References:

1. Celebi, M. and Penzien, J., "Experimental Investigation into the Seismic Behavior of Critical Regions of Reinforced Concrete Components as Influenced by Moment and Shear," EERC Report No. 73-4, University of California, Berkeley, Jan. 1973.

2. Celebi, M., and Penzien, J., "Hysteretic Behavior of Epoxy-Repaired Reinforced Concrete Beams," EERC Report No. 73-5, University of California, Berkeley, Feb. 1973.

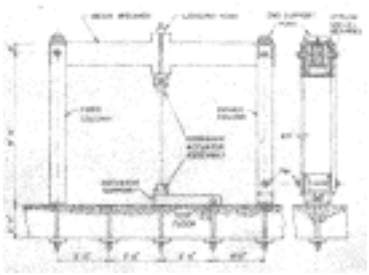


Fig. 3

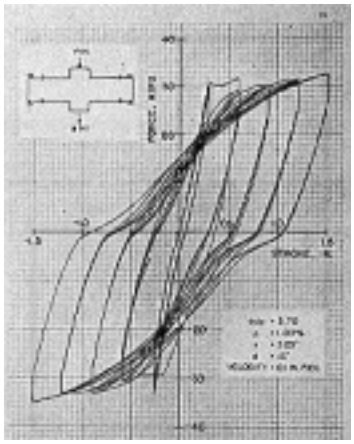


Fig. 5

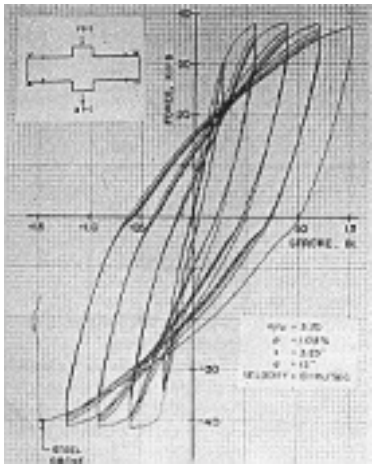


Fig. 7

PROJECTS REVISITED: Ferry Building, S. F.

The project-1967. The Ferry Building on San Francisco's Embarcadero was constructed in 1896 and has always been one of the city's more notable attractions. Facing out over San Francisco Bay and the business district of the city is the 6-story, 4-sided clock tower which was modeled after a famous tower in Spain. Until 1958, the Ferry Building was the terminus for ferry boats from Oakland and Sausalito which now dock next door.

The problem. The tower's brick walls were badly damaged in the 1906 earthquake, but the original steel columns with wrought iron bracing were not too seriously impaired. In 1907, most of the bricks were removed and the walls rebuilt with a 4-in. thickness of concrete, including concrete pilasters between the steel comer columns.

Over the years, shrinkage cracks, rain, moisture penetration, fog and salt-laden air united to deteriorate the concrete walls on all four sides, with the weathering north and east walls the most severely eroded. By 1967, the concrete walls were in extremely poor condition.

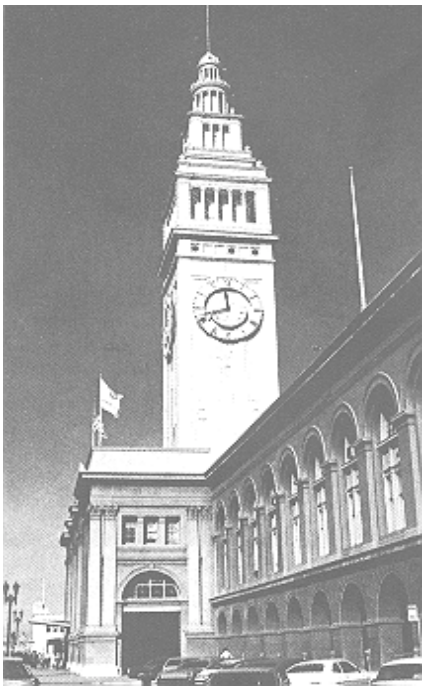
Deterioration consisted mainly of extensive spalled areas, holed-through sections, large expanses of exposed reinforcing bars, and considerable random cracking through the walls. Many of the cracks ran from one floor to the next, with more than 500 lineal feet of cracks in each tower wall. Crack widths ranged from a minimum of 0.004 in up to 0.100 in. It should be pointed out, however, that the concrete was still essentially sound.

The solution. *To* restore the tower's exterior surfaces architecturally, as well as its overall structural strength, the San Francisco Port Authority specified: two coats of gunite on the outside walls; followed by the filling of all cracks internally using a low viscosity structural repair epoxy injection resin using automated mix pumps.

Within 24 hours after guniting, crack repairs began on several floors simultaneously, with up to four pumping machines in operation. The cured gunite acted as a firm backstop to the pressure injected epoxy adhesive.

After an epoxy surface seal was applied over the cracks on the interior, the adhesive was pumped into the crack until it oozed out at a point further along the crack plane. This process was continued until all of the cracks had been filled.

Approximately 3300 lineal feet of cracks. were repaired in this manner, requiring 14 working days and 66 gal injection resin, applied at the rate of about 1 gal. per 50 linear ft. of crack. When the adhesive had cured at ambient temperature, the concrete was permanently bonded once again into a sound, monolithic structure.



April 1975. Front view of Ferry Building illustrates excellent condition of tower walls seven years after repairs by epoxy injection.

The outcome-1975. In the past eight years all of the tower walls have been inspected annually as part of the Port Authority's regular preventive maintenance program. James E. Read, Materials & Research Engineer, says that since 1967 no repairs of any kind have been necessary on the walls. All injected cracks are still bonded and there is no evidence of cracking on any of the surfaces. "In that time," he adds, "we have experienced several minor earthquakes in San Francisco, but the resultant tremors and shakes have not affected the tower in any way. I would venture to say that the repaired tower probably is stronger structurally now than when it was built."

1967. Exterior of Ferry Building prior to guniting. The concrete was 61 years old and showed deterioration caused by rain, moisture and salt air.