



Получена: 14.12.2022 г.

Приета: 20.02.2023 г.

HORIZONTAL SHEAR TRANSFER AT INTERFACE IN COMPOSITE CONCRETE FLEXURAL MEMBERS

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Keywords: *shear friction, shear transfer, horizontal shear design, bond between the old and new concrete*

ABSTRACT

The paper presents the horizontal shear transfer at interface in composite concrete flexural members. They occur in many monolithic and precast constructions and need to be properly designed and constructed by structural engineers. The requirements and recommendations in the world design codes, as well as some Bulgarian and world scientific researches, are examined. Graphics are proposed for calculating horizontal shear of joints in composite reinforced concrete elements based on the design code BDS EN 1992-1-1. Conclusions and recommendations for practical application are made.

1. Introduction

Construction joints in reinforced concrete structures occur under the following circumstances: the process of casting the concrete at different times in horizontal or vertical elements (foundations, beams, slabs, walls, etc.); precast reinforced concrete elements (pre-girders, pre-plates, bridge girders, etc.) with an additional concrete section performing on them; joints in precast and load-bearing precast panelized structures; unplanned situations during the execution of concrete (i.e. delivery of concrete mixture with characteristics not corresponding to the design, bad climatic conditions), etc. Composite concrete flexural members are constructed in separate placements but connected so that all elements respond to loads as an unit. The connection between the separate layers needs to be designed and constructed in an appropriate

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way so that the horizontal shear, resulting from the bending of the element, is effectively transferred at the interface of the separate placements.

2. Shear at the interface between concrete cast at different times at horizontal members

The shear at the interface between concrete cast at different times have been studied in numerous scientific works [6 – 10]. A series of parameters affecting the behavior of the construction joints were studied experimentally. The examined specimens are with different:

- types and shapes;
- processing of the contact surfaces;
- support conditions;
- type, location and quantity of reinforcement, etc.

Analogous to the experimental studies, analytical studies were also carried out. Comparative analyses and relevant conclusions have been made in scientific works.

At 2014 in the laboratory of the “Reinforced Concrete Structures” at the University of Architecture, Civil Engineering and Geodesy (UACEG), 16 specimens were made and tested. The influence of the amount of metal or polypropylene fibers in the concrete mixture was studied, as well as the treatment of the construction joint with epoxy composition. A typical stress-strain curve has been derived and the presence of epoxy resin in construction joints has been reported [5].

Graphical methods have been found for calculation and design of horizontal shear transfer at interface in composite concrete flexural members. This paper aims to develop a graphical method for calculation based on the design code BDS EN 1992-1-1.

Shear in construction joints depends mainly on the following factors: roughness and cleanliness of contact surfaces; compressive strength of the concrete; the normal stresses on the shear plane; the angle of inclination of the shear force; the amount, type and angle of reinforcement intersecting the shear plane.

The shear stress in construction joints can be described by three main components: adhesive bonding and mechanical interlocking between the working surfaces τ_c ; the friction τ_f (friction) from the external compressive forces and the normal stresses generated by the reinforcement on the joint; as well as, the dowel action τ_d of the reinforcement.

Generally, the equation for shear bearing capacity is:

$$\tau = \tau_c + \tau_f + \tau_d. \quad (1)$$

3. Determination of shear stress in construction joints

The horizontal shear stress in construction joints can be determined based on the following three different equations:

$$v_h = \frac{V}{b_v \cdot d}, \quad (2a)$$

where V is shear force in the calculated section of the element; b_v – width of the contact surface; d – effective depth of the element.

$$v_{nh} = \frac{C_1 - C_2}{l.b} \quad (2b)$$

where v_{nh} is the average (nominal) shear stress in the joint; $C_1 - C_2$ is the difference between the compressive forces from the ultimate limit state in the section with maximum bending moment in the beam and the section with zero bending moment. To determine v_h , the mean stress v_{nh} is distributed proportionally to the vertical shear forces in the member.

$$v_h = \frac{V.S}{I.b}, \quad (2c)$$

where S is static (first moment of inertia) of the part of the section above the shear plane, taking into account the location of neutral axis of the section; I – moment of inertia of entire section.

The results for the horizontal shear force determined according to formulas (2a), (2b) and (2c) are almost identical.

4. Design codes review

4.1. American standard ACI 314-14 [1]0

The main method for determining the shear stress in horizontal construction joints is according to formula (2a), but as an alternative formula (2b) can be used. For joints with smooth or grooved amplitudes up to $\frac{1}{4}$ in ($\approx 6,5$ mm), the stress v_n is determined by the following formula if the code requirements for minimum amount of transverse reinforcement are met:

$$v_n = (1,8 + 0,6.\rho.f_y) \leq 3,45 \text{ MPa}, \quad (3)$$

where ρ is the ratio of transverse reinforcement;

f_y – yield strength of reinforcing steel for the transverse reinforcement.

If condition (3) is not met, it is necessary to insert transverse reinforcement according to the calculation:

$$v_n = \mu.\lambda.\rho.f_y \leq \min(0,2.f_c ; 5,5 \text{ MPa}), \quad (4)$$

where μ is a coefficient of friction equal to: 1,40 for concrete placed monolithically; 1,0 – for hardened concrete and new concrete with a groove amplitude of about $\frac{1}{4}$ in ($\approx 6,5$ mm) and 0,6 – smooth, ungrooved concrete;

λ – coefficient equal to $\lambda = 1$ for ordinary concrete and $\lambda = 0,75$ – for lightweight concrete;

f_c is the compressive strength of the concrete in *psi*.

4.2. British standard BS 8110-1 [3]0

In [3], the horizontal shear force is determined according to formula (2b), with the compressive force $C_1 - C_2$ being corrected by the ratio of the longitudinal force in the new concrete and the full value of the force in the compressive or tensile zone (when the neutral axis is in the height of the second stage of concrete casting, the coefficient is equal to 1,0).

BS 8110-1 [3] presents the design limit values of shear stress in a horizontal joint v_n (defined for 1 m²) in Table 5.5. Where the horizontal shear stress exceeds the value given in table 5.5 [3], all the horizontal shear force should be carried by reinforcement anchored in either side of the interface. Transverse reinforcement shall be with minimum reinforcement percentage of 0,15 % and shall be anchored in both sides of the working joint.

When the limit stresses from Table 5.5 of [3] are reached, required vertical reinforcement A_h should be calculated from the following equation:

$$A_h = \frac{1000 \cdot b \cdot v_h}{0,95 \cdot f_y} \left[\text{mm}^2 / \text{m} \right]. \quad (5)$$

4.3. CEB-FIB Model Code 2010 [4]0

The shear bearing capacity equation in [4] is:

$$\tau = \tau_c + \tau_f + \tau_d = \tau_c + \mu \cdot (\sigma + \kappa \cdot \rho \cdot f_y) + \tau_d < \beta \cdot v \cdot f_{cd}, \quad (6)$$

where μ is the coefficient of friction between the concrete surfaces;

ρ – degree of reinforcement crossing the interface;

f_y – yield strength of the reinforcing steel;

κ – interaction (“effectiveness”) factor, taking into account the tensile force in the reinforcement.

At high tensile stresses in the transverse reinforcement, the factor κ varies between $0,5 < \kappa \leq 1,0$ and the dowel action is reduced. In [4] it is recommended to use $\kappa \leq 1,0$ and $\tau_d = 0$.

4.4. Design code BDS EN 1992-1-1 [2]

In design code [2], shear stress at the interface between concrete cast at different times should also satisfy the following:

$$v_{Ed,i} = \frac{\beta \cdot V_{Ed}}{b_i \cdot z}, \quad (7)$$

where β is the ratio of the longitudinal force in the new concrete area and the total longitudinal force either in the compression or tension zone, both calculated for the section considered; V_{Ed} – the transverse shear force; z – the lever arm of the composite section; b_i – the width of the interface.

Design shear resistance at the interface is given by:

$$v_{Ed,i} = c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho \cdot f_{yd} \cdot (\mu \cdot \sin \alpha + \cos \alpha) \leq 0,5 \cdot v \cdot f_{cd} \quad (8)$$

where $f_{ctd} = f_{ctk,0,05} / \gamma_c$ is the design value of concrete tensile strength; c and μ are factors which depend on the roughness of the interface (Table 1); σ_n is stress per unit area caused by the minimum external normal force across the interface that can act simultaneously with the shear force, positive for compression, such that $\sigma_n < 0,6 \cdot f_{cd}$, and negative for tension. When σ_n is tensile, $c \cdot f_{ctd}$ should be taken as 0; α – angle of inclination of the transverse reinforcement, which should be limited by $45^\circ \leq \alpha \leq 90^\circ$ (Fig. 1).

Table 1. Factor of adhesion/interlocking c and factor of μ

Roughness of the interface	c	μ
Very smooth	0,25	0,50
Smooth	0,35	0,60
Rough	0,45	0,70
Indented	0,50	0,90

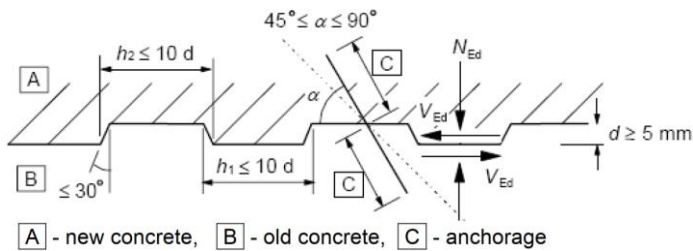


Figure 1. Indented (interlocked key way) construction joint

A stepped distribution of the transverse reinforcement may be used, as indicated in Figure 2. Where the connection between the two different concretes is ensured by reinforcement (beams with lattice girders), the steel contribution to $v_{Ed,i}$ may be taken as the resultant of the forces taken from each of the diagonals provided that $45^\circ \leq \alpha \leq 135^\circ$.

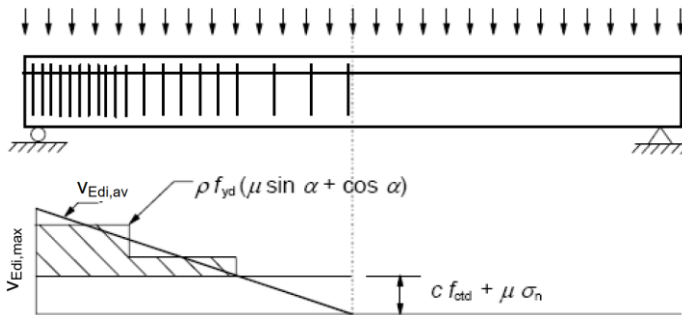


Figure 2. Shear diagram representing the required interface reinforcement

5. Proposal for graphic solution of construction joints, according to BDS EN 1992-1-1 [2]

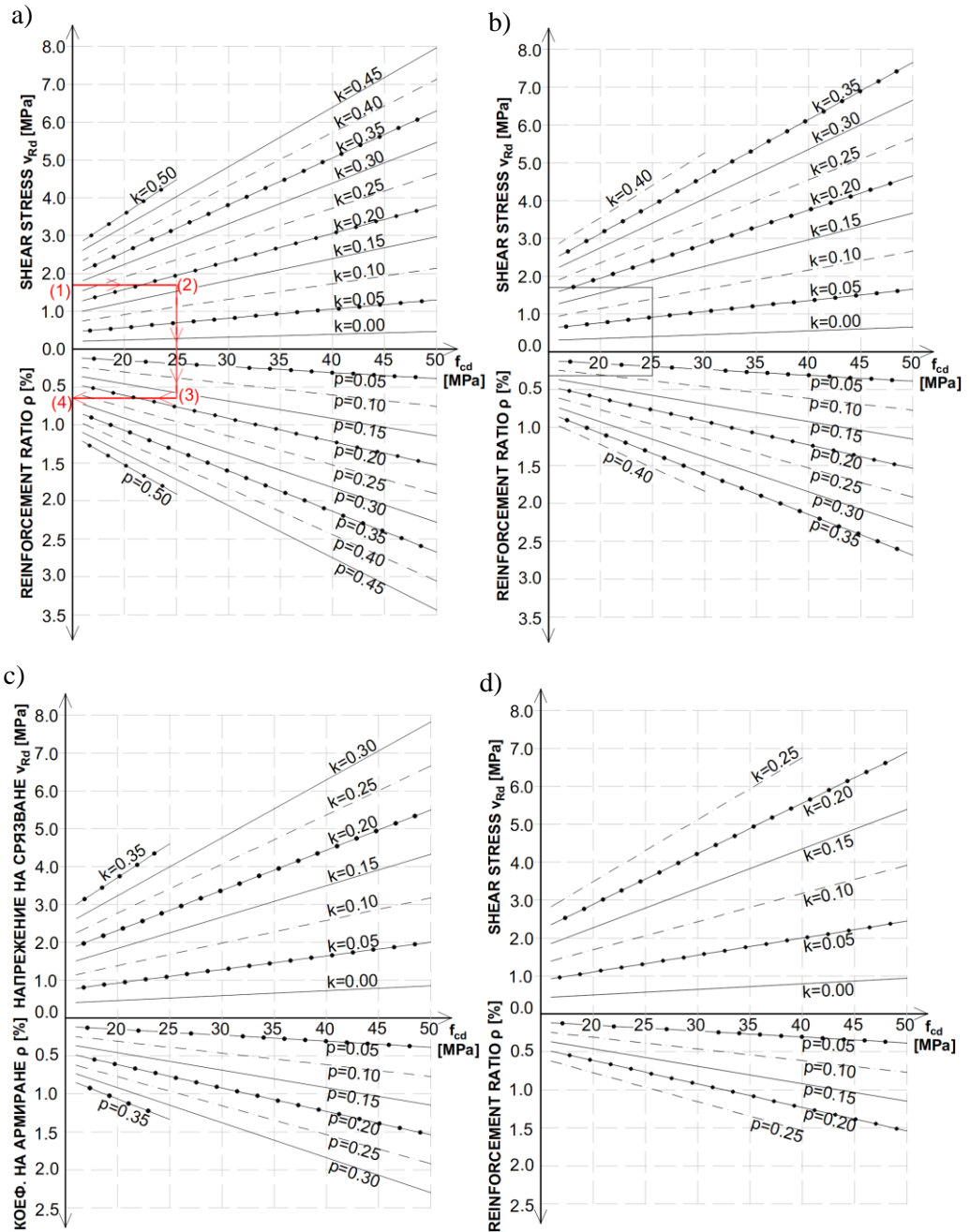


Figure 3. Graphical determination of reinforcement ratio ρ (for steel class B500) and the coefficient k as a function of the shear stresses v_{Rd} and concrete grade when the surface is: a) very smooth; b) smooth; c) rough; d) indented, according to Figure 1

Graphics have been developed to determine the required amount of vertical reinforcement depending of concrete grade and roughness of the interface of the working joint surface.

If there is no vertical stress σ_n , the determination of ρ is made through the sequence presented in Figure 3a – (1) account of the shear stress $v_{Rd} = v_{Ed}$; (2) – determination of the coefficient k for the required concrete grade; (3) and (4) – determination of the corresponding coefficient $p = k$ and the required reinforcement ratio ρ .

If there is a vertical stress σ_n , the difference compared to the case described in the above paragraph is in step (3), the coefficient p has value $p = k - \sigma_n / f_{cd}$.

When using reinforcement steel B420, the results of the graphic solution need to be increased by a factor of 1,19.

Example: Determine the required transverse reinforcement B500 at construction joint with horizontal shear stress $v_{Ed} = 1,70$ MPa and concrete grade C25/30 at: a) very smooth surfaces and $\sigma_n = 0$; b) smooth surfaces and $\sigma_n = 0,05 \cdot f_{cd}$.

According to the diagram in Figure 3a, coefficient $k = 0,17$ is determined for concrete grade C25/30 and coefficient $\rho \approx 0,65\%$ is calculated for $p = k = 0,17$.

From the diagram in Figure 3b, coefficient $k = 0,135$ and coefficient $p = 0,135 - 0,05 = 0,085$ are calculated. The reinforcement factor is equal to $\rho \approx 0,30\%$.

6. Conclusions and recommendations

On the basis of the presented research, the following main conclusions and recommendations can be made for the design of horizontal shear transfer at interface in composite concrete flexural members:

A) The developed graphs for determining stresses in a construction joints, as a function of concrete grade, reinforcing steel and roughness of the interface, with or without transverse reinforcement, facilitate the application of the procedure in BDS EN 1992-1-1.

B) According to BDS EN 1992-1-1 [2], see 6.2.5(3) and Figure 6.10 (Figure 2 of this paper) no clear recommendation is presented to determine the length of zones with the distribution of the transverse reinforcement absorbing part of the horizontal forces. The author is of the opinion that such guidance is necessary, because in each of the zones the code recommends design with the average stresses $v_{Edi,av}$ and not with the maximum stress $v_{Edi,max}$ (Fig. 2). In long and heavy loaded beams, this acceptance can lead to significant undersizing near the support.

C) BDS EN 1992-1-1 [2] does not present coefficients of friction and adhesion for lightweight concrete by analogy with the American standard [1].

D) The friction coefficients in the American standard [1] are increased compared to those in BDS EN 1992-1-1, and the adhesion component of the shear stress is indirectly included in them.

E) Application of the British Standard [3] is facilitated, due to the presentation of the allowable horizontal shear stresses in tabular form, as a function of concrete grade and roughness of the interface.

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ХОРИЗОНТАЛНО СРЯЗВАНЕ В РАБОТНИ ФУГИ НА КОМПОЗИТНИ СТОМАНОБЕТОННИ ЕЛЕМЕНТИ, ПОДЛОЖЕНИ НА ОГЪВАНЕ

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Ключови думи: хоризонтално срязване, технологични фуги, връзка между стар и нов бетон

РЕЗЮМЕ

В настоящата разработка е изследвано поведението на технологични (работни) фуги при хоризонтални стоманобетонни елементи. Те възникват в множество монолитно и сглобяемо изпълнявани конструкции, поради което е необходимо да бъдат правилно проектирани и конструирани от проектантите. Разгледани са основните постановки в световните нормативни документи, както и някои български и чуждестранни научни трудове и изследвания. Предложени са графики за изчисление на хоризонтално срязване на фуги в композитни стоманобетонни елементи на база на нормативния документ БДС EN 1992-1-1. Направени са изводи и препоръки за практическо приложение.

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