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# Analysis of reinforcement anchorage zone behavior of prestressed concrete elements under static and cyclic loads

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**Abstract**

The article briefly discusses about the bond characteristics of different pretensioning reinforcement and some problems of reinforcement anchorage zone. In the present study bond characteristics of three-wire strand under static and cyclic load are investigated. The research revealed that bond stress-slip characteristics of three-wire strand are different from those proposed in Model Code for deformed and plain bars. The bond strength of three-wire strand is not negatively influenced by cyclic load at lower bond stress levels up to $0,7\tau_{stat.max}$.


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*Keywords:* bond, static load, cyclic load, strand.

## 1. Introduction

Efficiency of application of prestressed concrete structures depends on the overall behavior of reinforcement and concrete at the reinforcement anchorage zone. Reinforcement and concrete has different mechanical and physical characteristics. According to the theory of composite structures sufficient links between materials with different mechanical and physical properties must be ensured for composite structure to work as monolithic [1,2,3,4,5]. The same principle is applicable in prestressed concrete structures ensuring sufficient bond strength between reinforcement and concrete, which could resist various loads.

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Different types of reinforcement (deformed or plain bars, wires or strands) and recently different FRP (fiber-reinforced plastic) reinforcement (carbon, glass, aramid) [6,7] are used in prestressed concrete structures. The reinforcement anchorage type at the end of the structure depends on the bond properties of the reinforcement. Reinforcement with higher surface roughness (ribs, indentations) is anchored in concrete through bond and anchorage of plain bars can be ensured by bearing plates at the end of the element. Bond stress-slip behavior differs depending on the reinforcement type and surface properties.

## 2. Behavior of pretensioned reinforcement under static load

High stresses are induced in prestressed concrete structures during service life. Therefore, it is important to ensure good bond conditions in prestressed concrete elements. Bond strength of reinforcement depends on many factors such as type of reinforcement, reinforcement surface roughness, strength of concrete, bar diameter, pretensioning force etc. Stresses at the interface between reinforcement and concrete varies through the anchorage length and is dependent on the slip of reinforcement. Guyon [8] was one of the first to describe bond stress distribution:

$$\tau_x = K(q_x) \text{ or } \tau_x = \tau_{max} \cdot e^{-\frac{x}{\lambda_1}} \tag{1}$$

where $\lambda_1$ - bond parameter; $\tau_{max}$ - maximum bond stress; $\tau_x$ - bond stress at distance x; $K$ - empirical coefficient.

However, it is hard to determine real distribution of bond stresses. Therefore, average bond stresses ($\tau_{b,m}$) are assessed in different codes, which are constant through the reinforcement anchorage length. Average bond stress can be calculated:

$$\tau_m = F / (\pi \cdot \varnothing \cdot l_a) \tag{2}$$

where $F$ - tension force of reinforcement; Ø - bar diameter; $l_a$- anchorage length of reinforcement.

Usually bond of deformed bars is ensured through bond between reinforcement and concrete. In this case two types of failure can occur: failure due to slip of reinforcement or due to splitting of concrete. Neither of these types of failure is expected in prestressed concrete structures. However, high stresses at the interface between reinforcement and concrete are induced due to the load applied to the reinforcement anchorage zone. High stresses induced by crushed concrete at the face of the reinforcement rib are high enough to exceed concrete tensile strength. From the bond stress-slip theory transversal cracks appears at the tips of the ribs and longitudinal cracks propagate through the concrete cover. If the concrete cover is not sufficient to resist the radial stresses induced by wedging action of crushed concrete at the face of the ribs anchorage zone of pretensioned reinforcement fails due to concrete splitting (Fig 1 a). Our research of anchorage zone of prestressed concrete beams reinforced with pretensioned deformed bars showed that in case of insufficient concrete cover confining reinforcement should be used to restrain radial stresses in concrete. Therefore, spiral type of confining reinforcement around pretensioned bars was introduced in prestressed concrete beams. Consequently, type of failure of prestressed concrete beams was due to bending moment and there was no slip of reinforcement or splitting of concrete (Fig 1 b). Confining reinforcement enhanced bond properties of reinforcement anchorage zone and bearing capacity of prestressed concrete beams with confining reinforcement was about 30% higher comparing to beams without confining reinforcement.