Seismic Behavior of Reinforced–Concrete–Filled Steel Tubes

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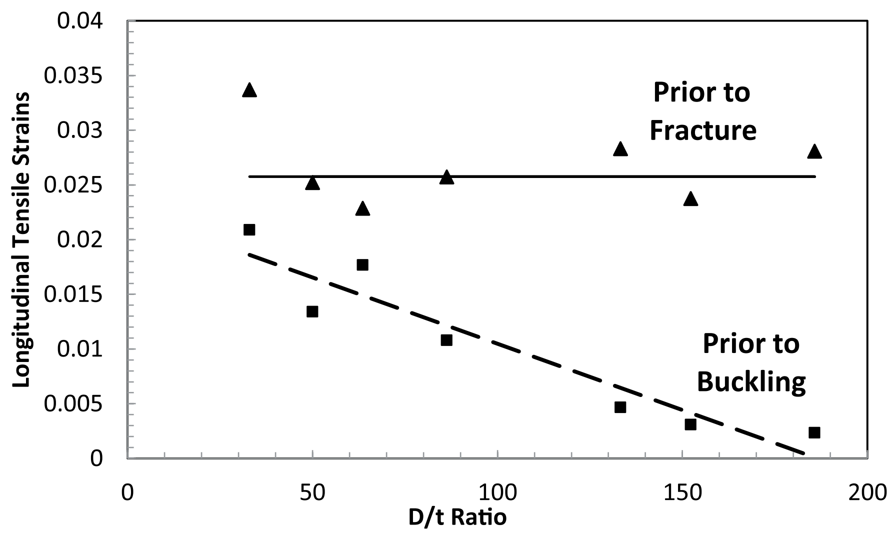
Research on concrete-filled steel tubes is vast and has been conducted for many decades. Over the last 10 years, a research program undertaken at North Carolina State University (NC State) has aimed to investigate the seismic performance of reinforced-concrete-filled steel tubes (RCFSTs). The system involves a reinforcing bar cage that is placed inside a steel shell, which is then filled with concrete. In the research done at NC State, both spirally welded and straight-seam pipe have been studied, with diameter-to-wall thickness ratios (*D*/*t*) varying from 32 to 192. As noted in the companion article in this issue of *ASPIRE*® on the Brotherhood Bridge near Juneau, Alaska, the use of RCFSTs is common in Alaska, as well as other states. In the case of Alaska, the RCFST system is preferred for bridge design for several reasons:

- The steel tubes serve as the formwork for the piles/columns.
- The steel tubes can be used in driven or drilled foundation applications.
- The steel tubes provide high levels of confinement, thus resulting in large deformation capacity, which is important for good seismic performance.
- The system has less environmental impact than conventional substructures requiring larger cofferdams.
- Construction is simplified because the steel tubes serve as piles below the soil surface and as columns above the ground level.

When subjected to lateral demands, these RCFST systems may develop plastic hinges at the connection to the cap beam as well as below grade at the point of maximum moment. Therefore, research has been directed toward developing guidelines for the designs of these regions. Among the parameters that have been investigated are below-grade plastic hinge length, energy dissipation capacity, and quantitative measures of key limit states such as buckling and rupture of the tube wall.



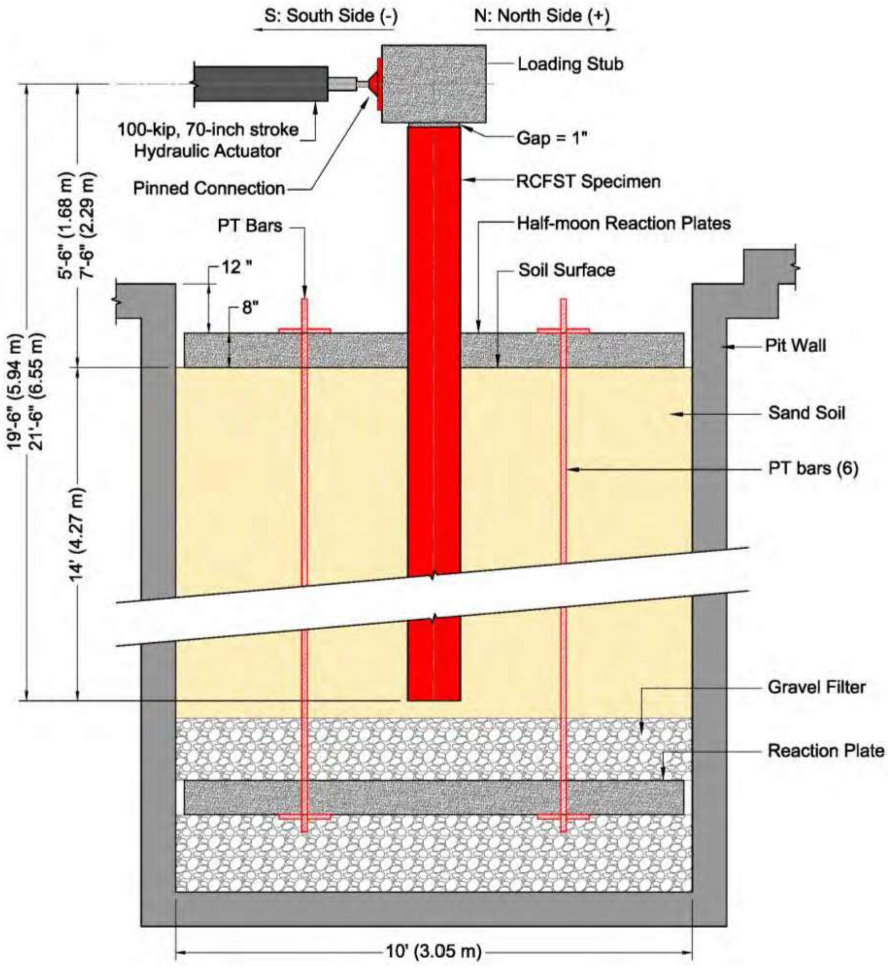
Strain limit states as a function of tube diameter/wall thickness ratio (*D*/*t*). Figure: Nicole Brown.

Initial tests at NC State on RCFSTs were conducted where the test units were subjected to reversed cyclic four-point bending.[1–4] The span between actuators was adjustable to account for different constant-moment regions, which in turn model different soil stiffnesses. In total, 30 RCFST specimens were tested: 22 were 2 ft in diameter and 33 ft long, and eight were 10¾ in. in diameter and 14 ft long. Four of the tests were conducted at –40°C (–40°F) to investigate the RCFST behavior at wintertime temperatures typical of Alaska.

The testing program showed that tube wall buckling is strongly dependent on the *D*/*t*, while fracture occurs at an approximately constant strain, irrespective of *D*/*t*. In all cases, tube wall local buckling was followed by tube fracture. The energy dissipation capacity of these systems was also shown to be large.

The next series of tests focused on RCFSTs in soil using the soil-structure interaction facility at NC State.[5,6] This setup allowed the soil stiffness to be modified by prestressing the sand between two concrete plates. Each specimen was subjected to reversed cyclic lateral loads during testing. Damage levels were similar to what was observed for the initial four-point bending tests.

In addition to tests on the below-ground hinge, the RCFST column-to-cap connection, which was developed at the University of California, San Diego, in the 1990s, was subjected to simulated seismic forces at NC State at temperatures as low as –40°C (–40°F). The connection, which leaves a gap between the RCFST shell and the bottom of the cap, was shown to perform well at low temperatures. Recommendations on material strength and plastic hinge lengths as a function of temperatures typically encountered in Alaska were also proposed.[7] Combined with the extensive research on the RCFST itself, the system has been deployed in numerous Alaska bridges over the last 20 years. Approximately 20 multispan bridges with



Test setup to model reinforced-concrete-filled steel tubes in soil. Figure: Diego Aguirre.

RCFST piers were located within areas having a peak ground acceleration greater than 0.25*g* during the 7.0-magnitude earthquake event on November 30, 2018. Even though many of these bridges were located in liquefiable soils, none experienced any damage or signs of significant movement.

In summary, based on research over a 10-year period that indicated good performance of these systems, design guidelines have been developed for RCFST seismic design. Recommendations have included strain limits, plastic hinge lengths, and analysis methods.

Deformation of reinforced-concrete-filled steel tube during test in soil. Photo: Diego Aguirre.

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