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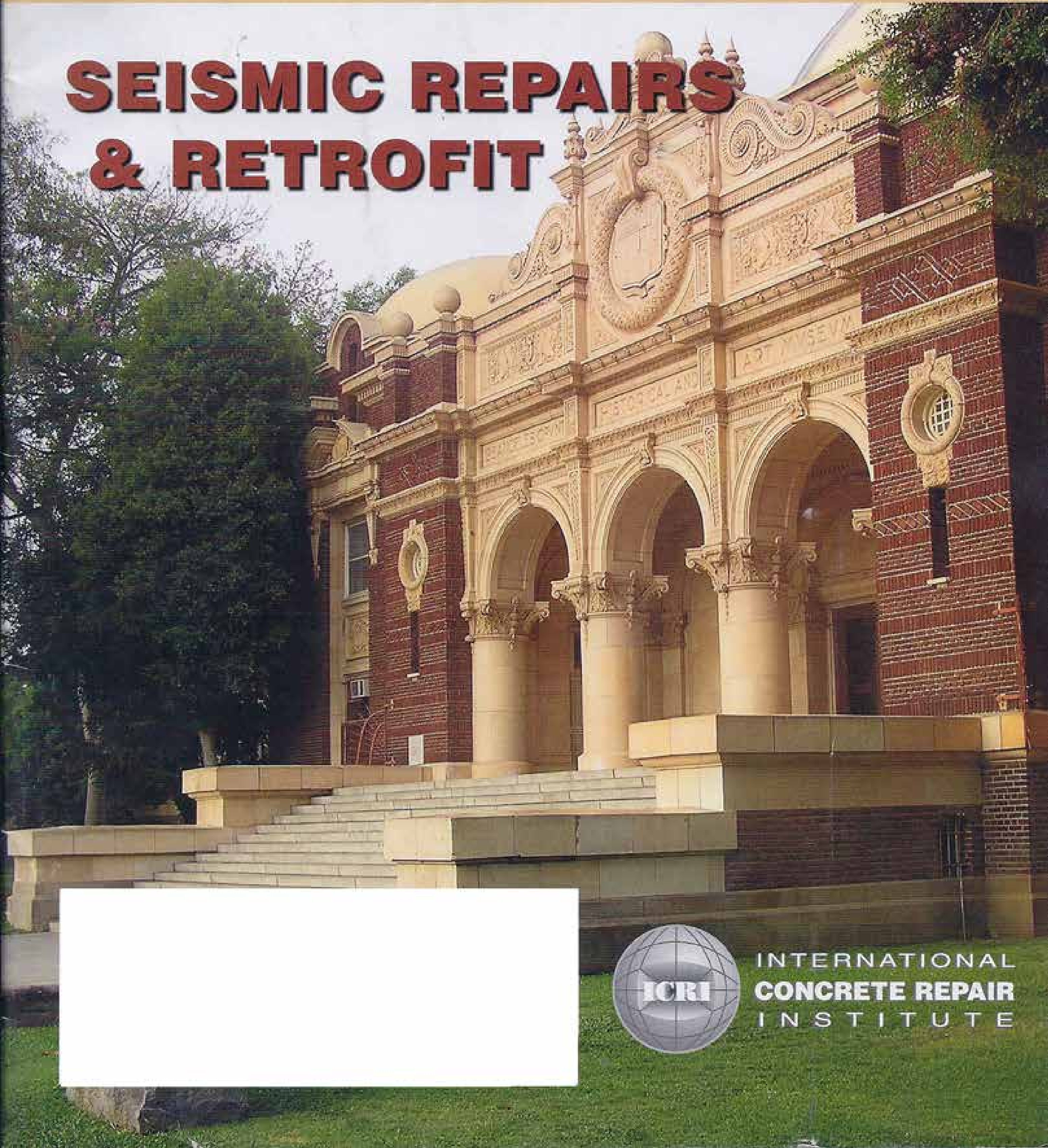
SEISMIC REPAIRS & RETROFIT



INTERNATIONAL CONCRETE REPAIR INSTITUTE

SEISMIC RETROFIT OF THE LOS ANGELES COUNTY MUSEUM OF NATURAL HISTORY

BY MO EHSANI

The original T-shaped portion of the Los Angeles County Museum of Natural History that fronts the Rose Garden was designed in 1910 by the prominent Los Angeles, CA, architectural firm of Hudson & Munsell. Construction of the Spanish Renaissance-style building began on December 17, 1910, and the total cost for the building was $225,000. The central portion of the cross-shaped building is 75 x 75 ft (23 x 23 m) with a dome that is 80 ft (24.4 m) high. The east and west wings are each 54 x 110 ft (16.5 x 33.6 m) and the north wing is 54 x 125 ft (16.5 x 38.1 m). The framing consisted of steel frame and unreinforced brick walls.

Fig. 1: Original building constructed in 1913

Fig. 2: Building with scaffolding during seismic upgrade in summer 2007

Since its opening in 1913, the museum has been a major regional attraction and continues to serve 355,000 visitors annually. The museum is culturally significant because of its extensive collection; its specimens are unique in Los Angeles and are among the fourth-largest in the nation. In 2000, the Natural History Museum began considering a modernization of its exhibit space and programs. The Historic Structures Report was completed in 2001 and proposed modernization of the facility while maintaining the building's architectural and historical significance, existing conditions, and character-defining features. The renovation costs totaled nearly $12 million.

The original design of the building did not include seismic resistance provisions, and as part of the current renovation, the building had to be upgraded to meet modern seismic codes. The seismic retrofit included the addition of steel frames and stabilization of the walls and roof slab. Considering the historic nature of the building, care was taken to minimize the impact on the appearance of the structure. The retrofit of the masonry walls was achieved by drilling vertical anchors through the entire height of the walls and epoxy anchoring the vertical reinforcement at the footing level. The roof structure was retrofitted with carbon fiber-reinforced polymer (CFRP) and that aspect of the project is discussed in detail in the following sections.

SEISMIC UPGRADE OF THE ROOF SLAB WITH CFRP

The cross-shaped building is comprised of three large roof portions, each with a U-shaped sloping geometry. To bring the building to current seismic design code requirements, the roof slabs had to be strengthened to work as shear diaphragms that placed significant demand on these elements. The roof slab was unreinforced and was coated with shingles that were placed on 2 in. (50 mm) wide wood strips (tile nailers). Historical preservation required that the shingles be salvaged and reinstalled at the end after they had been cleaned and restored. The strengthening of the roof was a design-build task, with the FRP subcontractor providing the design for the roof.

The design led to the use of 24 in. (610 mm) wide bands of unidirectional carbon fabric that were to be positioned along the length of the roof slab. The plan was to remove the shingles and tile nailers and fill the small indentations that would be left behind upon removal of the nailers with a grout. Once the shingles were removed, however, it was observed that the nailers could not easily be removed; this resulted in an extremely rough surface that could not be used for direct bonding of CFRP. This aspect of the project is discussed in more detail in the following sections.

The construction team consisted of a crew of five plus a foreman. The black carbon fabric reflected the heat, so there were a number of days that the high job-site temperatures on the roof resulted in shutting down activities early. Moreover, other activities on the job site required doing each of the three sections of the roof at different times, so three separate mobilizations were necessary. Nevertheless, the project was completed well within the 2-month window that was allocated for the retrofit of the roof.

The steep 25-degree slope of the roof made it impractical to use that large area for any staging. The saturator machine was set up on the ground and the impregnated fabric was hoisted up to the roof level. Likewise, all resins were measured and mixed at the ground level and were carefully hoisted to the roof level.

SPECIAL PROJECT FEATURES AND CHALLENGES

- **Roof surface preparation**: Once the shingles and tile nailers were removed, it was found that the surface of the deck was extremely rough and weak. A number of products were tested to see if the sloping roof surface could be made smooth. Most of these products were cost-prohibitive. A special non-sagging thixotropic two-component epoxy was selected that could be troweled on the surface of the roof. Pull tests were conducted in the field to ensure that the material was suitable for developing the full strength of the system. This activity added nearly 3 weeks of additional work that was not originally planned.

Fig. 3: View of roof and shingles before seismic upgrade

Fig. 4: Smoothing the rough concrete deck

Fig. 5: Roof deck after it has been prepared for CFRP installation

Fig. 6: Installation of CFRP strips over protected steel bolts

Fig. 7: Retrofitted slab after broadcasting of sand on top of CFRP

Fig. 8: Restored shingles replaced on the roof with new skylights

- **Protection of steel bolts**: As part of the connection of the newly added steel frame, steel bolts were penetrating through the slab. Direct contact between steel and carbon may lead to galvanic corrosion of the steel. To prevent this, the threaded heads and protruding shanks of the bolts were protected during the installation and the carbon fabric was cut in a circular area around the shank. In addition, because long steel plates were going to be laced over the bolts, a 12 in. (305 mm) wide strip of glass fabric was installed along the bolt lines to prevent direct contact between the steel plate and the CFRP.
- **Meeting tight construction deadline**: The installation of the CFRP and the retrofit of the roof was on a critical path and a firm schedule had to be followed. This was further complicated by the discovery of the rough roof surface that was not anticipated. Although the roof surface prep caused an additional 3 weeks of work to fix, the project was completed well within the given time, and significant public pressure was imposed to finish the building retrofit under a tight deadline. A total of 55,000 ft^2 (5110 m^2) of fiber-reinforced polymer (FRP) fabric was installed in 11 weeks, allowing for a quick reopening of the retrofitted building.
- **Economical seismic retrofit**: FRP products have been extensively used in the retrofit of beams, columns, bridges, and buildings. This application to strengthen a diaphragm in a historic building for seismic loads, however, was unique. The overall cost of the installed project was about \$30 per ft^2 (0.9 m^2) of slab. Not only was the cost very reasonable, but this was also the only option that could maintain the historic nature of the roof without altering its original appearance.
- **Slippery slope**: Once the FRP is cured, it leaves a fairly smooth and slippery surface. Considering the steep 25-degree slope of the roof, there was concern for the safety of the workers from other crafts that would have to walk on such a smooth surface. Consequently, immediately following the installation of CFRP, a thin film of resin was applied as a top coat and sand was broadcast on top of that. Upon curing of the epoxy, this resulted in a non-slippery surface.
- **Inspection**: The project was fully inspected by a deputy inspector. His duties included monitoring and recording all the product lot numbers for the carbon fabric, the resins used on the job, and the locations where each product was used.
- **Testing**: As a measure of quality control, the crew prepared two samples of the saturated carbon fabric each day. These samples were

prepared by placing resin-impregnated pieces of the fabric between two sheets of glass and curing them for 24 hours in field ambient conditions. The deputy inspector submitted these samples to an independent testing laboratory to verify the strength of the installed products. All test results were satisfactory.

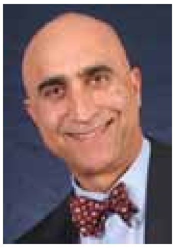
Los Angeles County Museum of Natural History Seismic Retrofit

ARCHITECT
CO Architects
Los Angeles, CA

STRUCTURAL ENGINEERS
John A. Martin and Associates
Los Angeles, CA

GENERAL CONTRACTOR
Matt Construction
Los Angeles, CA

- **Maintaining the historic appearance**: The application of thin layers of CFRP kept the overall appearance of the roof structure virtually unchanged. Upon completion of the project, the shingles that were salvaged and restored were placed on the roof, giving back the historic building its original beauty. As a result, the owner commented, "seismically upgrading and structurally improving a building listed on the National Historic Record without impacting its appearance was a tall order and without your critical work would have been virtually impossible."



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