USE OF FRC FOR BRIDGE DECK SLABS


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Abstract

The use of fibre reinforced concrete for structural applications has steadily increased over the last few years. The fibre reinforcement significantly increase the mechanical properties of concrete elements, especially shear and punching resistance. For certain type of application fibre reinforcement allows the complete eliminations and/or substantial reduction traditional reinforcement. The use of Fibre Reinforced Concrete is therefore particularly suited for structural elements with limited thickness subjected to punching load such as concrete bridge slabs. The paper present the theoretical frameworks and the most commonly formulae for the evaluation for shear and punching strength of Fibre Reinforced Concrete slabs. Based on these formulae, the advantage of using Fibre Reinforced Concrete slabs in large span composite girder is discussed with reference to large structures currently under construction..

Keywords: Fibres, punching shear, slabs, composite girder

1 Introduction

Steel-concrete composite decks are today very popular because of speed and ease of construction and erection. The typical cross section layout is made by two or more plated girders connected by transverse beams or truss-type diaphragms. The deck is then finished with the concrete slab, either cast in situ, precast or a mixture of the twos.

Bridge deck slabs differentiate from other similar concrete elements mainly because of durability aspects, fatigue resistance to concentrated loads and construction issues. The problem of durability stem from the corrosion of reinforcing bars due to use of de-icing salt in most of the northern hemisphere. For large spans, increase of thickness and cover is not an available option since self weight of these elements needs to be kept to a minimum. Similar reasoning apply to the fatigue resistance to concentrated loads that are constantly increasing with size of the trucks. The need for deck slabs with enhanced mechanical properties and durability is therefore of paramount importance and draws an ever increasing interest from researchers and designers worldwide.

The paper present the most commonly adopted formulae for the evaluation of shear strength of Reinforced Concrete (RC) and Fibre Reinforced Concrete (FRC) slabs. Based on these formulae the advantage of FRC slab over RC ones is discussed and few case studies presented.

2 Design equations for RC shear strength

The formulae used to evaluate shear strength by the major International norms and guidelines [2] [3] [4] shall be compared together with a new one proposed by the authors. The formulae will be compared for a RC rectangular section while varying the following parameters over a significant range: aspect ratio (A_r), longitudinal reinforcement (ρ_l), transverse (hoop) reinforcement (ρ_t) and axial load (N).

MODELCODE 2010 – In the new Model Code [1][2] the shear strength is a sum of the contributions of concrete resistance ($V_{Rd,c}$) and truss mechanism ($V_{Rd,s}$).

EUROCODE 2 – In the last issue of Eurocode 2 [3], contrary to the previous ones, concrete and transverse steel contributions are not added. Either the concrete or the steel one must be used for the design of new structures.

PRIESTLEY – In the Prestley's proposed formula [4], the shear strength is a sum of the contributions of concrete resistance (Vc), inclined strut due to axial load (Vp) and truss mechanism (Vs).

PROPOSED – In the proposed formulae, concrete and transverse steel contribution are added similarly to the Model Code. The difference with respect to the previous formulae is with the definition and evaluation of the concrete resistance. We identify a concrete cohesive contribution (V_{CH}) and a concrete friction contribution (V_{FR}). The concrete cohesive component can only be exploited before diagonal cracking and therefore cannot to be added to the transverse steel mechanisms (V_S). The rational beyond this approach is that the concrete contribution is made of two parts, a mode I (tensile) resistance and a friction component carried out by the section portion under compression. A beam column element subjected to a given load history will first use the concrete mode I resistance until cracking develops and thereafter it will relay only on the transverse steel resistance. Transition between the two is out of the scope of this formulation. When RC structures develop shear cracks, the loss of this cohesive (mode I) contribution must be taken over by the transverse steel. A significant concrete contributions remain there though, that is the one carried by friction by the uncracked portion of the section.

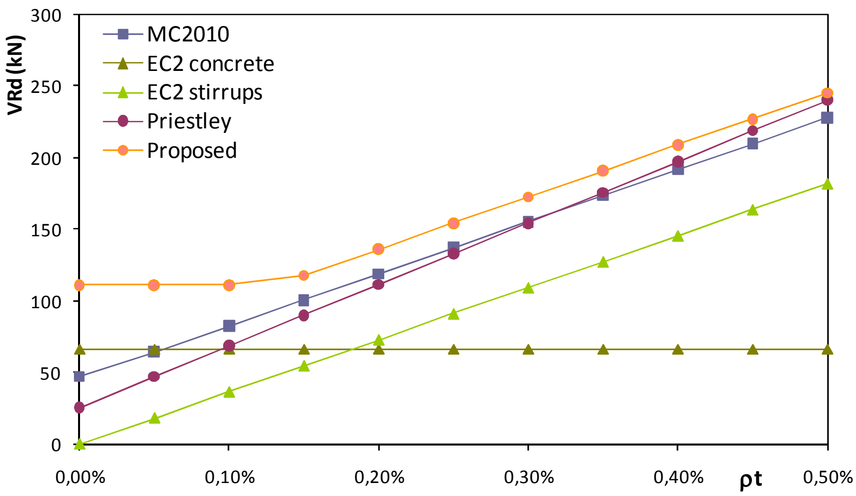

Fig. 1 Shear Resistance as a function of transverse steel (ρt) (A_r = 2.5, ρ_l = 1% N = 0)

2.1 Punching shear of RC Concrete

Comparison for the punching shear resistance of RC structure has been carried out using the formulae proposed in the Model Code (level III) [2] and Eurocode 2 [3].

3 Design equation for FRC shear strength

Fibre reinforcement enhances tensile ductility and (to a lesser extent) resistance of concrete. Bending and shear resistance of FRC members is therefore larger compared to similar RC elements with equal amount of traditional reinforcing. Use of fibres can therefore reduce or totally eliminate the need for traditional reinforcement, especially the shear one. Although the topic has been extensively investigated in the last decade, design applications are still scarce although the potential for the new technology are quite significant. Evaluation of FRC shear strength will be performed using the formulae proposed in the new Model Code 2010 [2].

In the Model Code, the fibre reinforcement as a similar effect to that of longitudinal rebar, improving strength and ductility. The fibre contribution is therefore applied as a modification to the concrete contribution already found for RC members, as follows:

$$V_{Rd,F} = \left\{ \frac{0.18}{\gamma_C} \cdot k \cdot \left[100 \cdot \rho l \cdot \left(1 + 7.5 \frac{f_{Ftuk}}{f_{ctk}} \right) \cdot f_{ck} \right]^{1/3} + 0.15 \cdot \sigma_{cp} \right\} \cdot b_w \cdot d$$

For the design of members with shear reinforcement the contribution of concrete with fibres ($V_{Rd,F}$) must be added to those already found for RC members.

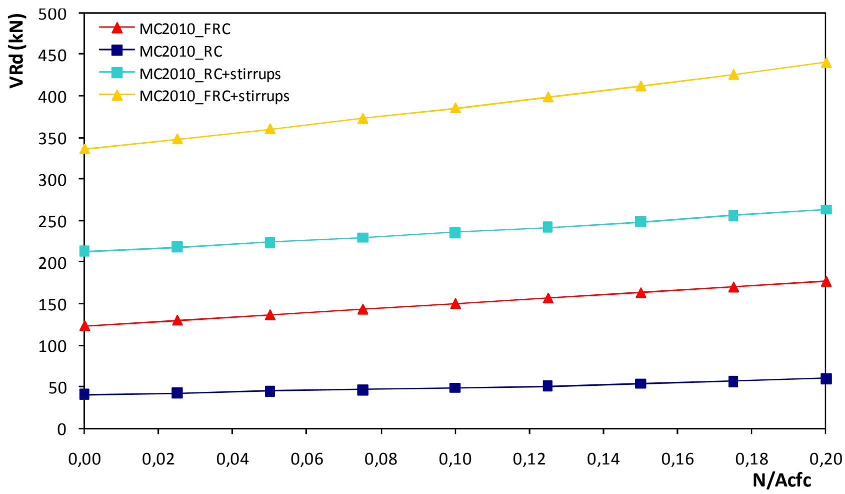

Fig. 1 MC2010 shear resistance for RC and FRC concrete elements as a function of axial load ($A_r = 2.5$, $\rho_l = 1\%$, $\rho_t = 0.5\%$)

3.1 Punching shear of FRC Concrete

Studies and researches published in literature clearly demonstrated fibre reinforcement has quite an influence on punching behaviour of concrete slabs. Strength and ductility are increased, the geometry of the failure cone changes and the overall response become much more ductile. To date, specific formulae for the strength evaluation of punching shear in FRC members have not consolidated yet.

4 FRC deck slab

Current practice in RC slab design for beam and slab bridges, is to use a 25-30cm slab so that bending reinforcement can be placed with sufficient cover and local punching strength easily exceed the one required by modern monster trucks. Another issue in bridge construction is the slab casting. Casting in situ of the slab is not straight forward though, special travelling formwork are required or otherwise some sort of sacrificial elements can be used like thin prefabricated concrete shells or ribbed steel sheets. Precasting of the slab is also used, although this often implies the loss of its contribution in terms of deck bending resistance because of lack of reliability in rebar continuity across the slab joints. All these issues have been practically overcome by using slab thicknesses well beyond what would be strictly required by the applied loading.

In the meanwhile, composite bridge design has been steadily increasing its range of application; today composite girders spanning more than 100 metres are standard practice with few examples spanning over 150 metres. For these bridges, weight of the RC slab becomes significant and its reduction economically interesting. Even more so if we take into the picture the new cable supported (stayed, arch, etc..) composite girders that are being extensively used up to the 500 metre span range.

The most logical and technologically ready solution seems to be the use of FRC slabs for this type of structures. With FRC the slab thickness can be reduced to 15cm circa with significant saving in the self weight of the structure. 10 cm of concrete amount to 240 kg/m^2 which is roughly half the weight of the steel carpentry in medium to large span composite girders. The use of FRC does require special provisions when casting these elements, so much that use of precasted slabs seems almost compulsory. Luckily enough, FRC does simplify the use of precast elements because it strongly reduce the rebar anchorage length and thus the joint dimension between slab panels and the weight of the precast slab elements thus making precasting very competitive and structurally sound.

Use of FRC slab for few large span bridges currently under construction has been simulated to show the potential of the proposed solution and compared it to the other structures built so far using this technology.

References

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