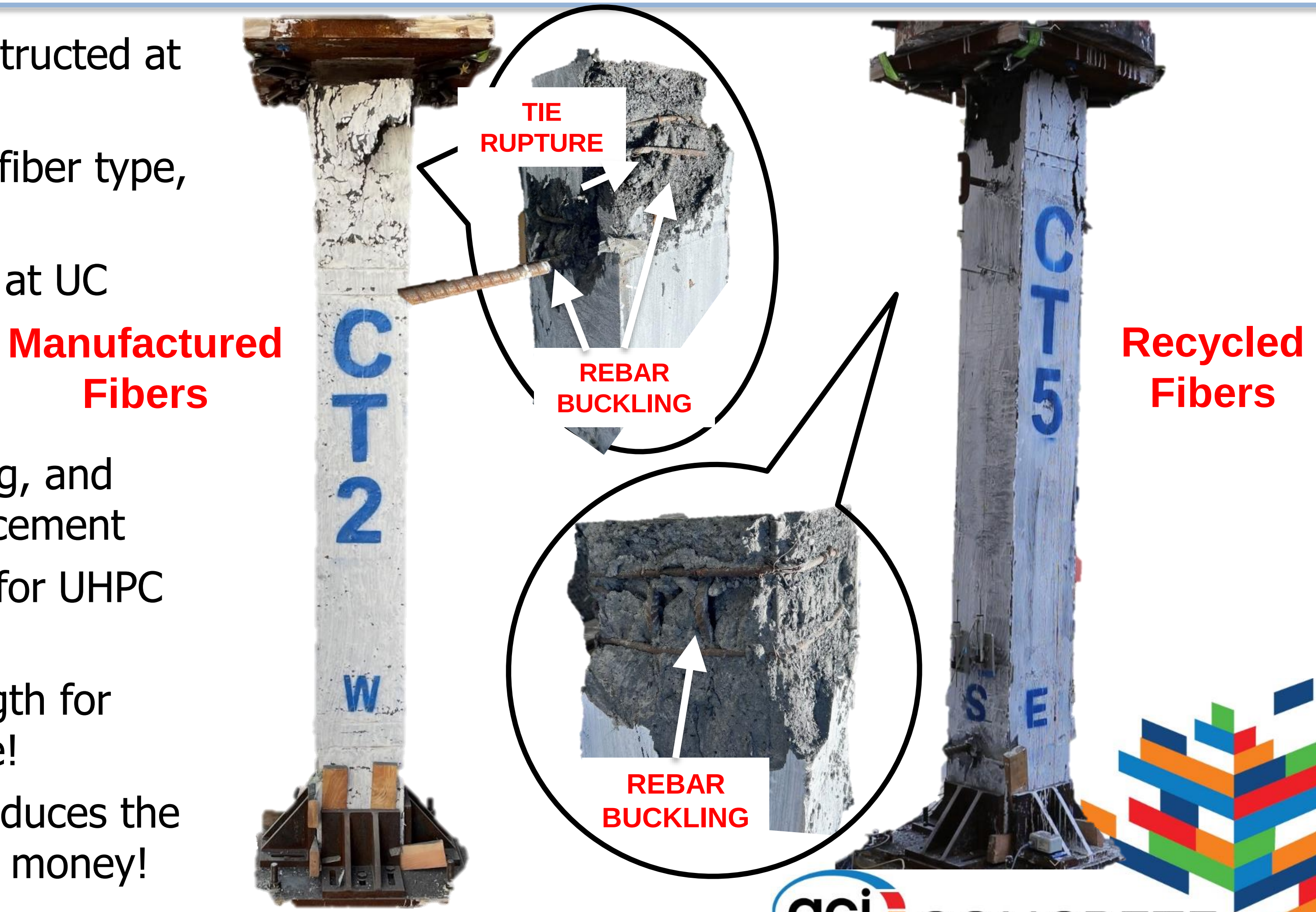
- ➢ High aspect ratio of RSF leads to fiber segregation (recommend fiber volume <1.6%)
- ➢ Compressive strength of UHPC RSF within a 10-20% difference
- ➢ The aspect ratio of RSF affects the flexural performance significantly
- ➢ High-shear and trucking mixing works!

Full-scale Axially Loaded UHPC Columns

- Five full-scale UHPC columns (9 ft.) constructed at UNR
  - Specimen varied with confinement, fiber type, and fiber volume
  - Tested the columns in the big press at UC Berkeley

Key Findings

- ➢ Failure mode: Spalling, tie rupturing, and buckling of the longitudinal reinforcement
- ➢ Proper confinement is still needed for UHPC columns under pure axial loading
- ➢ Differences in the axial load strength for UHPC RSF and MSF were negligible!
- ➢ Reducing fiber to 1% by volume reduces the axial strength by only 9.5%! Saves money!



UHPC in Accelerated Bridge Construction

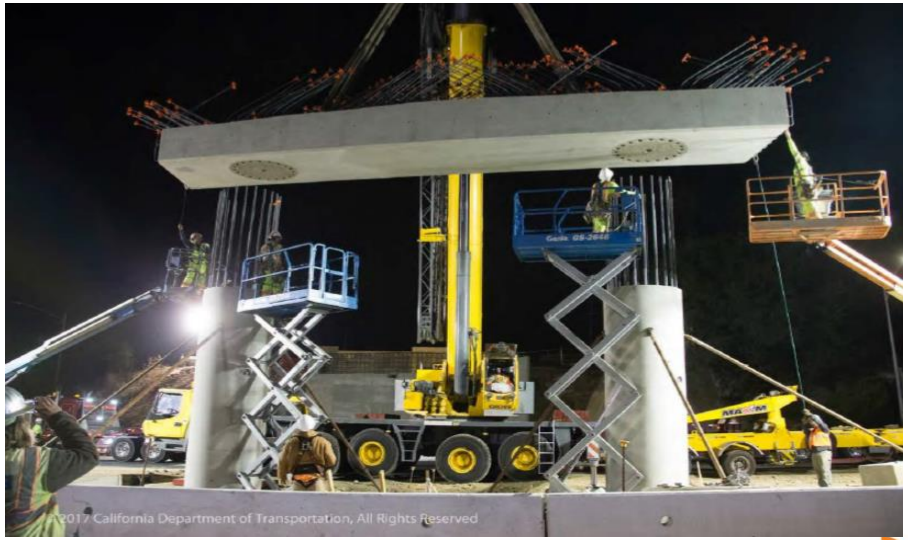
Why ABC?

- Prefabricating bridge elements and systems (PBES) → major time savings, cost savings, better quality control, safety advantages, convenience for travelers, etc.
- PBES connections use advanced materials such as **UHPC** → simplify rft, smaller joints, better interface bond, etc.

Needs:

- demonstrate validity using large-scale testing
- Will UHPC RSF mix in the precast setup?
- Does UHPC behave the same way in ABC columns?

Precast deck panels with transverse and longitudinal joints, photo credit: Georgia DOT)



Precast columns and drop bent cap for Laurel Street Overcrossing project in CA (courtesy of Dorie Mellon)

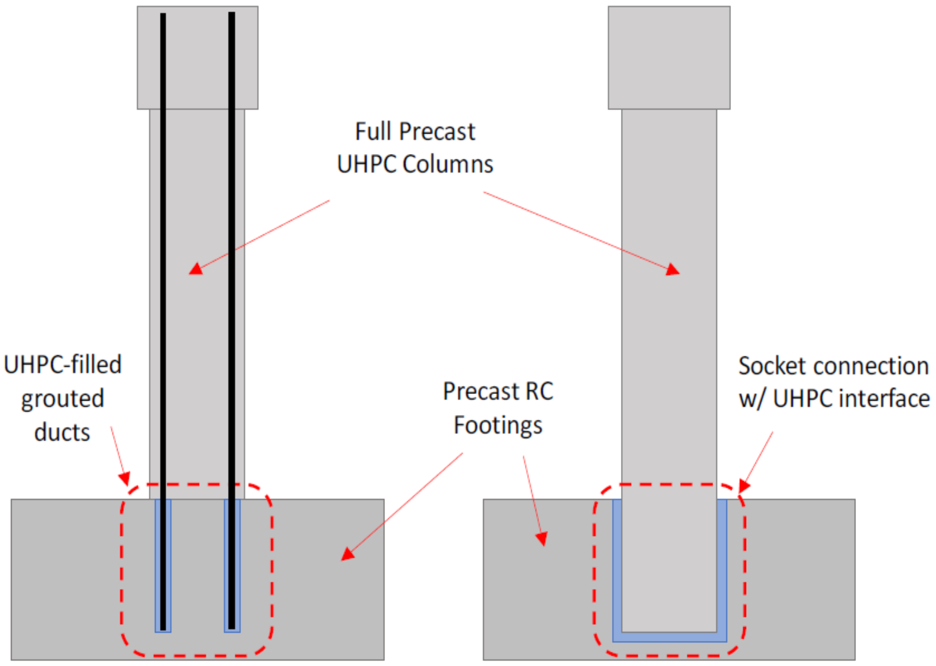
Seismic Precast UHPC ABC Columns Project

- March & April 2023
  - Construction of **8 UHPC (+2 RC)** columns at Con-Fab (Lathrop, California) Production scale of a cheaper UHPC using local and sustainable materials
- August 2023
  - 10 RC footing cast around August 2023 at Jensen Precast (Sparks, Nevada) used for precast seismic UHPC columns.
- October 2023
  - Columns and footings assembly at UNR Fabrication yard using UHPC for ABC joint connection
- November 2023-January 2024
  - Testing **10 seismic columns** at the Earthquake Engineering Laboratory using a shake table and quasi-static cyclic loading.

Test Matrix

- 8 UHPC bridge columns (+2 NSC) constructed at Con-Fab California (Lathrop, California)
- 1/3 scale of typical bridge columns
- Specimens were varied based on fiber type in UHPC, connection detailing and material, loading protocol

Specimen ID	Test Matrix							
	Connection	Column Material	Connection Filler	Type of Test	Longitudinal Rft.	ρ_l [%]	Transverse Rft.	ρ_t [%]
SP1	Grouted duct	NSC	UHPC MF	Cyclic	10 #6	2.19	#3 spiral at 3" pitch	1.04
SP2	Socket	NSC	UHPC MF	Cyclic	10 #6	2.19	#3 spiral at 3" pitch	1.04
SP3	Socket	UHPC RF	UHPC MF	Cyclic	10 #6	2.19	#3 spiral at 3" pitch	1.04
SP4	Grouted duct	UHPC RF	Grout	Seismic	10 #6	2.19	#3 spiral at 3" pitch	1.04
SP5	Grouted duct	UHPC RF	UHPC MF	Seismic	10 #6	2.19	#3 spiral at 3" pitch	1.04
SP6	Grouted duct	UHPC MF	UHPC MF	Cyclic	10 #6	2.19	#3 spiral at 3" pitch	1.04
SP7	Grouted duct	UHPC RF	UHPC MF	Cyclic	10 #6	2.19	#3 spiral at 1.5" pitch	2.08
SP8	Grouted duct	UHPC MF	UHPC MF	Cyclic	10 #6	2.19	#3 spiral at 1.5" pitch	2.08
SP9	Grouted duct	UHPC MF	UHPC MF	Seismic	10 #6	2.19	#3 spiral at 3" pitch	1.04
SP10	Socket	UHPC MF	UHPC MF	Cyclic	10 #6	2.19	#3 spiral at 3" pitch	1.04



Column Fabrication

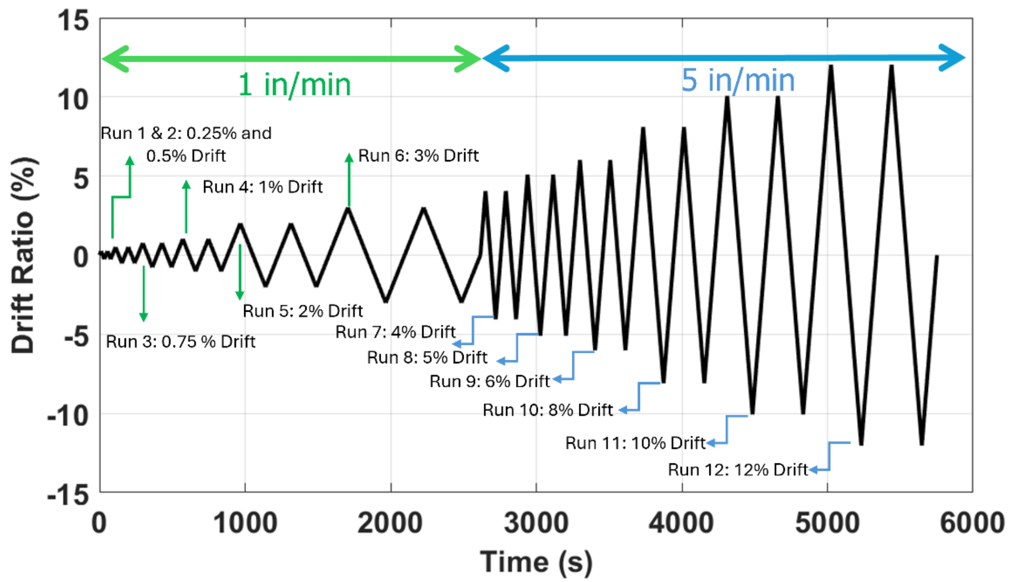
Mixing Sequence

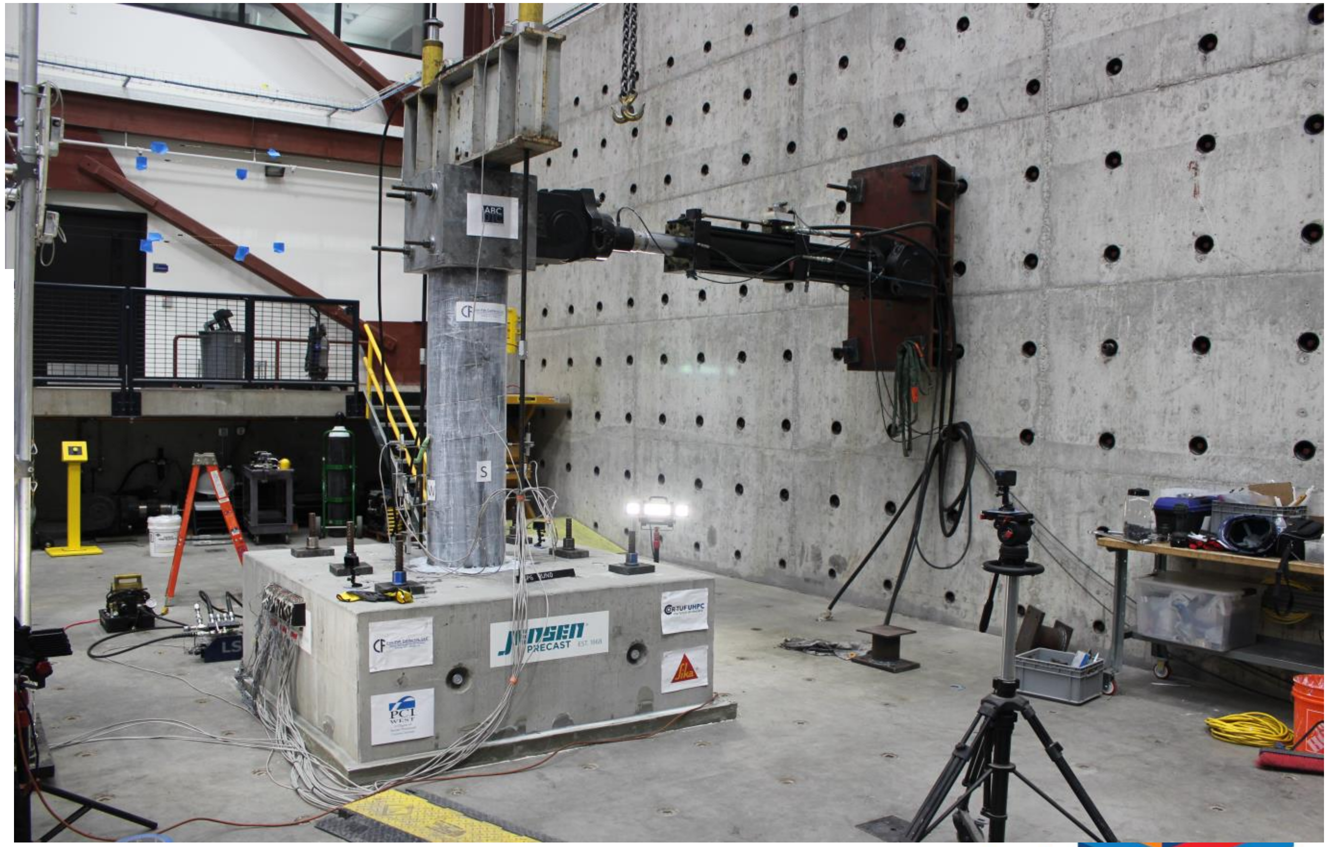
Footing Fabrication

Specimen Assembly

Quasi-Static Cyclic Testing

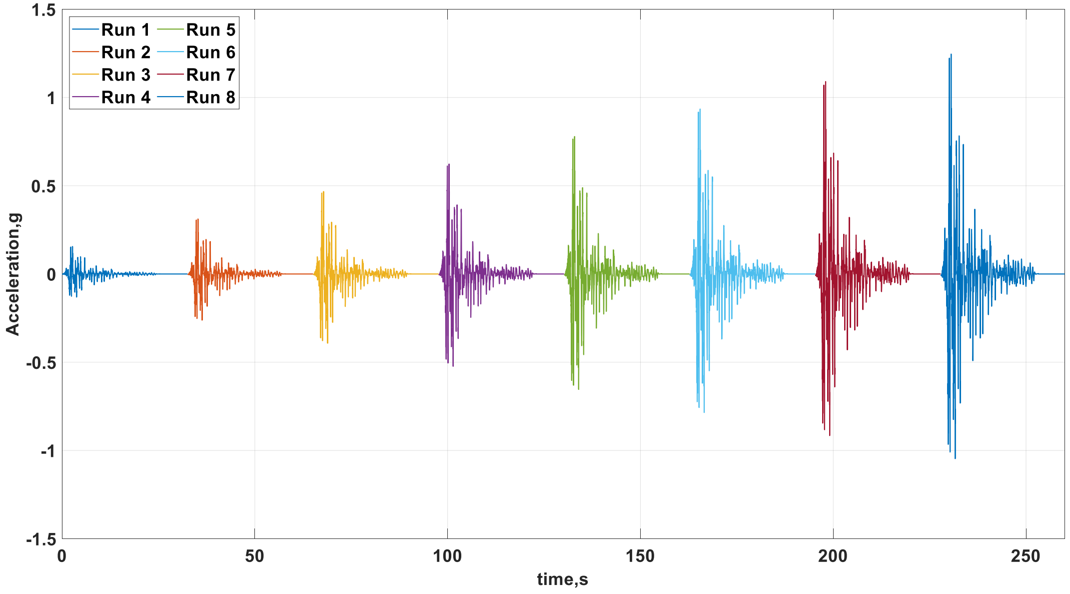
- 5 UHPC ABC columns (+2 NSC) tested under displacement-controlled quasi-static cyclic loading
- 110-kip servo-hydraulic actuator used to provide a maximum ~12% drift ratio





Shake Table Testing

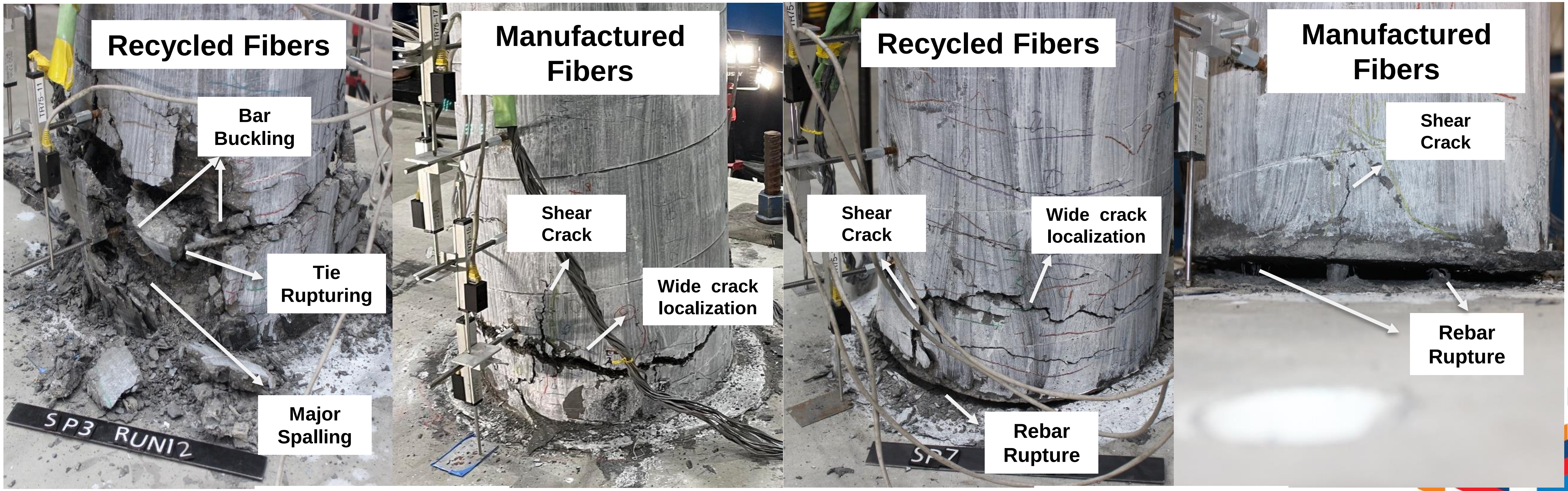
- 3 UHPC ABC columns tested in one of the biaxial shake tables at the Earthquake Engineering Laboratory in UNR
- Simulated with the 1994 Northridge earthquake with scale from 25%-200%



Shake Table Testing

Visual Damage of Select Columns

- RSF showed typical plastic hinge behavior with significant spalling, tie rupturing, and
- Localized crack formed at the plastic hinge zone with socket connection; rupturing at the interface for duct connection

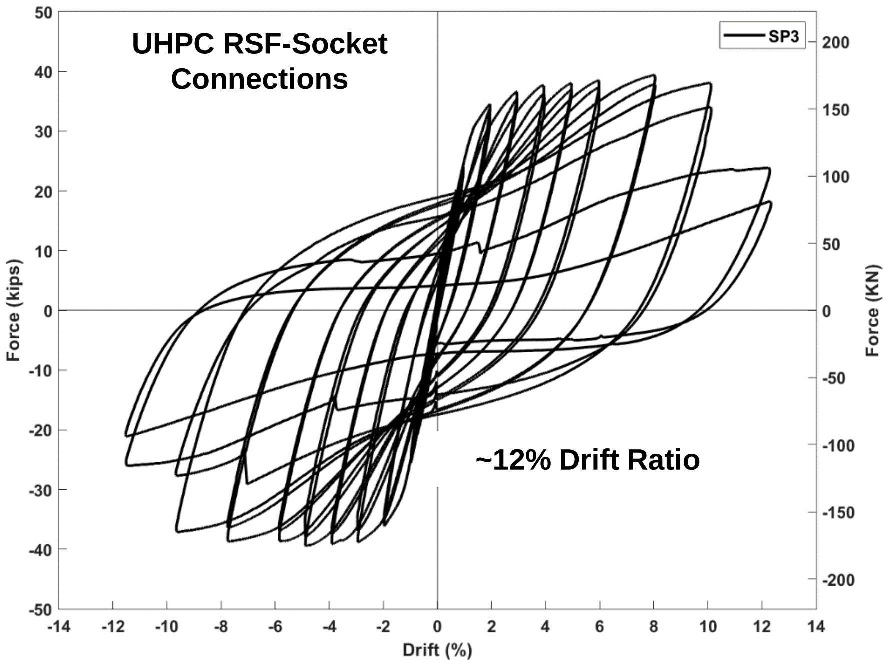


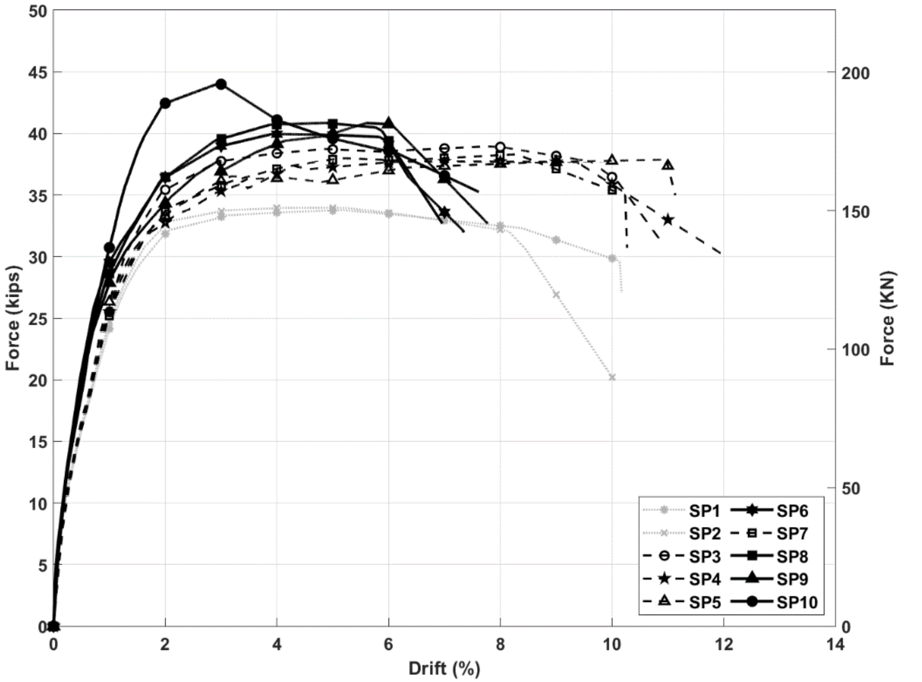
Socket Connection

Duct Connection

Preliminary Findings

- All columns showed good energy dissipation, particularly with RSF!
- Maximum lateral force capacity of UHPC RSF around 38 kips (not far from UHPC MSF with 41 kips)
- High ductility for columns with UHPC RSF (μ_d = 6-10)





Conclusion

- Recycled steel fibers can be a potential alternative to regular steel fibers
- Aspect ratio of recycled steel fibers crucial for tensile and flexure, susceptible to fiber segregation
- Recycled steel fibers work greatly with columns subjected to pure axial loading with appropriate confinement still needed
- UHPC RSF can be used for seismic bridges based on good energy dissipation and ductility achieved!

Thank you! Questions?