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Friction and cohesion coefficients of composite concrete-to-concrete bond

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ABSTRACT

Experimental study is conducted to quantitatively assess the effects of different surface textures on the friction and cohesion coefficients of concrete-to-concrete bond under different normal stresses. The top surface of concrete base specimens are treated with five different surface textures; surface "left as-cast", deep groove, indented, and wire-brushing in longitudinal and transverse directions. The roughness profile of the treated concrete base is measured using a portable stylus roughness instrument. In addition, the "push-off" test method is conducted to determine the relationship between the roughness profile and the interface shear strength. Results show that the mean peak height, R_{pm} has the most significant influence on the pre-crack interface shear strength where the correlation coefficients, R^2 ranged from 0.9009 to 0.9209. Analytical equations are then proposed to predict the friction and cohesion coefficients by integrating R_{pm} into the proposed equations. The comparison shows a good concordance with the experimental results within an acceptable range.

1. Introduction

Precast concrete slab is normally tied with cast-in-place concrete topping by composite action at the interface between the concrete layers. The composite action between the concrete layers plays a significant role in achieving monolithic behavior of the slab system. Such action, development and provision by the precast concrete slab and the concrete topping are achieved via mutual and adequate interface shear and bond strength. The horizontal shear transfer crossing between two members of concrete must be maintained through concrete cohesion, friction and dowel action from the projecting shear reinforcement [1–3].

The type of surface roughness at the interface influences the cohesion, friction and the bond strength between concrete layers [4–6]. To characterize the horizontal shear strength at the interface between concrete layers cast at different times, design codes such as and ACI 318 [1], Eurocode 2 [2], and CEB-FIB Model Code 2010 [3] recommended certain design values in which based on the surface texture and the surface with projecting shear reinforcement links. In this study, the comparison is made on the surface texture.

ACI 318 [1] mentioned the interface shear strength is only categorized by two types of surface texture; rough and very rough at full amplitude of 6.4 mm. The compressive strength concrete is not specified in ACI 318 [1] as a function of interface shear strength which is only based on qualitative assessment. On the other hand, the CEB-FIB Model Code 2010 [3] and Eurocode 2 [2] mention the compressive strength concrete of concrete layers and categorized the degree of roughness from very smooth to very rough surfaces.

Eurocode 2 [2] states that the friction and cohesion coefficients at interface of concrete layers are influenced by the degree of the roughness. Also, the recommended roughness height for rough surface should be at least 3 mm and for indented or very rough surface at least 5 mm. The friction coefficient ranged from 0.50 to 0.90, while the cohesion coefficient ranged from 0.025 to 0.50 which are postulated for surface profile from very smooth to very rough. However, the selection of these values may be subjective as it is difficult to distinguish the characteristic of surface roughness profile between very smooth and smooth as well as between rough and very rough.

CEB-FIB Model Code 2010 [3] quantifies the surface roughness by using average roughness, R_a which is determined as the mean value of texture heights along a certain length, l_m. The surface texture concrete is measured and categorized from very smooth to very rough by applying the roughening method. Very smooth surface is cast against steel formwork, thus R_a is not measurable.

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Meanwhile, smooth surface is untreated and cast against wooden formwork where the average roughness, R_a is taken as less than 1.5 mm, and rough surface is roughened by sand blasted where the average roughness, R_a is more than 1.5 mm. For very rough surface, the surface is roughened using high pressure water jet where the indented has an average roughness, R_a of more than 3 mm. The friction coefficient ranged from 0.50 to 1.40, and the concrete adhesion is categorized into rough and very rough surface with mean shear resistance ranged from 1.5 to 3.5 N/mm^2.

Studies [4–9] on the quantification of the degree of surface roughness and its correlation with the bond strength between concrete layers cast at different times have been carried out by several researchers. It was established from these studies that there is a high correlation between surface roughness and bond strength. In this study, a "push-off" test method is used to determine the interface shear strength between two concrete layers cast at different times. The test method is adopted from the shear friction model. The shear friction model used to characterize the interface shear strength is separated into two components; Coulomb friction and cohesion between two surfaces. Furthermore, a linear approximation of the Mohr–Coulomb failure envelope is obtained and the friction and cohesion coefficients are then determined. The relationship between horizontal load and interface slip is obtained under variable normal stresses of 0 N/mm^2, 0.5 N/mm^2, 1.0 N/mm^2 and 1.5 N/mm^2. Meanwhile, the peak (or pre-crack) interface shear strength is also determined from the relationship where the correlation with the roughness parameters is further evaluated. The peak or pre-crack interface shear strength is referring to when the concrete layers having a little slip with the load increments at maximum before the concrete layers break apart.

The motivation of study is to verify fourteen roughness parameters using a portable stylus roughness instrument as tools from the previous study of only eleven parameters. The aim of this research is to determine the friction and cohesion coefficients at the interface for different surface textures of concrete-to-concrete bond of both precast elements and cast in place by quantifying the roughness parameter. The highest coefficients of correlation (R^2) from the set of pre-crack interface shear strength and roughness parameters are then selected and recommended in the proposed equation to predict friction and cohesion coefficients.

2. Existing works on interfacial behavior

Friction is one of main parameters to assess the interface shear strength and the monolithic behavior of composite concrete-to-concrete bond [1–3]. The major sources of friction are roughness interaction, adhesion and plowing [10,11]. The friction referring to previous study is in general term in which the adhesion is included as part of friction. To be specific in this study, the interface shear strength is chosen as the combination of concrete cohesion or adhesion and friction. The friction in this study includes the present of variable normal stresses and the ratio of the shear strength to normal stress is the friction coefficient. Roughness theory assumes that the frictional force is equal to that required to work against the roughness of the slope, θ. The slope is taken at relationship of the shear strength to the variable normal stresses. Such that its associated coefficient can be defined as $\mu = \tan\theta$ [12]. The relationship shows that the more intense the degree of roughness on the surface texture, the higher the value of friction coefficient. By quantifying the roughness parameter, it can be used to predict the friction coefficient instead of only observing the surface quality. The concrete cohesion bond strength is taken without normal stress applied and the interface shear strength is at the minimum value that required the stress breaks the cohesion bond between the concrete layers. The weight of concrete topping is neglected because of very small value and the normal stress is taken as zero normal stress. The surface roughness also affects the concrete cohesion bond in which the increase degree of roughness surface contributing to higher value of cohesion strength. The higher degree of roughness provides more surface area for the cohesion bond at the interface concretes. The cohesion strength in this study includes the tensile strength concrete and the cohesion coefficient is taken at ratio of the interface shear strength to the tensile strength. The cohesion coefficient can be predicted by quantifying the roughness parameter of the surface texture. Therefore, the design expression of interface shear strength in this study is appropriate for the surface textures without provision steel crossing the interface.

The Mohr–Coulomb failure theory criterion suggests that the shear stress between two contact surfaces against the normal stress is defined as:

$$\tau = C + \mu \cdot \sigma \tag{1}$$

where τ is the interface shear strength also known as the peak point on the failure plane, σ is the normal stress, C is the cohesion strength and μ is the friction coefficient. To get a better understanding of Eq. (1), consider two concrete blocks where the top is added later onto the existing bottom part as shown in Fig. 1. The shear strength of the composite concrete is assessed when variable normal stresses are applied and there is the contact of the concrete-to-concrete occurred at the surface texture which is made through cohesion and friction coefficients. When the normal load is zero ($\sigma = 0$ N/mm^2), the shear stress increases to maximum cohesion strength, C to break the bond between the two concretes. For normal stress of more than zero ($\sigma > 0$ N/mm^2), the shear stress increases more to overcome the sliding resistance caused by friction. Therefore, the term $(C + \mu \cdot \sigma)$ is the maximum shear stress needed to separate the two concrete blocks [13].

In Eurocode [2] the interface shear strength between two concretes cast at different times is a combination of three main components defined as:

$$\tau = c \cdot f_{ct} + \mu \cdot \sigma_n + \rho \cdot f_{yd}(\mu \cdot \sin\alpha + \cos\alpha) \leqslant 0.5\upsilon f_{cd} \tag{2}$$

where $c \cdot f_{ct}$ is the cohesion strength, C resulting from concrete chemical adhesion in the interface layer, in which c is the cohesion coefficient and f_{ct} is the concrete tensile strength of the lower strength. The term $\mu \cdot \sigma_n$ is the frictional force resulting from μ at the interface, in which σ_n is the normal stress, while $\rho \cdot f_{yd}$ $(\mu \sin\alpha + \cos\alpha)$ is the capacity component resulting from the presence of shear reinforcement crossing the interface, in which ρ in the reinforcement ratio, f_{yd} is the design yield stress of the reinforcement and α is the angle between the shear reinforcement and the plane considered.

CEB–FIB Model Code 2010 [3] described the surface texture by classifying the average roughness, R_a. The interface shear strength is given as:

$$\tau = \tau_c + \mu(\sigma_n + \kappa \cdot \rho \cdot f_y) \tag{3}$$

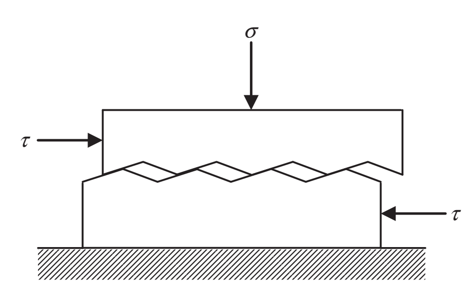

Fig. 1. Mechanical concept of sliding.