FRP Rebar in Slabs on Grade Benefit from Low Modulus of Elasticity

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Abstract:

Steel reinforcement of concrete has been used for many years. Its primary shortcoming is that it is easily corroded, and corrosion results in structural failure. Recently, there has been a significant amount of interest in using non-corroding FRP rebar to overcome the issue of corrosion.

While the properties of steel reinforcing bars are well known to most structural engineers, the same cannot be said for FRP rebar. One of the main differences in properties between steel and FRP is the relatively low modulus of elasticity of FRP rebar.

This paper addresses the issue of whether the lower modulus of elasticity of FRP rebar is a benefit as it relates to its use in slabs on grade. Other research is reviewed and synthesized to conclude that the lower modulus of elasticity of FRP is positive as it relates to its use in slabs on grade.

Keywords: Modulus of elasticity, reinforced concrete, FRP, GFRP, BFRP, temperature and shrinkage reinforcement.

OVERVIEW

This white paper is a general discussion of the benefits of the use of non-prestressed, fiber reinforced polymer (FRP) rebar in non-structural slabs on grade such as roadways, parking lots, and floors. These slabs on grade can take many forms such as plain concrete slabs with temperature and shrinkage reinforcement, jointed reinforced concrete pavement, continuously reinforced concrete pavement, and structurally reinforced concrete slabs.

The use of FRP rebar has been widely studied over the last 40 years. The impetus for this has been the expensive, frequent repairs needed for steel reinforced concrete structures, particularly those exposed to corrosion and cyclic loadings. These studies, mainly of glass fiber reinforced polymer (GFRP) rebar, have shown that their use can increase structure life by up to four times and typically reduces maintenance. When life cycle costs are considered, FRP rebar, even the more expensive carbon fiber reinforced polymer bar (CFRP), is usually lower cost than steel (Eamon, etal (2012)) for bridge superstructures.

The primary resistance to its more common use has been its higher initial cost. A Michigan company, Neuvokas Corporation, has made advances in high speed manufacturing allowing FRP rebar to be made at costs competitive with steel and at a lower cost than epoxy coated or corrosion resistant steel (Neuvokas Corporation's primary product is basalt fiber reinforced polymer (BFRP) rebar. Neuvokas has chosen basalt because of basalt's superior alkali resistance to glass fiber and higher tensile strength). With this reduction in price, the industry may be approaching an inflection point regarding wider adoption of FRP rebar.

REVIEW, ANALYSIS, AND SYNTHESIS OF RESEARCH BY OTHERS

FRP rebar has unique physical and mechanical properties that must be taken into consideration during design. It is not a direct, one for one, replacement for steel reinforcement. The American Concrete Institute Committee 440 has developed and published design guidelines for the use of FRP reinforcement that reflects FRP's unique properties.

From a longitudinal tensile strength perspective GFRP rebar is much greater than steel. However, its modulus of elasticity (Young's modulus) is much lower (6,000 ksi v. 29,000 ksi), as is its transverse shear strength (22 ksi v. 45 ksi). BFRP rebar has nearly three times the tensile strength of 60 ksi steel and a similar Young's modulus to GFRP. The lower Young's modulus of FRP rebar is the primary difference with steel, affecting slab on grade performance.

As concrete cures it shrinks, and cracks will result when the tensile stress from drying exceeds the tensile strength of the concrete. The tensile stress is then transferred to the reinforcement. The frequency/spacing of cracks, the internal concrete stresses (thermal and contraction) and the modulus of elasticity of the reinforcement determine the width of those cracks.

Choi and Chen (2005) evaluated the concrete stresses resulting from temperature and shrinkage in continuously reinforced concrete pavements using GFRP reinforcement. They found that the lower Young's modulus of GFRP when compared to steel led to lower stress levels in the concrete and greater crack spacing. Mufti and Neale (2007) looked at a bridge deck slab reinforced with GFRP and found that it could withstand over 20 times the cyclic fatigue of steel as a result of its lower modulus of elasticity.

Controlling the location and width of cracks in slabs on grade is a major purpose of reinforcement and tooled or saw cut contraction joints. The width of cracks is important since they must be minimized to retain the aggregate, on either side of the crack, in contact with each other to engage the shearing strength of the concrete across the crack. An additional consideration, where rapid corrosion of the reinforcement is likely, is that the reinforcement will be exposed at the cracks and corrosion resistant reinforcement is preferred to extend the life of the slab. As an example, the American Association of State Highway Transportation Officials (AASHTO) guideline for crack width in continuously reinforced concrete pavements is less than 0.04 inches.

Chen, Choi, GangaRao and Kopac (2008) reported on a continuously reinforced concrete pavement in West Virginia where a section was paved with steel reinforcement at mid-depth of a 10 inch roadway and a section was paved with GFRP also at mid-depth. The result was that the GFRP reinforced section had significantly greater spacing between cracks, theorized to be the result of the low modulus of elasticity of the reinforcement. The crack widths were found to be somewhat greater in the GFRP section than the steel section, but the crack widths were within the AASHTO guidelines. The longitudinal reinforcement ratios were 0.7 percent for steel and 1.12 percent for GFRP. Thebeau, Eisa and Benmokrane (2008) conducted a similar study in Quebec and found that crack widths for GFRP sections reinforced with the same 0.77 percent used for steel had crack widths within AASHTO guidelines. While more study is needed, it may be said that FRP rebar is a preferable reinforcement to steel in many respects and its lower modulus of elasticity appears to have positive benefits.

Katz (2004) found that an additional benefit of FRP rebar usage is its much lower environmental impact load. This is a result of the lower environmental impact in the reinforcement manufacturing and transportation process, reduced maintenance activities, and the reduced impact of disposal. The reduced maintenance is in part the result of increased life because of the lower modulus of elasticity that increases the number of cycles resulting in cyclic fatigue failure, as well as the elimination of corrosion.

AN EXAMPLE

Many jurisdictions have standards for reinforcement of jointed concrete pavement that are simple prescriptions of a certain size rebar placed at a prescribed depth at a certain spacing in a pavement of a given thickness. As an example, Harris County, Texas (Houston area) requires #4 bars at 18 inches on center for a 7 inch concrete pavement section. This is approximately equivalent to 0.13 square inches of reinforcement per foot of concrete. The reinforcement is to be placed at mid-depth and contraction joints installed at 20 foot spacing with expansion joints at 80 foot spacing. Thus, the reinforcement provides negligible structural strength, and the pavement is designed more like a plain jointed concrete pavement with larger than "normal" contraction joint spacing ("normal" is less than twenty four times the thickness of the concrete). The reinforcement's apparent purpose is to restrain cracking and to maintain slab integrity and is considerably less than the commonly used 0.6 percent ratio for continuously reinforced concrete pavement.

ACI uses the drag equation to estimate the stress in the steel in slabs on grade:

$$A_s = \frac{\mu L w}{2 f_s}$$

Where:

- A_s is the cross sectional area of the steel in inches per lineal foot
- μ is the coefficient of subgrade friction, usually 1.5
- L is the distance between joints in feet
- w is the dead weight of the slab in pounds per square foot
- f_s is the stress in the steel in psi

Solving for the stress in the steel using the area of steel in the Harris County design, the stress in the steel would be 11,500 psi. If the steel is replaced with FRP, with a modulus of elasticity of 6,000 ksi, the strain in the FRP would be 0.002 at this same stress. Even using a #3 FRP bar in place of the steel would only increase the stress to 20,400 psi and the strain to 0.0034. This small strain will result in less than the AASHTO guideline of 0.04 inches of crack width. Checking this stress, 20,400 psi, against the ultimate bond stress of Neuvokas BFRP bar, the tension on the #3 bar would be just over 2,250 pounds and the bar has a bond stress at failure of approximately 2,500 psi, or nearly 3,000 pounds per inch of embedment length.

Substitution of FRP for steel would likely be beneficial, since it would also eliminate pavement deterioration from corrosion of the reinforcement.

OTHER BENEFITS

FRP rebar has other benefits that are also worth considering in this application. Principally, they are corrosion resistance and a coefficient of thermal expansion similar to concrete.

Both ACI 440 and AASHTO identify the corrosion resistant properties of FRP rebar as significant. This is particularly important as the failure of epoxy coated steel rebar, which had previously been thought to provide corrosion protection, to adequately protect against corrosion has been experienced in the field. Thus, if substantial corrosion resistance is desired only stainless steel, galvanized steel, corrosion resistant specialty steels, or FRP are the remaining alternatives. All of which have been dramatically more expensive than epoxy coated steel. Although, recent developments in FRP manufacturing have brought the cost down to the point of being competitive with epoxy coated steel and in some instances competitive with black steel.

The higher coefficient of thermal expansion of steel than concrete has resulted in concrete pops and spalling in pavements exposed to higher temperatures. FRP rebar has a coefficient of thermal expansion similar to concrete and thus little or no differential in expansion occurs. In pavements where either high ambient temperatures or large differential ambient temperatures are experienced, this is an important consideration in reducing maintenance costs and poor ride quality.

SUMMARY

In summary, the lower modulus of elasticity of FRP rebar must be incorporated into the design of slabs on grade. And if it is, the lower modulus of elasticity is an advantage over steel, since it is closer to the modulus of concrete. The benefits are primarily:

- Lower internal stresses in the concrete during shrinkage and temperature
- Greater flexibility
- Increase in crack width spacing
- Reduced life cycle costs

Corrosion resistance and a coefficient of thermal expansion closer to that of concrete are additional advantages of FRP rebar for their use in slabs on grade.

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