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Report on Design and Construction of Fiber- Reinforced Precast Concrete Tunnel Segments

Reported by ACI Committee 544

Emerging Technology Series



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Report on Design and Construction of Fiber-Reinforced Precast Concrete Tunnel Segments

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

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Reported by ACI Committee 544

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James I. Daniel
Sidney Freedman
Christian Meyer
Henry J. Molloy‡
Antoine E. Naaman
Venkataswamy Ramakrishnan

*Chair of the task group that prepared this report.

†Individuals who prepared this report.
‡Deceased.

V. Nasri is acknowledged as a significant contributor to this report. Special acknowledgements to M. Invernizzi, W. Bergeson, and S. Giuliani-Leonardi for their contributions to this report.

Consulting Members

P.N. Balaguru
Hiram Price Ball Jr.
Gordon B. Batson
Arnon Bentur
Andrzej M. Brandt

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Fiber reinforcement has emerged as an alternative to traditional reinforcing bars and welded wire mesh reinforcement for precast concrete tunnel segments. Due to significantly improved post-cracking behavior and crack control characteristics, fiber-reinforced concrete (FRC) segments offer advantages over tradition-

ally reinforced concrete segments such as saving cost and reducing production time while developing a more robust product with improved handling and long-term durability. Specific guidance on the design of fiber-reinforced precast concrete tunnel segments is needed for this emerging technology. This document offers general information on the history of FRC precast segments from tunneling projects throughout the world; a procedure for structural analysis and design based on governing load cases; and a description of the material parameters, tests, and analyses required to complete the design. The proposed guidelines are based on the knowledge gained from experimental research, analytical work, and the experience gained on numerous FRC precast tunnel projects.

Keywords: crack widths; earth pressure; fibers; fiber-reinforced concrete; grout pressure; hydrostatic pressure; lining; precast segment; stripping; surcharge load; thrust jack forces; tunnel.

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Precast concrete segments are installed to support the tunnel bore behind the tunnel-boring machine (TBM) in soft ground and weak rock applications. The TBM advances by reacting against the completed rings of precast concrete segments that typically provide both the initial and final ground support as part of a one-pass liner system. These segments are typically designed to resist the permanent loads from the ground and groundwater, as well as the temporary loads from production, transportation, and construction. Tunnel segments are generally reinforced to resist the tensile stresses at both the serviceability limit state (SLS) and the ultimate limit states (ULS). With traditional reinforcing bar, a significant amount of labor is needed to assemble the cages and place the reinforcing bar.

Fiber-reinforced concrete (FRC) can be used to enhance handling and placement of precast concrete segments with the added benefit of reducing job-site labor requirements. FRC considerably improves the post-cracking behavior, defined as toughness (di Prisco et al. 2009), and it has better crack control characteristics than conventional steel-bar-reinforced concrete (Minelli et al. 2011; Tiberti et al. 2014). The use of FRC generally results in smaller crack widths and improved durability over the life of the structure. Because of the uniform dispersion of fibers throughout the segment, including the area around the segment face, fiber reinforcement effectively resists the bursting and spalling stresses that develop during the TBM jacking process. de Waal (1999) and Schnütgen (2003) highlight the beneficial effect of FRC in the presence of concentrated loads and bursting. Furthermore, the presence of fiber in the concrete matrix increases the fatigue and impact resistance of the segments that help mitigate against unintentional impact loads during segment handling and tunnel construction operations (di Prisco and Felicetti 2004).

Reinforcing bar is efficient for resisting localized stresses in the concrete segment such as stresses due to concentrated loads during production. The distributed stresses such as stresses due to earth pressure and groundwater loads at final service stage, however, are better dealt with by fiber reinforcement. Because both localized and distributed stresses are generally present in tunnel linings, segments can be manufactured using a combination of conventional reinforcing bar and fiber reinforcement—that is, a hybrid system. For larger-diameter tunnels with high internal forces, a combined solution of fibers and reinforcing bar may present an ideal solution (Plizzari and Tiberti 2006, 2007; de la Fuente et al. 2012). Using current technology with high-strength concrete segments, tunnel rings of more than 23 ft (7 m) in diameter have been used successfully (Abbas et al. 2014). Examples include Grosvenor Coal Mine, Channel Tunnel Rail Link Tunnel, and Blue Plains Tunnel with internal diameters of 23, 23.5, and 23 ft (7, 7.15, and 7 m), respectively.

The slenderness of the tunnel segment (λ), defined as the ratio between the breadth or curved length of segment along