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# Probabilistic evaluation of the design development length of a GFRP rod pull-out from concrete

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ABSTRACT

With an additional target reliability index of 1.098, the Rackwitz–Fiessler method was used to evaluate the coefficients associated with the design development length of a GFRP rod in concrete in the case of pull-out bond failures. As a result of the evaluation, the coefficients are proposed to be 0.0816 and 0.0933 for ordinary and aggressive exposures, respectively. The coefficient of variation of GFRP strength could exert the most significant influence on averaged coefficients. The effects of diameter and GFRP average strength greater than 750 MPa are found to be negligible. A linear relationship between the averaged coefficient and additional target reliability could be employed for developing a performance-based bond design methodology. With the combination of flexural analysis, the proposed relationship between the averaged coefficient and the so-called strength utilization factor could be applied to for the determination of a customized design development length of a GFRP rod in concrete.

## 1. Introduction

As one kind of advanced reinforcing materials widely used in civil infrastructures, fiber reinforced polymer (FRP) rods have been regarded as a good solution to durability problems associated with conventional steel-reinforced concrete structures under some aggressive environmental conditions [1]. During the manufacturing process of FRP rods, continuous fibers are pultruded continuously through a resin impregnation bath and then through a shaping die where the resin is subsequently cured in the intended shape [2]. There are three types of FRP rods commercially available, i.e. carbon fiber reinforced polymer (CFRP) rod, glass fiber reinforced polymer (GFRP) rod and aramid fiber reinforced polymer (AFRP) rod.

Bond of FRP rods with concrete is a crucial element in designing their reinforced concrete components. Insufficient bond resistance would lead to premature failures. Design with inadequate development length could result in a substantial drop in flexural capacity, shear resistance and deformability of FRP-reinforced components [2]. Like steel reinforcing bars, the bond actions between an FRP rod and surrounding concrete are also transferred by three mechanisms, i.e. chemical adhesion, mechanical friction and aggregate interlock (only for deformed FRP rods) [3]. There are various factors affecting the bond behavior of an FRP rod with concrete. The major ones are the properties of the reinforcement fibers, the matrix resin, and their interfacial adhesion [4]. FRP rods are typically anisotropic materials whose mechanical and physical properties differ greatly from those of isotropic steel reinforcing bars. Reinforcement fibers usually dominate the longitudinal behavior of FRP rods. All the fibers have extremely high tensile strength in their longitudinal direction, generally greater than 3000 MPa. The PAN-based carbon fiber has the highest tensile modulus of elasticity (>200 GPa) among all the fibers [5]. Polyester resin, vinyl ester resin and epoxy resin are commonly used as matrix resins in commercial FRP rods. The tensile strengths of those resins approximately range from 34.5 to 130.0 MPa, much lower than those of steel reinforcing bars [5,6]. The tensile moduli of elasticity of those resins vary only between 2.10 and 4.10 GPa [5]. In an FRP rod, bond force is usually assumed to be transferred through the resin to the fibers. The interface interaction between the resin and fibers make the stresses caused by external loads redistribute within the FRP rod [3]. The weakest link along this stress transferring path is located either in the resin or in the interface between the resin and fibers. For those fibers with lower elasticity modulus, e.g. glass fiber, the interface bond resistance between the fibers and the resin is usually determined by the strength of the resin. However, those fibers with

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