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Durability based design of FRP jackets for seismic retrofit

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Abstract

Although FRP composites are increasingly being used for the rehabilitation of civil infrastructure, there is still a lack of well documented long-term durability data, and of design methodologies that explicitly consider effects of deterioration over time at a structural level. This paper provides results of an investigation aimed at assessing the effect of deterioration over time, at the materials level, on the effectiveness of FRP jackets used for seismic retrofit. Three different systems are investigated and results of accelerated testing are used to provide predictive equations for long-term performance of the material, which are then used to analyze effectiveness at the level of seismic retrofit through four specific cases. The effect of deterioration is expressed, for ease in comparison, to an increase in the required thickness of the jacket with expected service-life. Results using unexposed values for materials performance are compared to those obtained using the values recommended by ACI-440 procedures, as well as through the use of time-dependent materials degradation models. It is shown that the ACI recommendations for durability may be excessively conservative for the 50-year period considered herein. The use of the proposed predictive methodology for materials durability combined with the analytical tools for design of FRP jacket thickness are shown to not only enable a better assessment of required jacket thickness but can also enable assessment of the dominant mechanism controlling selection of thickness which can change with time of exposure. Results of the accelerated tests are also linked to field exposure results providing a set of correlation factors.

Keywords: Fiber reinforced polymer (FRP); Seismic retrofit; Concrete column; Jacket thickness; Durability; Accelerated testing; Design

1. Introduction

Concrete columns that need to be retrofit are commonly deficient in flexural ductility, shear strength, bar buckling restraint, and/or lap splice clamping. The use of jackets around existing deficient columns induces lateral confining stresses in the concrete as it expands laterally as a function of the high axial compressive strains, or in the tension zone as a function of dilation of lap splices, or through the development of diagonal shear cracks. Jacketing has been effected through the application of steel shells, additional reinforced concrete, and the wrapping of fiber reinforced polymer (FRP) composites around the deficient column. While all three methods provide the required retrofit efficiency FRP composites offer significant advantages as related to speed of application, substantially less disruption of traffic, reduced weight, insignificant change to dimensions and the overall configuration, potentially lower life-cycle maintenance, and directional anisotropy. Since the efficacy of the jacket is dependent on hoop confinement FRP composites offer tremendous tailorability since they can be designed to have fibers oriented primarily in the hoop direction to provide constraint without substantially increasing stiffness over the height of the column.

The effectiveness of FRP jacketing has been extensively validated through large and full-scale laboratory tests [1–3], field applications [4] and in situ field tests and assessment [5,6]. In addition significant research has been conducted in developing an understanding of the mechanisms of interaction between the FRP jacket and the concrete and the overall retrofit response. To date advances have also been made in the development of design guidelines and specifications including for construction [7–10]. While the structural effec-

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tiveness of FRP jackets has been widely accepted by the community there is still some reservation regarding its use due to concerns related to cost and long-term durability in field environments.

In recent years, durability of FRP jacketing materials has been assessed through laboratory tests [11–14] and limited field tests [15] and a detailed set of evaluation criteria and durability test protocols have been established by the Civil Engineering Research Foundation under the aegis of the Federal Highway Administration [16]. This research has, however, largely been at the level of materials deterioration and has not been linked to the design, or assessment of deterioration, at the structural level. This link is crucial both for purposes of safe design and to assess life of jacket systems. If deterioration rates for a specific FRP composite were known jackets could be designed with an appropriate safety factor, accomplished through use of "sacrificial" thickness, to ensure their reliability over expected periods of field use. This paper reports on the results of an investigation aimed at providing a means for this as well as a basis for the future development of reliability based design tools that incorporate materials deterioration.

2. Materials systems and test methods

Three different systems, representative of commercially available products that have been used extensively in the field were investigated. System A is representative of the prefabricated class wherein a hollow circular cross-sectional shell is first fabricated under carefully controlled factory conditions, including elevated temperature cure over an extended period of time. This cylinder is then slit down the length to create an opening and after the addition of adhesive to the inner surface is pulled over a column. Subsequent layers are added with the position of the slit being staggered to enable good overlap with the overall configuration being akin to that of an onionskin. Bonding is achieved under ambient conditions with external pressure applied by separate circumferential straps tightened manually and removed after a period of time. Systems B and C are representative of the extensively used wet layup process wherein fabric is impregnated with an appropriate resin system in the field, then wrapped around the column and cured under ambient conditions. The primary difference between these systems was that system B used Aramid tows in the transverse direction whereas system C was completely constituted of E-glass fibers. The volume fraction of transverse direction fibers in both cases was extremely small with the fibers essentially serving to hold the warp direction fibers in place. All three systems considered in this investigation were primarily of unidirectional orientation with the reinforcing fibers being of E-glass.

Following earlier investigations on the development of an appropriate test method that would capture materials, manufacturing and structural aspects in a single coupon [15,16] the ring burst test was used in this investigation. The 510 mm (20 in. internal diameter) rings allowed the stressing of the material in a fashion closely simulating the actual structural system during dilation of concrete during a seismic event. Following procedures detailed by Reynaud et al. [16], as part of the HITEC specifications, specimens were fabricated by manufacturers as in the field, in the form of blanks of 178 mm (7 in.) height, to enable the system to be exposed to environmental conditions in the jacket, rather than ring, configuration. All blanks were coated in the same manner as would be applied in the field to provide protection against environmental exposure and all edges were sealed using the same coating. Specimens were immersed in water at 15 °C, 23 °C, 40 °C and 60 °C for extended periods of time to enable use of time–temperature superposition principles for prediction of long-term durability. Baseline specimens were also stored under controlled conditions of 23 °C and 55 relative humidity (RH).

Once exposures were completed, four rings each of 25.4 mm (1 in.) height were cut from the central portion of each blank (Fig. 1) with a fifth ring being also cut from the same section for specimens to be tested in short-beam shear (SBS) using specimens of nominal span-to-depth ratio of 5:1, assessment of glass transition temperature (T_g), moisture content, and microscopic investigations. A set of five samples was tested in each of these cases. In order to provide ease of comparison and to reduce uncertainty due to operator judgment the glass transition temperature was determined from the peak of the tan δ

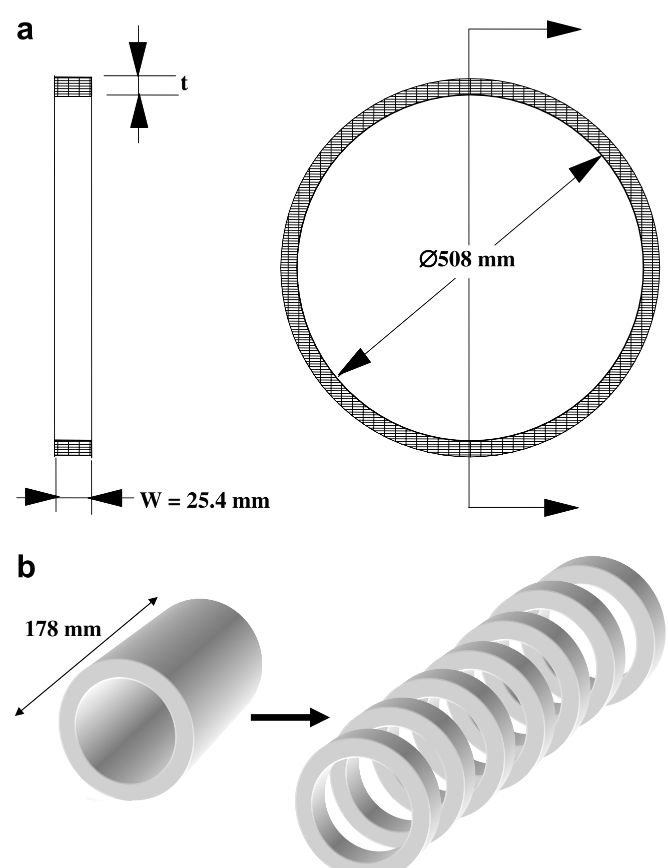

Fig. 1. Details of test specimens: (a) dimensions of NOL-ring test unit; (b) schematic of test blank and ring specimens obtained from a blank.