EFFECT OF CONCRETE COVER ON DEVELOPING LENGTHS OF FRP BARS

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Summary

In modern structures a new materials are often used as reinforcement to exploit the properties of materials to the full. The mostly used advanced material in reinforcement today is FRP. Advantages of FRP reinforcement are resistibility against aggressive environment and possibility to use smaller concrete cover of reinforcement.

This paper is focused on anchoring and the development length of such reinforcement. A large number of surfacing types were tested to find the best cohesion between reinforcement bars and concrete. The gained results were gathered and analysed using a bond-slip relationship to describe the behaviour of a reinforcement bar along the anchoring length. This principle served as a basis for creating analytical relations suited to the calculation of the minimal required anchoring length of reinforcement. To factor the influence of the thickness of the concrete cover into the calculation a new extension was proposed. Finally the comparison was prepared to determine the amount of material used/saved using different methods of calculating concrete cover.

Keywords: FRP reinforcement, anchoring, development length, concrete cover

1 Introduction

The thickness of concrete cover is a critical factor when anchoring reinforcement particularly when using only thin concrete cover. At the same time this is usually one of the main points when presenting the advantages of FRP materials – thanks to their resistibility against aggressive environments it should be possible to reduce cover and thus save material.

Generally speaking the calculation of minimal concrete cover is based on the diameter of the reinforcement bar, tensile strength of the reinforcement and partially strength of the concrete (although some studies challenge the relation between bond strength of FRP reinforcement and the strength of the concrete). However most of design codes today come from origins based on using steel reinforcement and thus they are influenced by the need of providing additional protection for the reinforcement bar.

While the cracks in the concrete cover pose a threat for the steel bars (access of the water followed by the development of corrosion), the FRP reinforcement is usually influenced by mechanical changes of the surrounding concrete only. Pursuing this knowledge a new field of possible material saving are opening – by precising the design of concrete cover it is possible eliminate the material previously needed for the protection of reinforcement.

2 Bond properties without the influence of concrete cover

For the basic theoretical approach a bond-slip model [1] was used. This theory assumes constant stress along the anchored length of the reinforcement when the limit bond stress τ_{max} is reached. Also, the behaviour of the reinforcement material is assumed to be linear. The combination of these two conditions makes it possible to obtain a differential equation. This basis was used in the past to create several analytical models that describe the progression of bond stress $\tau(x)$ along the anchoring length. Basically the bond properties in this model are described by two branches in a bond-slip diagram (**Fig. 1**).

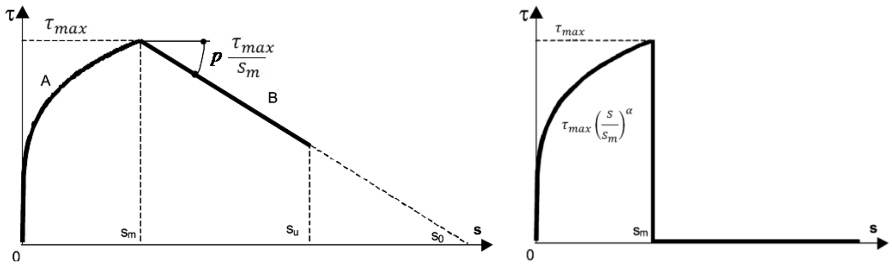

Fig. 1 *Original bond-slip diagram describing the dependence of the bond stress on the slip of the reinforcement bar (left-hand side picture) and the modified diagram used for calculation*

Using this theory it is possible to calculate the tensile stress τ_l in the reinforcement that is reached during maximal slippage s_m of the bar and which is also the moment when maximal bond-stress τ_m is reached. Using a similar procedure it is possible to express the ultimate anchoring length l_m which is needed to reach maximal bond stress.

3 The influence of concrete cover

Although accurate, the relationships described above do not include the influence of the concrete cover and are only usable in situations when concrete cover is sufficient. For this reason, a set of numerical models was prepared to study the influence of the proximity of the reinforcement to the concrete surface.

This distribution can be transformed into a simple strut and tie analogy to obtain the compressed diagonals (the compressed side of the cone) and stretched ties perpendicular to the axis of the bar (the transverse tensile stress along the circumference of the bottom of the cone, **Fig. 2**).

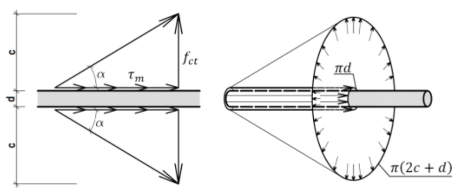

Fig. 2 *Decomposition of the stresses around the anchored reinforcement bar*

If equality is presumed between the ultimate bond stress and the ultimate tensile stress in the surrounding concrete, the minimal concrete cover c can be calculated using the equation:

$$c = \frac{\tau_m d \tan\alpha}{2 f_{ct}} - \frac{d}{2} \tag{1}$$

where f_{ct} is the tensile strength of the concrete [MPa]; α is the angle of the stress distribution [°]; d is the diameter of the reinforcement [mm].

Using a similar approach it is possible to calculate the maximal tensile force that can be anchored if the concrete cover c is given, or in other words, to determine the tensile force that can act in the reinforcement bar without the risk of longitudinal crack propagation. In the case that the bottom of the cone meets the surface of the concrete, the circumference transferring tensile forces in concrete is smaller, thus increasing the stress in the concrete. This can be expressed in the equation where τ_m gives the maximal bond stress that can be reached before the longitudinal crack opens:

$$\tau_m = \frac{f_{ct}\left(2c_1 - \frac{\theta}{180}c_1\right)}{d \tan\alpha} \tag{2}$$

where c_1 is the concrete cover [mm].

The theoretical relationships and FEM results were tested in a real-world situation (but only with a limited number of test specimens to date).

4 Conclusions

4.1 Determination of sufficient concrete cover

The experimental results prove the linearity of the progress of the reinforcement's displacement. It follows that the stress propagation progresses in the same manner along the whole anchoring length and therefore it is possible to use the premises used to derive the stated analytical relationships.

To ensure the minimal concrete cover thickness the equation (1) can be used. This value guarantees that no longitudinal cracks appear along the developing zone of the bar and the forces are safely transferred from the reinforcement into surrounding concrete.

4.2 Influence of the concrete cover on material savings

To determine the impact of a designed concrete cover on a material consumption a number of different design approaches [2], [3], [4] and analytical solution (equation (1)) have been used and studied. When using the more precise approach it is possible to save some material otherwise used to provide necessary concrete cover. Based on the theory above this mass of concrete is basically only ballast because it does not provide any additional bond strength for the reinforcement and also it is redundant in the view of reinforcement protection as there is no risk of corrosion.

The possible savings of material are calculated in **Tab. 1** for each design approach. This calculation was prepared for a concrete ceiling slab (ground plan dimensions are

3,0×3,0 m) used as a pre-cast ceiling in heat line access shafts i.e. an ideal construction to exploit the benefits of non-metallic reinforcement.

Tab. 1 *Minimal concrete cover based on several calculation methods*

Design method	Concrete cover thickness for bars ø8 [mm]	Material excess [%]	Concrete cover thickness for bars ø14 [mm]	Material excess [%]
Proposed equation (1)	7	0	13	0
ACI [2]	8	+14	14	+7
EC2 [3]	20	+185	24	+85
JSCE [4]	25	+257	25	+92

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