

SHAKE, RATTLE and HOLD

Researchers in Utah shook a bridge to the failure point and then applied carbon fiber reinforcement, which doubled the ductility and increased the lateral load capacity by nearly 20%.



After crews wrapped the column-cap beam joint with carbon fiber, a hydraulic activator simulated seismic loads on the bridge bent.

**CHRIS P. PANTELIDES, P.E., EVERT C. LAWTON, P.E.,
LAWRENCE D. REAVELEY, P.E., AND SCOTT M. MERRY, P.E.**

Many reinforced concrete bridges are vulnerable to seismic deformations, but tests carried out on a bridge section in Utah could lead to better bridge designs and rehabilitation techniques. In situ tests on bridges allow researchers to verify design methods and establish failure capacities. By better understanding the lateral load capacity of bridges, especially older ones, engineers may be able to prevent catastrophic bridge failures during earthquakes.

Lateral load tests on two bridge bents on Interstate 15 in Salt Lake City determined the strength and ductility of an existing concrete bridge, as well as the effectiveness of using a fiber-reinforced plastic (FRP) composite for rehabilitation.

The opportunity to test two aging bridge bents arose because the Utah Department of Transportation (UDOT) is reconstructing I-15 in Salt Lake City. The South Temple Bridge, designed and built in the early 1960s, lacked the basic reinforcement necessary to provide adequate lateral load capacity and ductility in a seismic zone and was scheduled to be demolished and rebuilt.

Wasatch Constructors, which is reconstructing the highway for UDOT, made two bents and the deck between them available for testing prior to demolition. The National Science Foundation, the Federal Highway Administration, UDOT, the University of Utah, and the Idaho National Engineering and Environmental Laboratory provided about \$550,000 for the tests.

Lateral load testing of the reinforced concrete bents was performed with and without FRP composites to demonstrate the ability of composite materials to restore structural integrity and improve resistance to seismic loading.

The FRP composite strengthened the column-cap beam joints and increased the shear stresses by 35%. The retrofitted bent reached a displacement ductility of 10—twice that of the as-built bent. In addition, the peak lateral load capacity increased by 18%.

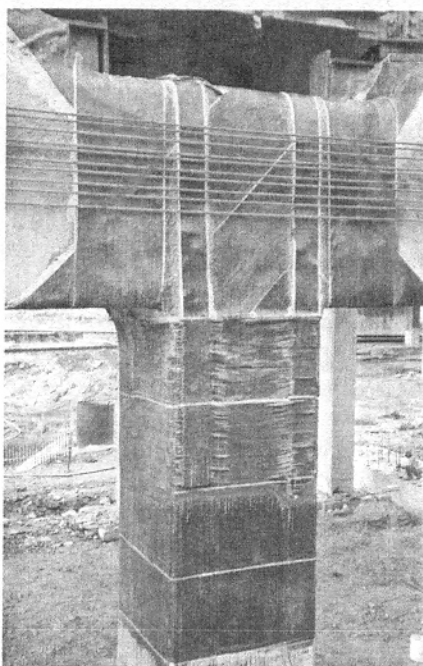
THE TEST SITE

The 27 ft high test bents were 64.6 ft wide and supported a 71.8 ft long deck. The three columns in each bent were 36 in. square and the cap beam was 36 by 48 in. A 7 ft square by 3 ft thick pile cap bearing on four 12 in. outside diameter concrete-filled steel pipe piles, which were 65 ft long, supported the two exterior columns. A 9 ft square pile cap bearing on five piles supported the mid-

dle pile cap (see Fig. 1).

Modifications to the deck supports ensured that the test could be conducted safely. The modifications included fixing the steel girders on one bent by attaching them to the cap beam and placing the girders on rollers at the cap beam of the other bent, enabling the deck to move during load application.

Modifications were also necessary at the interface of the pile cap and the concrete-filled steel piles at the foundation. This improved the connection so that the tops of the piles would not pull out of the pile caps in response to the large uplift and horizontal forces anticipated in the

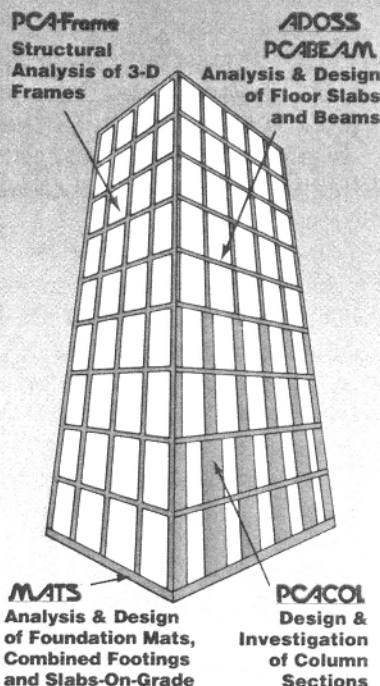


The ductility of the bent wrapped with carbon fiber nearly doubled.

tests. In addition, the three pile caps were linked to the foundations of the reaction frame using tensile and compressive struts. The struts prevented excessive lateral movements of the pile caps or flexural failure of the piles.

The soils at the site are deep and highly variable, for the most part comprising thinly bedded alluvium and Lake Bonneville deposits. The uppermost materials within the bearing zones consist of a 2 ft thick gravelly clay fill underlain by a 5 ft thick layer of very soft silty clay. Standard penetration test blow counts in the area varied from 0 to 3, with undrained shear strengths of 400 to 600 psf. The soils beneath these layers are primarily

PCA's Structural Software for Reinforced Concrete Structures



PC4Frame performs general purpose structural analysis of two- and three-dimensional structures subject to static loads.

ADOSS performs analysis and design of two-way reinforced concrete floor framing systems using the Equivalent Frame Method.

PCABEAM performs analysis, design and investigation of reinforced concrete continuous beams and one-way slabs including moment redistribution.

PCACOI performs design and investigation of short or slender round or rectangular reinforced concrete column sections subject to axial load and uniaxial or biaxial moment.

MATS performs analysis and design of reinforced concrete mat foundations and combined footings using the finite-element method and one-way soil springs.



Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077-1083

For more information call:
Portland Cement Association
Phone (847) 966-6200 ext. 353
FAX (847) 966-9781

In Canada, contact Canadian
Portland Cement Association
Phone (613) 236-9471

(Circle 28 Reader Service Coupon)

silts and clays of medium stiffness interbedded with thin layers of sands and silty sands.

A second soft layer approximately 15 ft thick exists about 20 ft below the bearing level. These materials were inadequate to support the large lateral and uplift forces from the reaction frame with shallow footings. As a result, the researchers considered two alternative systems for the reaction frame foundation: concrete-filled pipe piles and a geopier foundation system.

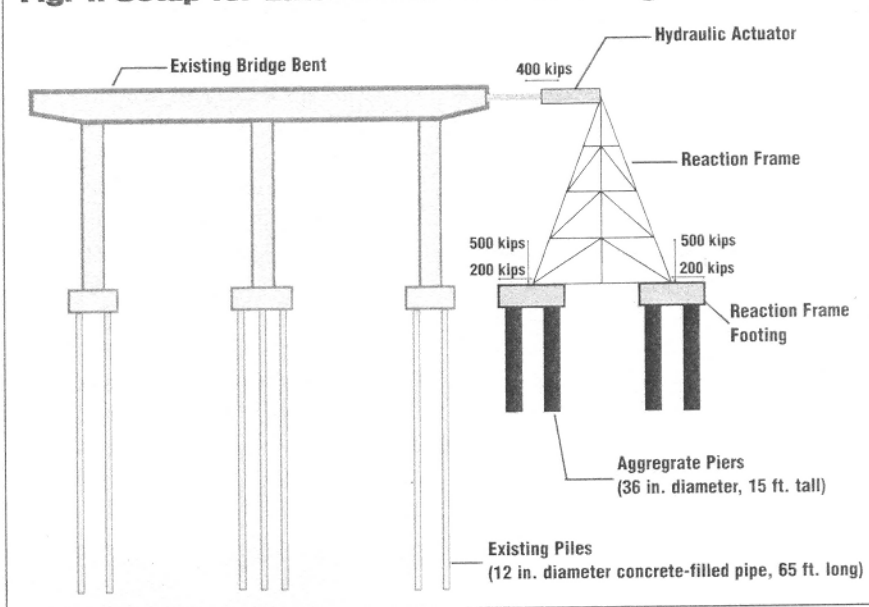
The foundation supplied by the Geopier Foundation Co., Atlanta, was selected because of lower cost, estimated to be about half that of the piles, and because the proprietary contractor was willing to donate a significant portion of the pier installation cost in return for research on the behavior of the system during the tests.

The reaction frame foundation consisted of two 8.25 by 24.5 ft rectangular footings 39 in. thick bearing on the ground surface. Each footing was supported by 10 piers, each 36 in. in diameter and 15 ft tall, arranged in two symmetric rows.

The piers provided resistance to the large uplift and lateral forces via 34 in. diameter, 0.5 in. thick circular steel plates located at the bottoms of the piers. Four no. 7 threaded steel bars extending vertically through the perimeter of each pier attached the plates to the footings.

The FRP composite had an ultimate tensile strength of 91 kips/sq in. and an ultimate tensile strain of 0.01. Specific design elements for the FRP included flexural plastic hinge confinement, lap splice clamping and shear strengthening for the columns; flexural plastic hinge confinement for the cap beam; shear strengthening of the column-cap beam joint; and development of column

Fig. 1: Setup for Lateral Load Test on Bridge Bent



bars into the column-cap beam joint.

Before applying the composite, contractors removed loose concrete, washed the surface with a high-pressure water jet and shotcreted the surface of the cap beam to bring it to its original shape. XXsys Technologies, San Diego, then applied a structural adhesive and the carbon FRP sheets using hand layup and a room-temperature curing system.

LOADING UP

A hydraulic actuator attached to a structural steel reaction frame applied the simulated seismic lateral loading along the axis of the bents. Preliminary analyses of the bent caps wrapped with FRP

composites indicated that the maximum sustainable lateral force applied to the bent cap would be 400 kips.

The corresponding forces generated by the reaction frame on its two footings consisted of alternating compression-uplift forces of 500 kips and cyclic lateral forces of 200 kips on each footing. The footings and their support systems were designed to support these loads, but the maximum loads applied during the tests were about 25% greater than the design loads.

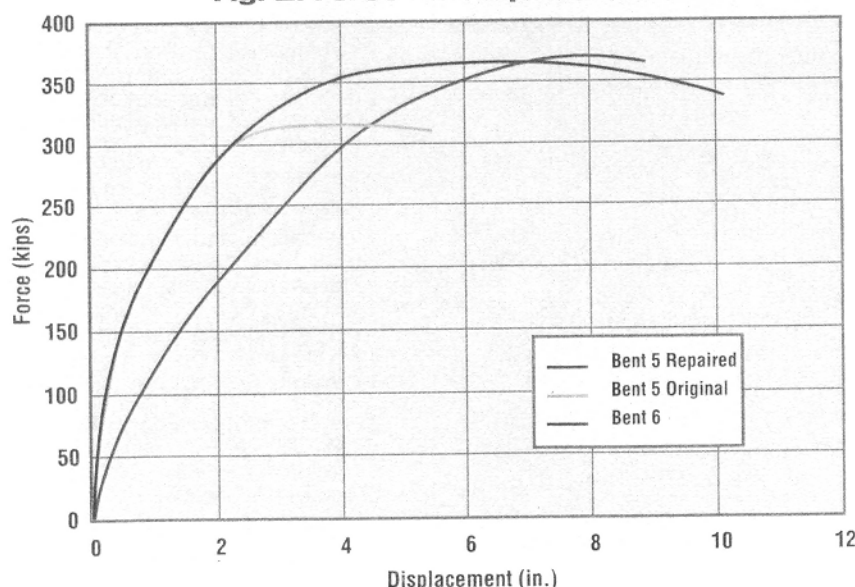
A horizontal quasi-static cyclic load was applied at the cap beam level in the transverse direction. After the first yielding occurred, the test was continued by controlling the lateral displacement. Three tests were conducted: bent 5 in the as-built condition, bent 6 with FRP composites, and repaired bent 5 with FRP composites.

Bent 5 in the as-built condition had extensive diagonal cracks in the joint region, which extended into the cap beam at the bottom level of the horizontal reinforcement. The use of a high-strength adhesive prolonged the onset of delamination of the composite from the concrete surface. This was the dominant mode of failure of the composite, which occurred at about one-fifth of its tensile capacity.

Approximately 80 electronic instruments, including strain gauges, linear variable differential transformers, load cells and displacement transducers, monitored the applied load, strains in the steel reinforcement and the FRP composite, and the displacement of the bents.

The ductility of both bent 6 and the retrofitted bent 5 almost doubled compared with the as-built bent 5 (see Fig. 2). In addition, the lateral load

Fig. 2: Force vs. Displacement



capacity of the retrofitted bents increased by 18%. The composite strengthened the joint, which had an increase in shear stresses of 35%.

The in situ tests conducted at the South Temple Bridge have shown that externally bonded carbon FRP composites can greatly enhance the displacement ductility of bents. In addition, the joint shear capacity was found to be enhanced, the overall damage was controlled and a residual strength was left to support the dead load.

UNDERGROUND REACTION

Upon completion of the structural tests on the two bents, researchers cut the lateral compressive and tensile struts linking the bent pile caps so that the foundation systems would act independently. Geotechnical tests were then conducted in which the bent caps were alternately pushed and pulled in two-cycle lateral deformation levels, starting at 1 in. and increasing by 1 in. increments to 12 in.

Approximately 100 electronic instruments installed in or adjacent to the foundation systems measured the movements, performance and response of the pile caps and the reaction frame foundations.

Both foundation systems performed well during all structural and geotechnical tests. No direct comparisons can be made between the performances of the two foundation systems because of significant differences in structural geometry, materials and dead loads. For example, the dead load was approximately 600 kips on the pile foundation system and 200 kips on the geopier foundation system.

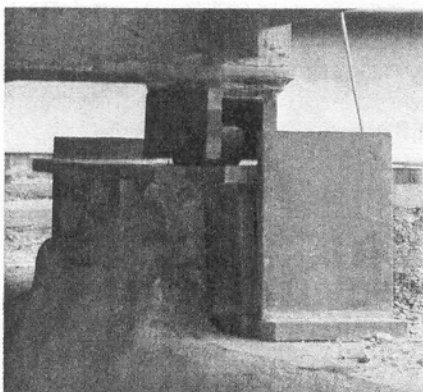
The size and shape of the pile caps and reaction frame footings were markedly different. Furthermore, the pile caps were buried to the top of the caps, while the reaction frame footings rested on the ground surface. The piles were rehabili-

tated before testing to ensure adequate performance during the tests.

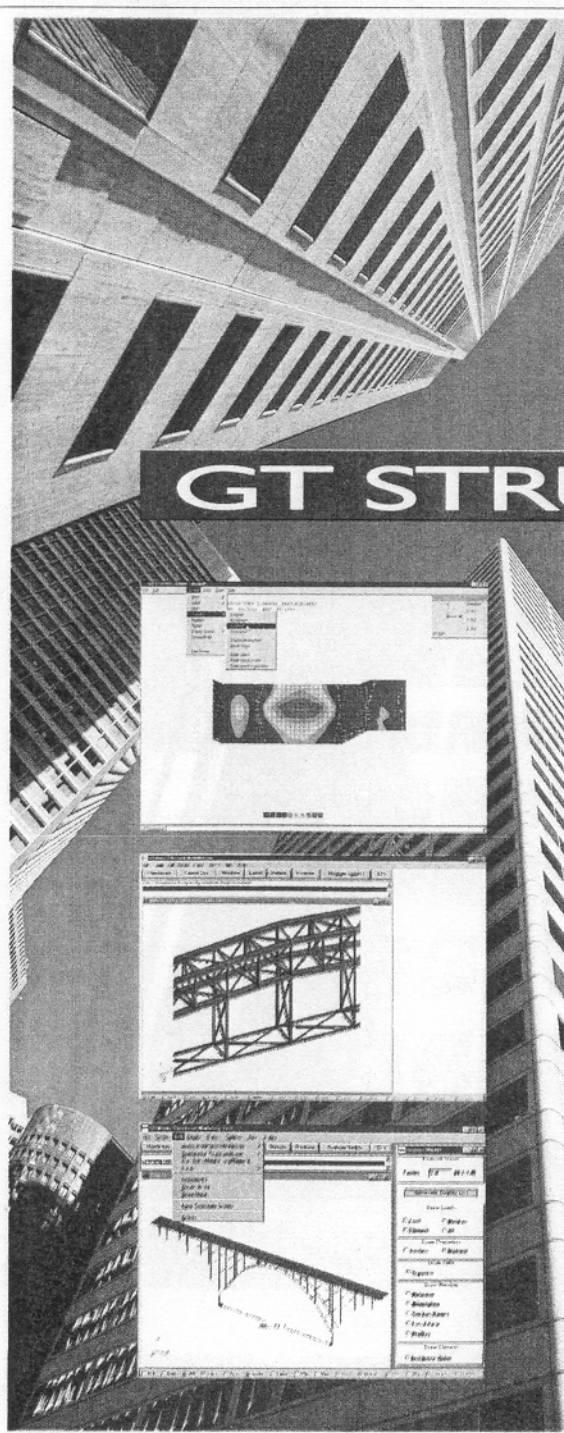
Future tests are planned in which direct comparisons of pile and geopier foundation systems will be made for identical structures under the same loads, soil conditions, and structure and foundation geometry and materials. The tests, to be conducted in the fall of 1999 at the South Temple Bridge, will include a complete seismic retrofit using FRP composite wraps for the cap beam,

columns and joints, as well as a strengthening of the foundations. ▽

Chris P. Pantelides, P.E., M.ASCE, and Evert C. Lawton, P.E., M.ASCE, are associate professors, Lawrence D. Reaveley, P.E., M.ASCE, is a professor and Scott M. Merry, P.E., M.ASCE, is an assistant professor in the civil and environmental engineering department at the University of Utah in Salt Lake City.



Rollers installed at the cap beam allowed the deck to move during testing.



One of the
most widely used
Structural
Design & Analysis
Programs has a
New Look and Feel ...
and the Right Price.

Flexible
Feature-Rich
Reliable

GT STRUDL exceeds
the industry's most
stringent standards for
quality, accuracy, and
technical support.

GT STRUDL
Georgia Tech - CASE Center
Atlanta, GA 30332-0355 USA
404/894-2260
casec@ce.gatech.edu
www.gtstrudl.gatech.edu

(Circle 29 Reader Service Coupon)