Award of Excellence 2012

Special Projects Category

Seismic Retrofitting of Hospital Floors

Bari, Italy

Submitted by Tecnochem Italiana, S.p.A.

The Domenico Cotugno Hospital was constructed in 1930 in Bari, Italy (located in Seismic Area Class 3) and was recently renovated to be the new headquarters of the Istituto Di Ricovero e Cura a Carattere Scientifico (IRCCS) Istituto Tumori Giovanni Paolo II.

The original work items included the following:

- The creation of elevator shafts;
- The expansion of existing offices to provide prevention clinics;
- The transformation of balcony extensions into bathrooms; and
- The creation of corridors on the fourth floor to serve operating rooms and the intensive care area.

To facilitate the work, all floor-covering materials and plaster walls were removed from the building. Upon exposing the structural elements of the building, the existing structural framework could be sized and analyzed. After completing the structural analysis, the need for seismic retrofitting of the structure was recognized and a plan for seismic strengthening was developed.

SEISMIC STRENGTHENING WORK ITEMS

As a part of the seismic strengthening plan, the following work items were designed and added to the overall renovation:

- Reinforced concrete partitions with 3600 to 5400 psi (25 to 37 MPa) concrete were anchored to the inside of the building with epoxy resin. The walls were installed to limit the movements and absorb the potential horizontal forces from an earthquake;
- Membranic reinforcement of the floors was performed using fiber-reinforced micro-concrete that was bonded to the existing concrete floors. This system was designed to transfer the horizontal earthquake forces to the new partition walls;
- Neoprene-coated metal plates were installed into the existing 2.4 in. (600 mm) structural joints to minimize the "pounding effect" during a seismic event;
- Carbon-fiber reinforcement of beams and pillars was performed to improve the local ductility of those structural elements;

Exterior view of Domenico Cotugno Hospital

- Steel plates at strategic beam-pillar nodes were installed to restrict certain movements; and
- Building expansions were connected to the existing retrofitted building.

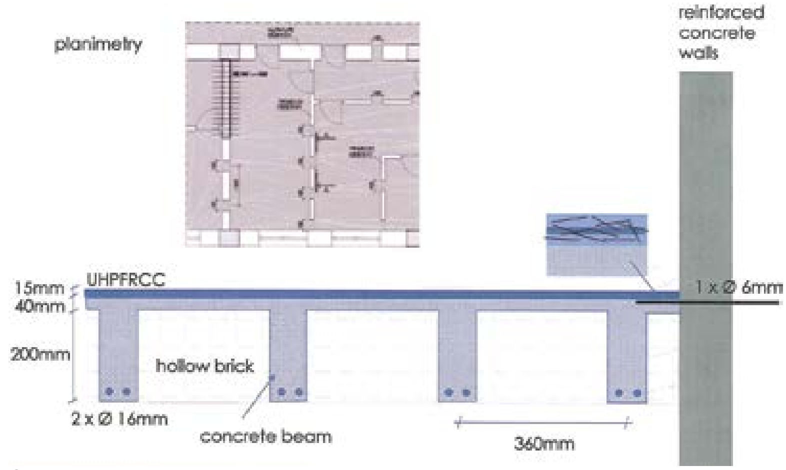
MEMBRANIC REINFORCEMENT OF FLOORS

One of the key elements of the seismic strengthening plan was membranic reinforcement of the floors using fiber-reinforced micro-concrete that is bonded to the existing concrete floors. This bond was needed to ensure that horizontal forces from an earthquake were transferred to the new partitions and existing walls. The following is a discussion of the concrete mixture used and the methods for bonding that were analyzed.

The membranic reinforcement of the floors was achieved by using specially formulated ultra-high-performance fiber-reinforced cementitious composite (UHPFRCC) micro-concrete. The UHPFRCC material was formulated to be applied in a layer on reinforced floors. While this layer was structurally designed for seismic retrofitting of the structure, it also provides an increased bearing capacity for the floors.

The membranic reinforcement system using the UHPFRCC was studied to verify the structural integrity of the system (cover slab), taking into

Scarifying existing concrete floor to prepare surface for overlay



Schematic of floor overlay (Note: 1 mm = 0.039 in.)

Workers adding fibers to overlay concrete mixture

Workers placing overlay mixture

account both the mechanical stresses and those imposed by the shrinkage of the cover slab. For the study, a numerical analysis (finite element method) was used to calculate strains, stresses, formation of cracks, and delamination of the cover slab based on nonlinear fracture mechanics.

CHARACTERISTICS OF THE UHPFRCC MIXTURE

UHPFRCC micro-concrete is a fiber-reinforced, self-consolidating mixture with very high mechanical strength and fracture energy. The mixture consists of special hydraulic binders, reactive fillers, and additives. The maximum aggregate size is 0.11 in. (2.7 mm) and the water-cement ratio (*w/c*) is 0.3. The three-component product consists of a powder component, a liquid additive, and steel and polymer microfibers (0.6 in. [15 mm] long). The product sets in about 1 hour and develops high strength in the early stages so it can be opened to foot traffic after about 14 hours.

NUMERIC ANALYSIS

Composite materials are typically considered as materials with limited ductility. Their fracture behavior is often described via models that simulate a cohesive crack. After exceeding the tensile strength when a cementitious material is loaded in pure tension, even under controlled deformation, a gradual decrease is observed in the stresses. This indicates that it forms a cohesive cracking area to be able to transfer the stresses.

To examine the stresses at the interface between the existing subfloor and the cover slab, the following analysis was performed. The mechanical model used for the numerical analysis is the dummy slot (Hillerborg, Bažant). In this analysis, the field of total strain ε is described by the sum of the elastic components ε^{el}, the deformation of the crack ε^{fes}, the viscous shrinkage ε^{vis}, and the deformation induced by hygrometric variances ε^{ri}.

$$\varepsilon = \varepsilon^{el} + \varepsilon^{fes} + \varepsilon^{vis} + \varepsilon^{ri}$$

CHARACTERISTICS OF THE UHPFRCC MIXTURE

Workability time	Approximately 1 hour
Density	0.16 lb/ft^3 (2.540 kg/m^3)
Compressive strength	18,850 psi (130 MPa)
Flexural strength	1230 psi (8.5 MPa)
Tensile strength	4640 psi (32 MPa)
Shear strength	2320 psi (16 MPa)
Young's modulus	1035 tsi (38 GPa)
Fracture energy	47,940 lb-ft (65,000 N/m)
Endogen shrinkage	Less than 0.06%
Depth of carbonation	0 in. (0 mm)
Anti-corrosion protection	Multiple corrosion inhibitors

Core of floor showing bonding of overlay to existing concrete

The deformation ε^{fes} is calculated with a bilinear function. When the stress in a point of the model exceeds the tensile strength of the material, it generates the creation of a fictitious crack. The real crack is developed only after consuming the energy of rupture of the material.

RESULTS OF THE ANALYSIS

The analysis found that the maximum tensile stresses that occur in the reinforcement cover slab are due to shrinkage. These stresses remain in the hardening zone of the material because they are lower than the tensile strength of the material (modulus of rupture). The resulting tensile stresses are induced mostly by drying shrinkage, but some are also due to the deformation of the floor that is generated by an applied load. The maximum stress is reached after about 4 weeks, after which there is a reduction of tensile stresses due to the increased incidence of creep on the endogenous shrinkage. The maximum displacement calculated with a complete load is 0.16 in. (4 mm).

Following the development of the stresses σ_{yy} at the interface of the micro-concrete and subfloor (in the zone of negative moment in contact with the beam), it was noted that those stresses remained at a lower level than those compared to σ_{xx}. It was observed that a maximum stress value of 33 psi (0.23 MPa) was reached. The adhesion of the cover slab to the subfloor was measured in the laboratory and was found to be greater than 145 psi (1 MPa), which is less than the maximum stress value, indicating that delamination is unlikely to occur.

RESULTS OF FIELD TEST

Type of connector and surface preparation	Adhesion to support tensile strength, psi (MPa)
Area with micro-concrete connector	290 (2.0)
Area without any connectors, sandblasted and power-washed	190 (1.3)
Area with metallic connector	310 (2.14)
Area without any connectors, only power-washed	210 (1.44)

FIELD TEST

For the field test, an area 6.6 x 6.6 ft (2 x 2 m) on the first floor of the Domenico Cotugno Hospital was used. Fifty percent of the substrate surface was prepared by sandblasting and the remainder was power-washed with water. To structurally bond the micro-concrete cover slab to the substrate, two systems of connectors were tested. The first used self-expanding metal connectors, while the second involved holes in the slab that were filled with the same micro-concrete as used for the cover slab.

ADVANTAGES OF MEMBRANIC REINFORCEMENT SYSTEM

- Minimal application thickness (0.6 to 0.8 in. [15 to 20 mm]) applies minimal load;
- Adhesion to the substrate without necessity for connectors or resins;
- No reinforcement mesh required;
- Very high ductility and resistance to cyclic loads;
- Increased bearing capacity in terms of bending moment and stiffness, and reduction of floor deflection;
- Speed of application because of self-leveling material properties; and
- No construction and shrinkage joints.

FINAL CONSIDERATIONS

The values obtained confirm that the use of connectors with the UHPFRCC is able to increase the anchorage of the cover slab to the substrate. Numerical analysis shows that the membranic reinforcing material is able to absorb all the stresses imposed without degrading. With the values of adhesion measured, the membranic reinforcing system should remain structurally functional throughout the operating life of the structure.

Domenico Cotugno Hospital

OWNER
ASL BA
Bari, Italy

PROJECT ENGINEER/DESIGNER
IRCCS Istituto Tumori Giovanni Paolo II
Bari, Italy

SGM Ingegneria SRL
Barletta, Italy

REPAIR CONTRACTOR
Salvatore Matarrese S.p.A.
Bari, Italy

MATERIAL SUPPLIER/MANUFACTURER
Tecnochem Italiana S.p.A.
Bergamo, Italy