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Structural reinforcement of bridge decks using pultruded GFRP grating

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Abstract

Fiber-reinforced plastic (FRP) products are being currently used in construction. Compared with steel, FRP products have the following advantages: non-corrosive, non-magnetic, high ratio of strength to weight, high durability, inherent resistance to weather and the corrosive effect of caustics and salts as well as aggressive chemicals. However, in case of structural applications, deflection control is usually expected to be the limiting factor in design rather than strength control. The objective of this research project is to investigate design options for a composite concrete slab without the use of ferrous materials but with relatively high stiffness. This is to avoid the current problem of deterioration of concrete due to expansion because of rusting reinforcement members. Such a target can be achieved by replacing the steel reinforcement of concrete slabs with pultruded I-shape glass FRP (GFRP) structural sections (pultruded GFRP grating sections). The composite action between the FRP structural shapes and the concrete aims to reduce the previous observed high deformation when FRP rebars were used in the concrete. An experimental investigation was conducted to study the applicability and behaviour of pultruded GFRP grating as a reinforcement of one-way concrete slabs and compare its behaviour with that of concrete slab reinforced by either steel or FRP rebars.

Nine medium-scale specimens were cast and tested under flexural loading. The first two specimens were used as control concrete slabs reinforced using different amount of reinforcing steel rebars. The third and fourth specimens were concrete slab reinforced using different amount of FRP rebars. The fifth specimen was a pultruded fiberglass grating without concrete. The sixth, seventh, eighth and ninth specimens were concrete slabs reinforced using pultruded fiberglass grating instead of steel reinforcement with different slab thickness. The experimental ultimate capacity of each of the tested slab was compared to the predicted theoretical capacity using compatibility of strains and equilibrium of forces. The comparison showed that the predicted theoretical values were in good agreement with the experimental ones. The test results indicated the feasibility of using pultruded fiberglass grating in resisting bending and shear stresses with reasonable ductility. This research clarified the behaviour of the composite action of pultruded fiberglass grating with concrete slabs showing it to be an alternative successful construction system. Useful Information for the designers, researchers are provided in the field of composite action of reinforced concrete slabs.

Keywords: Pultruded; Fiberglass grating; Reinforced concrete; Slabs

1. Introduction

The use of FRP composites as structural materials has gradually increased in the construction industry, thus, continuing to replace the more traditional steel and concrete materials. Properties such as high corrosion resistance, low densities, high durability, high strength, good stiffness to weight ratios and ease of handling and installation make composites far more desirable. Glass fiber-reinforced plastics (GFRP) has been already well documented as a structural material. Beam, plate and rod profiles are now currently produced, using the technology of pultrusion [1]. Pultrusion allows the ordering of the fibers in one (longitudinal) direction,

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hence, increasing the tensile and bending resistance of the structural elements. However, applications in current practice of this type of structural material are still rare due to high deformation and cost. To overcome such disadvantages, many authors have proposed structural elements in which GFRP is combined with other structural materials. For instance, GFRP rods have been proposed as reinforcing rebars for concrete, GFRP box sections have been used as permanents form (for confinement and reinforcement) for concrete columns. Also, GFRP plates (stuck to an external surface of reinforced concrete beams and slabs) have been used as strengthening and/or repair measure [2,3].

In the present research, a further application of combining a GFRP pultruded grating with concrete is proposed and tested. GFRP pultruded grating is commercially available and is mainly used to build walkways to be used in corrosive conditions. The modulus of elasticity of the FRP grating alone is relatively low thus, limiting the service load at a small fraction of the ultimate load. Adding a layer of concrete to the GFRP grating significantly increases the stiffness of the system, where the GFRP grating functions as reinforcement for the concrete. As a result, the allowable load for a given maximum deflection is considerably increased. The aim is to offer an effective alternative to the use of conventional steel in deck slabs. The advantages of this technique are the easy availability of the GFRP pultruded grating in industry, the simplicity and low cost of labor and shipping due to its lightness and the rapidity of construction of the GFRP-concrete composite system. This project will make use of standard pultruded GFRP grating which is currently available in 'Off the shelf' lengths. The grating material is a polymeric composite containing E-glass fiber reinforcement and a polymer resin. The biggest saving will be in the maintenance costs. If the material can reduce the number of maintenance expenditures over the life of the structure, it could offset the higher initial cost and be beneficial.

The proposed (GFRP + concrete) slab should behave in bending as a composite beam and therefore a sound connection between concrete and GFRP become a main structural issue.

There are two bonding mechanisms with concrete, i.e. mechanical bonding at the intersection points of the main GFRP I-sections and cross GFRP rods, and the physico-chemical (natural) bonding on the surface of the main I-sections. The natural bond stress between the main I-sections and the concrete is small and is not expected in design. Cross rods are arranged to connect the main I-sections, constrain the core concrete and carry shear between the main I-sections and the concrete. The interaction of the cross rods has an effect in increasing the maximum bond strength per intersection. The main I-sections and cross rods will be stressed in tension and shear while the concrete will be stressed in compression. Thus, the structural behaviour is optimized from a structural and an economical point of view.

Larralde [4] studied the behavior of one-way concrete slabs reinforced with fiberglass-reinforced plastic molded (not pultruded) grating by testing several concrete slabs reinforced with molded grating having different shear span-to-depth ratio. Diagonal tension failure was noticed as a failure mode which was not improved effectively when FRP and steel studs were used.

Bank et al. [5,6] tested full size concrete bridge deck slabs reinforced with two types of commercially produced pultruded FRP gratings under monotonic and cyclic quasi-static loading applied at the center of the slab representing the AASHTO [7] truck tire contact area. Further research is required to thoroughly investigate the pultruded grating behaviour as reinforcement in concrete members.

Hall and Mottram [8] tested 12 concrete beams in four-point bending having a fiber-reinforced plastic pultruded floor panels as tensile reinforcement. A generalized analytical model for flexural behaviour has been developed based on an iterative approach to allow for concrete cracking and real material constitutive laws.

Marisa et al. [9] proposed GFRP pultruded I-profiles consisting of FRP beams connected transversally by GFRP plates glued to the profiles. The results showed slippage between the profiles and the concrete due to the glue weakness and the insufficient GFRP plates.

2. Pultruded fiberglass grating description

Pultruded fiberglass grating is a composite of fiberglass reinforcements (fibers and mat) and a thermosetting resin system, produced by the pultrusion process. The grating consists of bearing I-sections in the longitudinal direction and cross rods in the transverse direction. The bearing I- or T-sections use both longitudinal (glass roving) and multidirectional (glass mat) reinforcements as well as a synthetic surfacing veil. The densely packed core of the continuous glass roving gives the section strength and stiffness in the longitudinal direction while the continuous glass mat provides strength in the transverse direction and prevents chipping, cracking and linear fracturing. The synthetic surfacing veil provides a 100% pure resin surface for additional corrosion resistance.

The cross rods used in the grating form a strong unified panel that can be cut and fabricated like a solid sheet. The cross rods consist of a center core wedge and two spacer bars that are notched at each bearing section so that each bearing section is both mechanically locked and bonded to the web of each bearing section. The cross rods are spaced at 300 mm on center.