Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars

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Fiber-reinforced polymer (FRP) materials have emerged as an alternative material for producing reinforcing bars for concrete structures. FRP reinforcing bars offer advantages over steel reinforcement in that FRP bars are noncorrosive, and some FRP bars are nonconductive. Due to other differences in the physical and mechanical behavior of FRP materials versus steel, unique guidance on the engineering and construction of concrete structures reinforced with FRP bars is needed. Other countries, such as Japan and Canada, have established design and construction guidelines specifically for the use of FRP bars as concrete reinforcement. This guide offers general information on the history and use of FRP reinforcement, a description of the unique material properties of FRP, and guidelines for the construction and design of structural concrete members reinforced with FRP bars. This guide is based on the knowledge gained from worldwide experimental research, analytical work, and field applications of FRP reinforcement.

keywords: aramid fibers; carbon fibers; development length; fiber-reinforced polymers; flexure; glass fibers; moment; reinforcement; shear; slab; strength.

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CHAPTER 1—INTRODUCTION

This is the third revision of the design and construction guide on fiber-reinforced polymer (FRP) reinforcement for concrete structures. Many successful applications worldwide using FRP composite reinforcing bars during the past decade have demonstrated that it can be used successfully and practically. The professional using this technology should exercise judgment as to the appropriate application of FRP reinforcement and be aware of its limitations as discussed in this guide. Currently, areas where there is limited knowledge of the performance of FRP reinforcement include fire resistance, durability in outdoor or severe exposure conditions, bond fatigue, and bond lengths for lap splices. Further research is needed to provide additional information in these areas.

Conventional concrete structures are reinforced with nonprestressed and prestressed steel. The steel is initially protected against corrosion by the alkalinity of the concrete, usually resulting in durable and serviceable construction. For many structures subjected to aggressive environments, such as marine structures, bridges, and parking garages exposed to deicing salts, combinations of moisture, temperature, and chlorides reduce the alkalinity of the concrete and result in the corrosion of reinforcing steel. The corrosion process ultimately causes concrete deterioration and loss of serviceability. To address corrosion problems, professionals have started using alternatives to bare steel bars, such as epoxy-coated steel bars and specialty concrete admixtures. While effective in some situations, such remedies may not be able to completely eliminate the problems of steel corrosion in reinforced concrete structures (Keesler and Powers 1988).

Recently, composite materials made of fibers embedded in a polymeric resin, also known as FRPs, have become an alternative to steel reinforcement for concrete structures. Because FRP materials are nonmagnetic and noncorrosive, the problems of electromagnetic interference and steel corrosion can be avoided with FRP reinforcement. Additionally, FRP materials exhibit several properties, such as high tensile strength, that make them suitable for use as structural reinforcement (ACI 440R; Benmokrane and Rahman 1998; Burgoyne 2001; Cosenza et al. 2001; Dolan et al. 1999; El-Badry 1996; Figueiras et al. 2001; Humar and Razaqpur 2000; Iyer and Sen 1991; Japan Society of Civil Engineers [JSCE] 1992; JSCE 1997a; Nanni 1993a; Nanni and Dolan 1993; Neale and Labossiere 1992; Saadatmanesh and Ehsani 1998; Taerwe 1995; Teng 2001; White 1992).

The mechanical behavior of FRP reinforcement differs from the behavior of conventional steel reinforcement. Accordingly, a change in the traditional design philosophy of concrete structures is needed for FRP reinforcement. FRP materials are anisotropic and are characterized by high tensile strength only in the direction of the reinforcing fibers. This anisotropic behavior affects the shear strength and dowel action of FRP bars as well as the bond performance. Furthermore, FRP materials do not yield; rather, they are elastic until failure. Design procedures must account for a lack of ductility in structural concrete members reinforced with FRP bars.

Other countries, such as Japan (JSCE 1997b) and Canada (Canadian Standards Association [CSA] 2000 and 2002), have established design procedures specifically for the use of FRP reinforcement for concrete structures. The analytical and experimental phases for FRP construction are sufficiently complete; therefore, this document establishes recommendations for the design of structural concrete reinforced with FRP bars.