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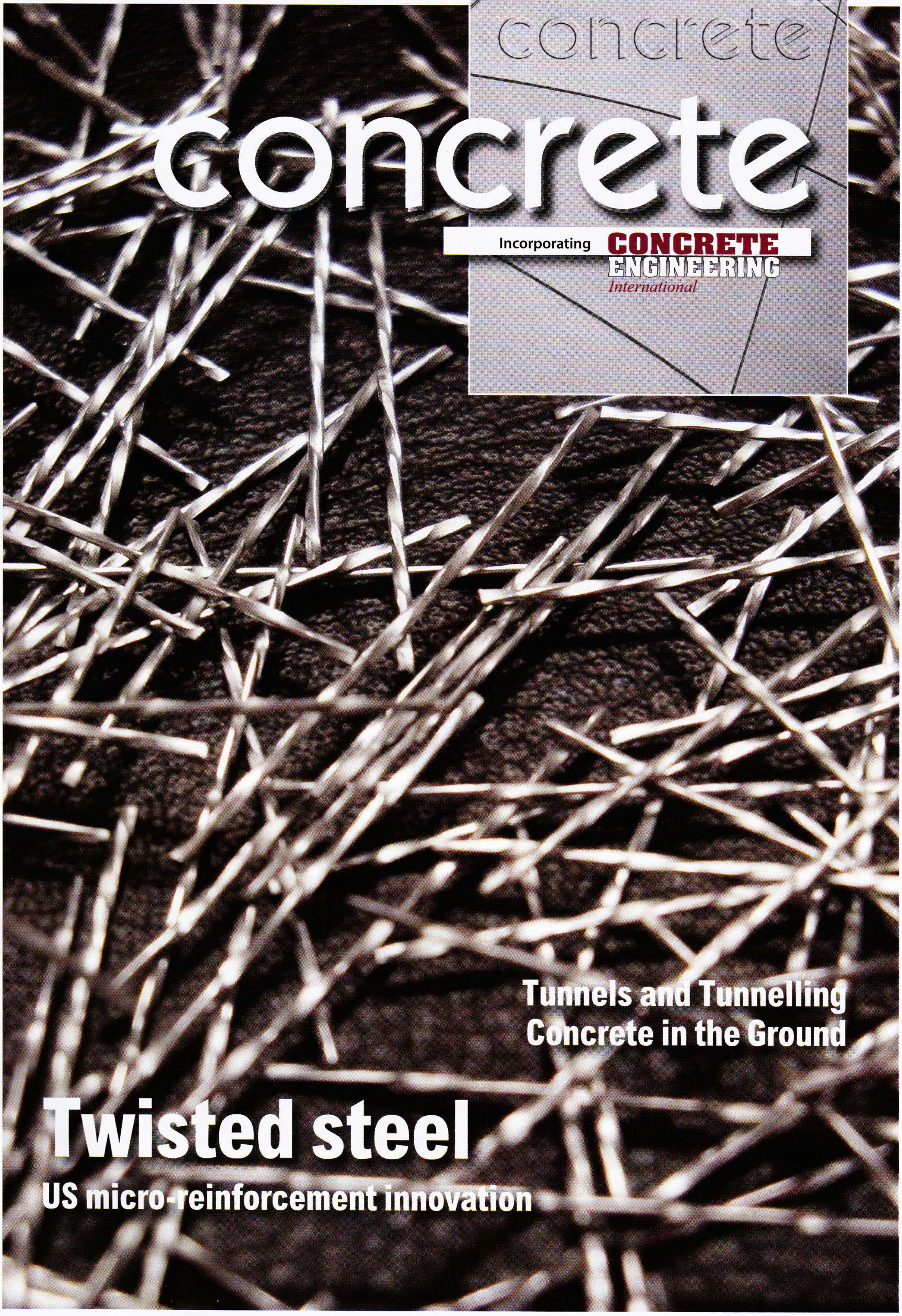

Tunnels and Tunnelling
Concrete in the Ground

Twisted steel

US micro-reinforcement innovation

Figure 1: HELIX twisted steel micro-reinforcement elements.

Twisted steel micro-reinforcement – advantages of microscopic composites

This article provides a description of the fracture mechanisms of micro-reinforced concrete composite, a novel method to measure performance characteristics of the composite and the ISO Guide 65[1]/IAF-accredited HELIX micro-reinforcement design method for structural concrete.

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Reinforced concrete can be described as a 'macroscopic' composite made of a concrete matrix and steel bar reinforcement. As the bars are large and widely distributed, they effectively carry load only after the concrete develops a macro-crack (dominant crack). Therefore, conventional reinforcing bars are reactive reinforcement.

A 'microscopic' composite can be created by combining concrete with HELIX twisted steel micro-reinforcement (herein referred to as micro-reinforcement). As this type of reinforcement is distributed throughout the matrix and is continuously deformed like reinforcing bars, it carries load both before and after the concrete develops a macro-crack. Thus, micro-reinforcement is proactive reinforcement that also acts as reactive reinforcement at higher strain levels.

Functional mechanisms

HELIX micro-reinforcement is produced with a unique twisted profile (Figure 1), allowing each piece to bond to the matrix over its full length. In addition, the reinforcement must untwist as it pulls out of the concrete, making this product significantly different from traditional steel fibres because pull-out is governed by twisting resistance rather than friction. The twisted shape engages the concrete even before the formation of a visible crack (Figure 2). Tests show that the tensile strain at the formation of the first visible crack increases with the addition of HELIX. After the formation of the crack the tensile stress remains constant as untwisting begins.

Performance characterisation

Tensile resistance is the primary engineering parameter needed for design with micro-reinforced concrete. While beam tests have been the traditional way to evaluate fibre-reinforced concrete, stresses must be calculated using the section properties for the uncracked section. As the fibre stresses vary over the depth of the specimen (both before and after cracking), the flexural test doesn't adequately measure the performance of micro-reinforced concrete[2]. We therefore apply direct tension tests to evaluate micro-reinforced concrete, using a load frame and a cylindrical tensile test specimen as shown in Figure 3.

The test set-up and instrumentation are capable of measuring strain before and after the formation of a dominant crack. The data collected in the direct tension test is a load deflection plot similar to Figure 2. After fracture, the number of micro-reinforcements crossing the failure plane is counted, and the load determined. The results of this test are not related to a particular dosage rate; only the load per micro-reinforcement element.

Since the mould for the tension specimens affects the quantity of micro-reinforcement crossing the failure surface, a separate test is used to link a dosage rate of micro-reinforcement to the number of pieces per square metre of fracture area in a more generic section.

Using mixtures with a range of micro-reinforcement dosages, we develop relationships for total tension load as a function of the compressive strength of the concrete and the number of micro-reinforcement elements crossing the dominant crack surface. Figure 4 shows the tensile force as a function of elements crossing the fracture surface. The LRFD method (load and resistance factor design) is used to derive limit state equations and resistance factors used in design from these data[3].

Design

While micro-reinforcement offers unique advantages due to its ability to provide proactive response, it is designed using the same cracked section assumptions as standard reactive reinforcement.

Micro-reinforcement design is accomplished with three simple steps:

- selection of the micro-reinforcement design class
- determination of the required number of micro-reinforcement elements
- calculation of micro-reinforcement dosage per unit volume of concrete.

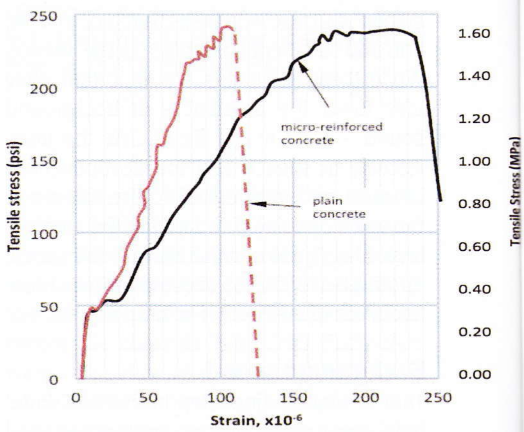

Figure 2: Phases I and II for plain and micro-reinforced concrete (1psi = 0.007MPa).

The micro-reinforcement contribution to the tensile behaviour of the concrete (characterised by the previously described testing) is applied as a rectangular stress block in the tensile zone of the concrete section. The first step requires that the engineer use standard design equations to compute the nominal area of steel required at the centroid of the tensile region.

The classes for micro-reinforcement design are based on the support and

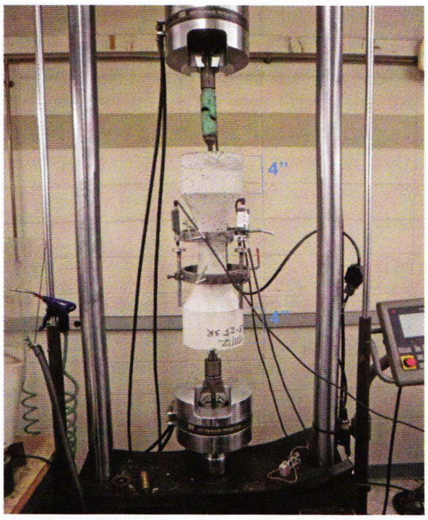

Figure 3: Direct tension test specimen mounted in a load frame. Load is applied to adhesive anchors embedded in the grip zones of the specimen, centred on the axis of the specimen. The strain gauge comprises four linear variable differential transformers in spring-actuated precision gauge heads. Tests are conducted in accordance with ASTM E111[6].

geometric conditions of the application. Soil-supported structures, requiring only temperature and shrinkage reinforcement, are Class A applications. Structural concrete that is soil supported, carries load as an arch, or is in a vertical component with closely spaced lateral supports, is considered a Class B application. All other structural applications, including suspended concrete floors, are Class C applications. Class C applications may require reinforcing bars in addition to the micro-reinforcement to provide load redistribution capacity.

Once the design class is known, the number of micro-reinforcement elements required to resist the tensile load (much the same way as one determines the quantity of reinforcing bars required in a section) is calculated. To simplify the design process, the required micro-reinforcement quantities have been tabulated based on the data obtained from direct tension testing (Table 1). The required micro-reinforcement dosage (kg/m^3) is calculated based on the cross-sectional area loaded in tension.

Finally, it is important to note that restrictions are imposed to minimise the risk of catastrophic failure. If the structure is not soil supported (slabs, foundations), in compression (arch geometry) or a laterally supported wall at each floor, a hybrid system (both Helix and reinforcing bars) is required.

Conclusion

The design method for HELIX twisted steel micro-reinforcement has undergone third party testing and validation. The method's compliance with the International Building Code is accredited by Uniform Evaluation Service[4] per ISO Guide 65. The accreditation is recognised by treaty in 99 countries and the European Union due to the MLA/MRA agreements in place under the International Accreditation Forum. This gives engineers assurance that the product meets the performance-based alternative allowances of their respective Codes (EN 1990 Section 1.4.5[5]).

Since 2003, when HELIX micro-reinforcement came to market, it has been used on various concrete projects including structural foundations, structural footings, slabs, walls, pavements/toppings, bridges, precast applications, tornado/hurricane- and blast-resistant structures. One recently completed project is the Pier 57 Ferris wheel in Seattle, Washington, USA (Figure 5). ■

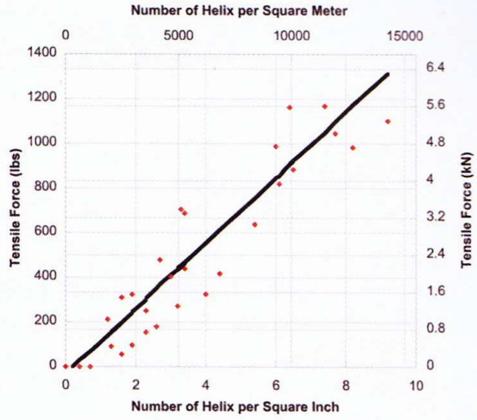

Figure 4: Example best-fit relationship for tensile force (at a strain of 1000 micro-strain) as a function of micro-reinforcement crossing the fracture surface at angles of 30° or more. This example is for concrete mixtures with 4000psi (27.6MPa) compressive strength.

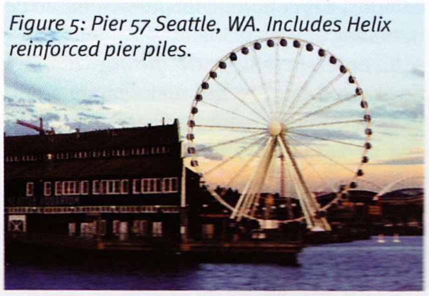

Figure 5: Pier 57 Seattle, WA. Includes Helix reinforced pier piles.

Table 1a – Helix micro reinforcement replacement - Metric

fy = 500Mpa	Nominal number of Helicon Micro Rebars required			
Nominal area of steel in tension As (mm^2/m)	20 MPa		30 MPa	
	Class A & B	Class C & Cs	Class A & B	Class C & Cs
Cells above omitted				
250	616.8	1233.6	616.0	1232.0
290	715.3	1430.6	714.5	1429.0
300	739.9	1479.8	739.1	1478.36
314	774.4	1548.8	773.6	1547.2

Table 1b – Helix micro rebar dosage rate - Metric

Number of Helix per unit area in tension (Helix / m^2)	Helix dosage rate, Φ H_d (kg/m^3)							
	20 MPa				30 MPa			
	Class A	Class B	Class C	Class C_s	Class A	Class B	Class C	Class C_s
Cells above omitted								
4000	7.1	8.9	8.2	7.1	7.1	9.0	8.3	7.1
4500	8.0	10.0	9.2	8.0	8.0	10.1	9.3	8.0
5000	8.9	10.9	10.1	8.9	8.9	11.0	10.2	8.9
5500	9.8	11.9	11.1	9.8	9.8	12.0	11.2	9.8

Table 1 Note: Portions of design tables used to determine required dosage of micro-reinforcement: (a) the total number of micro-reinforcement required to replace a given area of conventional reinforcing bars varies with concrete strength and design class; and (b) the micro-reinforcement dosage is based on the required number of micro-reinforcement per unit area. The method and models that serve as its basis have been validated with third-party testing, full-scale field-testing and peer reviews by structural engineers.

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