HISTORIC INFRASTRUCTURE REHABILITATION WITH FABRIC REINFORCED CEMENTITIOUS MATRIX (FRCM) COMPOSITES

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INTRODUCTION

Tourism in Cuba is expected to grow exponentially now that the United States government has eased some of the travel restrictions to that country. Suddenly, Cuba is one of the hottest destinations on the planet (ABC News, 2016). Two of the main tourist draws are the vintage cars and the diverse historical architecture, both captured like in a time capsule, practically frozen in time since the Cuban revolution over 50 years ago. Cuba—and especially Havana—is a treasure trove of architectural styles spanning six centuries. With buildings dating from the 16th through the 19th centuries, Havana is one of the most authentic colonial cities in the Americas (Havana Architecture, 2016). Its architectural diversity includes the Colonial & Baroque period (16-17th century), Neo-classical period (18-19th century), Art Nouveau, Art Deco & Eclectic influences (20th century), as well as modernist, revolutionary, and contemporary styles. Slowly over time, however, the beauty and grandeur of Cuba faded away as Havana's historic buildings began to decay and deteriorate due to lack of maintenance, lack of funds, an aggressive climate and non-existent governmental programs to preserve Cuba's architectural heritage (Thirdeyemom, 2016).

The positive impact that the influx of tourists will have on the Cuban economy is clear, but so is the tremendous strain on Cuba's aging infrastructure which is already in distress. In addition to new construction to satisfy the increased demand, rehabilitation of current structures, especially historical ones, is imperative.

CHALLENGES BEING ADDRESSED

Improving structures related to tourism and transportation infrastructure are key priorities for the Cuban government (Green, 2016). The state of disrepair of the architectural heritage as well as of the transportation infrastructure (roads, bridges, airports, ports, railroads) is always in focus when discussions of investment and tourism in Cuba take place. Along with others, the City of Havana, designated World Heritage Site by UNESCO, is currently in very poor shape, with crumbling infrastructure, inadequate roads, and crumbling façades (Patel, 2015). Much of Old Havana's built fabric is in disrepair due to decay, chronic neglect and the natural elements (UNESCO, 1982).

Most roadways, highways and streets are in dire need of safety improvements such as pavement restoration, including fixing pot holes, along with resurfacing to increase the life, rideability, and overall structural performance (Alfonso and Penin, 2009). Inefficient maintenance, advanced corrosion, and seismic vulnerability of bridges in Cuba make them a priority for repair and restoration (Subiaut, 2012, Sánchez et al., 2012).

STRUCTURAL REHABILITATION

Traditional techniques for rehabilitation of damaged or deteriorated structures include external application of fiber-reinforced polymers (FRP), steel plate bonding, section enlargement, and external post-tensioning. These methods are already known and used in Cuba. The country has a strong background in engineering education and training, due in part to several university institutions (Alfonso and Penin, 2009). One of the most commonly used external repair/strengthening method is the use of FRP, which consists of applying a "skin" on the damaged structural element. This "skin" is defined as a structural fabric applied with a polymer (Figures 1 and 2); it has numerous advantages such as compatibility with the substrate, protective of the substrate, lightweight, durable, and does not require formwork.

Figure 1. Typical FRP application

Figure 2. Examples of strengthening of historical and modern masonry with FRP

The FRP solution, however, also has some disadvantages such as no inherent fire protection, not suitable for historical restoration (if removal were to be necessary or if vapor permeability were to be required), intense substrate preparation, poor behavior of epoxy resins at temperatures above the glass transition temperature, inability to apply on wet surfaces or at low temperatures, and some concern that epoxy resins could be a toxic hazard to the installer. Additionally there is a required level of skill needed to ensure proper installation of such technologies.

An alternative to FRP involves replacing the polymeric matrix with a cementitious matrix such as ferrocement, textile reinforced mortar (TRM), and fabric reinforced cementitious matrix (FRCM) composites which are also external repair systems. Ferrocement, already well known and used in Cuba, consists of a metal mesh embedded in mortar/paste. These systems offer the same advantages as FRP plus fire protection, suitability for historical restoration, ease of substrate preparation, compatible permeability with the substrate, and an inorganic, non-toxic matrix.

FRCM SYSTEM

A new class of composite materials, FRCM is considered as the natural evolution of ferrocement where the steel mesh reinforcement, which is vulnerable to corrosion, is replaced with man-made and natural materials such as carbon, basalt, polyparaphenylene benzobisoxazole (PBO), hemp, flax, bamboo, or glass fiber fabrics (Figure 3).

The possibility of using thin-section cementitious products as repair materials for concrete and masonry structures makes them ideal for historic restoration. FRCM is a system where all constituents are developed and tested as a unique combination and should not be created by randomly selecting and mixing products available in the marketplace. FRCM can be

Figure 3. FRCM reinforcement fabric examples. Left: carbon fabric, right: PBO fabric

Figure 4. Application of FRCM on a masonry wall

applied to substrate surfaces subjected to moisture vapor transmission. The transmission of moisture vapor from a substrate surface does not typically compromise the bond between the FRCM and substrate.

Typical FRCM installation involves first a simple preparation of the substrate that involves removal of previous damage and cleaning to eliminate debris. Then, a thin layer of the mortar (cementitious matrix) is applied to the surface of the structural member to be strengthened manually with a trowel as in Figure 4 (left), then the fabric is applied with the primary fabric orientation in the direction of the load as in Figure 4 (center), and a finishing layer of the mortar is applied to the last fabric layer, completing the composite as in Figure 4 (right). The FRCM composite hardens within a few hours and achieves full strength at 28 days.

Installation of FRCM is simple and can be performed by construction workers after minimal training.

FRCM APPLICATIONS

Numerous commercial projects in Europe and the United States have already demonstrated the potential for FRCM composite applications (Nanni 2012) for infrastructure strengthening. In Figure 5, a worker installs FRCM onto the soffit of an unreinforced concrete vault, then advances rolls of the fabric network. Then a second fabric layer is installed over the first layer. Figure 6 shows how rolls of the fabric network hang from the vault as the scaffolding is advanced (Nanni, 2012).

Figure 5. Repair of unreinforced concrete vault

Source: Nanni, 2012

Figure 6. Rolls of fabric hang while scaffolding is advanced.

Source: Nanni, 2012

Figure 7 shows a structural steel trestle supported by numerous trapezoidal concrete pedestals in need of repair and in Figure 8, workers apply PBO fabric over a layer of the cementitious mortar matrix that had already been applied to one of the pedestals (Nanni, 2012).

Figure 7. Structural steel trestle supported by trapezoidal concrete pedestals

Source: Nanni, 2012

PROVISIONS FOR FRCM

In the United States, new materials such as FRCM can be accepted as code compliant by the International Building Code (IBC), by means of supporting evidence in the form of valid research reports demonstrating compliance to published acceptance criteria, performed by accredited laboratories. A criterion for evaluation and characterization of passive FRCM composite systems used to strengthen existing masonry and concrete structures was developed and recently published by the International Code Council Evaluation Service (ICC-ES) in conjunction with academia. The ICC-ES document is titled: AC434, "Acceptance Criteria for Masonry and Concrete Strengthening Using Fabric-Reinforced Cementitious Matrix (FRCM) and Steel Reinforced Grout (SRG) Composite Systems", and it establishes the guidelines for tests and calculations in order to receive an Evaluation (Research) Report (ESR) from ICC-ES. The research report is then used to demonstrate code compliance with any of the I-Codes. FRCM properties evaluated include axial, flexural and shear capacities of the FRCM system; performance of the FRCM system under environmental exposures; performance under exposure to fire conditions; and structural design procedures.

Figure 8. Application of PBO fabric over the cementitious matrix

Source: Nanni, 2012

Furthermore, the American Concrete Institute published ACI 549.4R-13, "Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening Concrete and Masonry Structures." This guide provides background information, field applications, FRCM material properties, capacities of the FRCM-strengthened structures (axial, flexural, and shear), and structural design procedures. ACI 549 is harmonized with AC434 and uses its protocols for FRCM characterization

CONCLUSION

Cuba's tourism will increase exponentially as a result of normalization of relations with the US. While Cuban authorities and the private sector are already addressing new construction and repair of the inadequate and aging infrastructure and architectural heritage, this paper presented the state of FRCM composite systems as a reliable and adequate solution for historical rehabilitation. FRCM as a repair technology can greatly benefit the restoration of Cuban historical treasures and infrastructure and positively impact the Cuban economy.

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