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Shear Strength Characteristics of Self Compacting Geopolymer Concrete Cast at Different Ages

Dhanabal G.
M.E. Structural Engineering, Department of Civil Engineering
Sri Krishna College of Technology Kovaipudur, Coimbatore

Dr. V. Sreevidya
Associate Professor, Department of Civil Engineering
Sri Krishna College of Technology, Kovaipudur, Coimbatore

Abstract: The shear strength characteristics of self compacting geopolymer concrete cast at different ages are studied in this project. This project shows how concrete strength, shear plane characteristics, reinforcement, and direct stress affect the shear transfer strength of reinforced concrete. Fundamental behavior of test specimens under load is reported, and hypotheses to explain the behavior are developed. It is concluded that shear-friction provisions of ACI 318-71 give a conservative estimate of shear-transfer strength below the stated limit of 800 psi. A design equation to develop higher shear transfer strength is presented.

I. Introduction

Numerous design cases require the calculation of the amount of reinforcement necessary to resist shear transfer across an interface between two concrete members that can slip relative to each other. The interface can be susceptible to a potential crack or can be cracked due to previous conditions such as external tension and shrinkage, and can be a cold joint. The interface between a precast girder and a cast-in-place deck slab, and the bearing zones in precast girders, corbels, and horizontal construction joints in walls, are examples of shear-transfer cases. Refer to Fig. 1(a).

The design for shear transfer has been largely based on empirical and semi-empirical methods that were developed using the experimental results from pushoff specimens and composite beam specimens. Figure 1(b) shows a typical pushoff specimen similar to that used in the early tests by Hofbeck et al. The applied compressive forces create shearing stresses (v) along the critical plane, which could be either precracked or uncracked. The shearing stresses at ultimate conditions are typically assumed to be constant along the interface plane, and an average shearing strength along the plane is calculated. These shearing stresses act in combination with compressive stresses (Fig. 1(b)).

There has been a considerable amount of experimental tests on pushoff specimens, which led to the development of numerous models. The well-known "shear-friction" model of the ACI Code is based on the assumption that a crack exists along the shear plane before the load is applied. The failure occurs by sliding along the shear plane and the opening of the crack around the aggregates. The clamping steel is stressed to its yield strength and a friction force proportional to the clamping yield force is activated. The ACI nominal shear strength is given by $v_{ACI} = \rho_y f_{y-y} \mu$

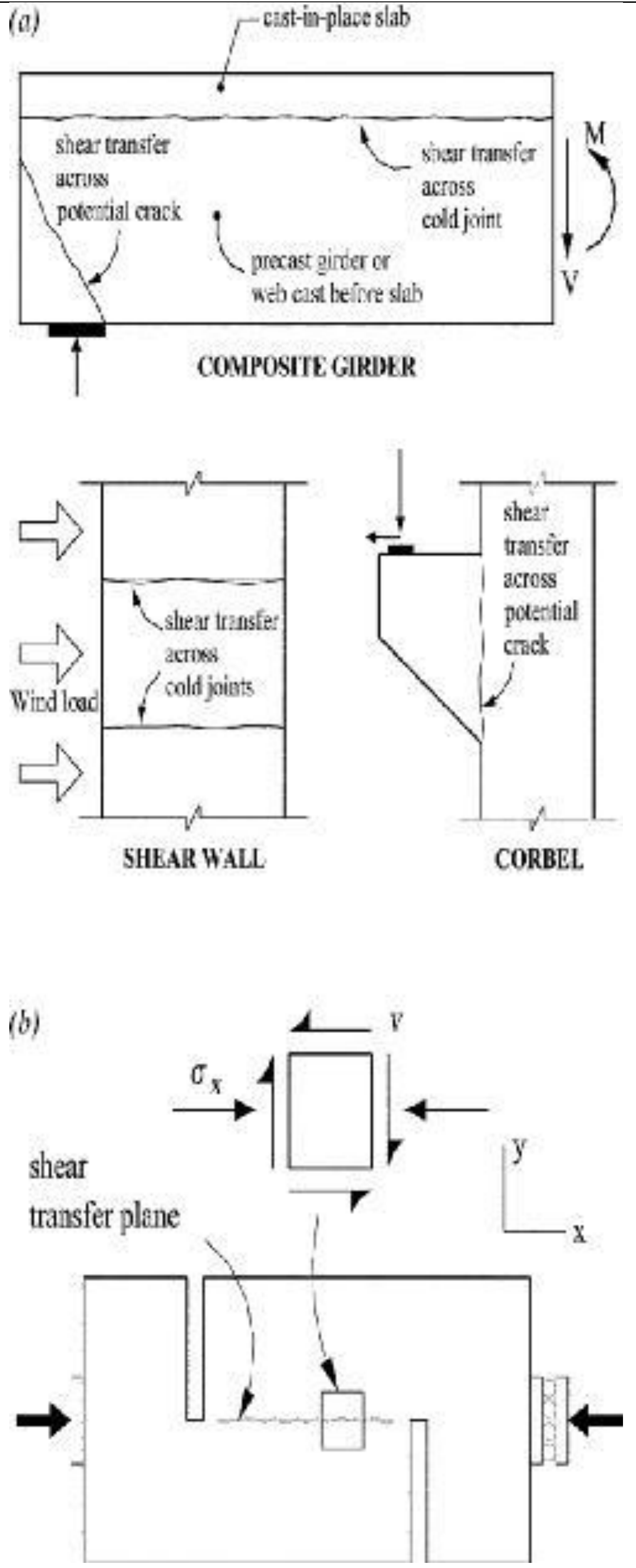
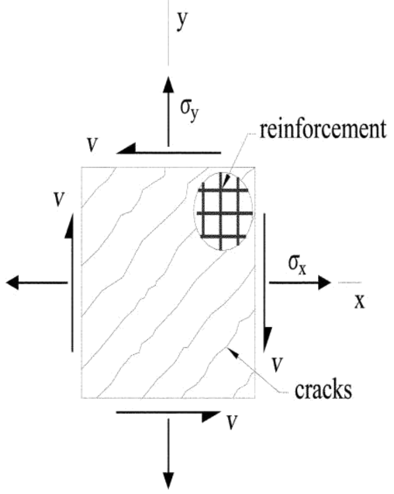


Fig. 1—(a) Examples of shear transfer in reinforced concrete structures; and (b) typical pushoff specimen and state of stress along shear transfer plane



SMCS Equations

$$\frac{v_{SMCS}}{f_c'} = \sqrt{\omega_x \, \omega_y} \le \kappa$$

$$\omega_x = \frac{\rho_x f_{y-x} - \sigma_x}{f'_c} \le \kappa$$

$$\omega_y = \frac{\rho_y f_{y-y} - \sigma_y}{f'_c} \le \kappa$$

$$\kappa = \tfrac{1}{3} - f_c'/900 \text{ (in MPa)}$$

$$= \tfrac{1}{3} - f_c'/130500 \text{ (in psi)}$$

Fig. 2—Membrane element subjected to in-plane stresses and summary of SMCS equations

Walraven et al.6 developed a model based on 88 test specimens with concrete strength ranging from 21 to 68 MPa (3000 to 9900 psi). The model relates the shear strength to the clamping reinforcement as well as fc′ , but does not place an upper limit on the shear strength

$$v_{WFP} = C1\,(C3\,\rho_y f_{y-y})^{C2} \qquad (2)$$

where $C1 = 0.88(f_c')^{0.406}$, $C2 = 0.167(f_c')^{0.303}$, and $C3 = 1$ in MPa ($C1 = 16.76(f_c')^{0.406}$, $C2 = 0.0371(f_c')^{0.303}$, and $C3 = 0.007$ in psi).

Hsu et al. adopted a more rational approach by considering the concrete along the shear-transfer plane to be a membrane element subjected to combined shearing and normal stresses. They used the equations of the softened truss model to calculate the shear strength and overall behavior. This analysis differs in concept from the more commonly used shear-friction models; however, the solution procedure is computationally deman other types of shear problems such ding and requires the use and Hsu.[14]

$$v_{MH} = (0.66\,f_c')\quad \rho_y f_{y-y} \le 0.3f_c' \qquad (3)$$

Loov and Patnaik[15] developed a similar equation for the nominal shear strength

$$v_{LP} = (0.6\sqrt{f_c'})\lambda\sqrt{0.1 + \rho_y f_{y-y}} \le 0.25f_c' \text{ (in MPa)} \qquad (4)$$

where λ is the factor to account for lightweight aggregates. The factor 0.1 is replaced by 15 in psi, and has a negligible effect at relatively large clamping steel. It was included to avoid “the discontinuities in the present codes at low clamping stresses.”[15]

Mattock[16] proposed a trilinear model calibrated using the results from 189 normalweight and lightweight test specimens with f_c' ranging from 16 to 99 MPa (2300 to 14,350 psi)

$$v_{Mat} = 2.25\rho_y f_{y-y} \quad \text{when } \rho_y f_{y-y} \le K1/1.45 \qquad (5a)$$

$$v_{Mat} = K1 + 0.8\rho_y f_{y-y} \quad \text{when } \rho_y f_{y-y} > K1/1.45 \qquad (5b)$$

but not greater than $0.3f_c'$ or 16.6 MPa (2400 psi) for normal weight concrete and $0.2f_c'$ or 8.3 MPa (1200 psi) for sand-lightweight concrete and all lightweight concrete. The factor $K1$ is taken as $0.1f_c'$ but not greater than 5.5 MPa (800 psi).

To account for a normal stress σ*y* acting perpendicular to the shear plane, the superposition of steel can be applied = and, consequently, the term ρ*y fy – y* is replaced by ρ*y fy – y –* σ*y*, where σ*y* is positive if tensile.

Equations (1) to (5) show that existing models are simple, but are empirical or semi-empirical. More rational models, such as those by Hsu et al.,[13] have the advantage of being applicable to other shear cases, but are iterative and, hence, are not readily suitable for use in a design office. The challenge is to develop a more rational model that shares the simplicity and accuracy of empirical methods.

A recently developed model called the simplified model for combined stress resultants (SMCS) is a simple, noniterative model for the calculation of the shear strength and the mode of failure of membrane elements subjected to in-plane shearing and normal stresses.[18] The model was generalized to apply to reinforced and prestressed concrete beams subjected to shear combined with flexure and axial forces,[19] to pure torsion,[20] and to torsion combined to flexure.[21] This paper extends the applicability of the model to solve the shear-transfer problem.

Research Significance

Most simple methods available to solve the shear-transfer problem in shear-friction specimens and across cold joints in composite beams are semi-empirical, and their application is limited as they cannot be applied to as shear and torsion in beams of a computer. A simple semi-empirical equation was subsequently proposed by Mau and shear in membrane elements. This paper presents a simple, noniterative model that is developed based on a rational theory and is applicable to other types of shear problems. The proposed model has a favorable combination of simplicity, generality, and accuracy in comparison with existing models.

SMCS for Pure Shear

The SMCS model developed for pure shear was applied without modification to the case of shear friction. A brief background of the development of the SMCS is presented. Full details of the model can be obtained from Rahal developed for the case of pure shear, and the effects of the normal stresses are accounted for using the concept of superposition.

The model assumes that the main factors that affect the pure shear strength of membrane elements are the amounts and the strength of the orthogonal steel and the concrete compressive strength. Other factors, such the maximum size of the coarse aggregate and the spacing and diameter of the reinforcement, have limited effects and are neglected in the simplified model. The three main factors are efficiently combined in the following reinforcement indexes.

Testing of Specimen

The test was conducted using a universal testing machine of 2000kN capacity. While testing the push off specimen was mounted on the testing machine in such a manner that the bar is pushed axially from the specimen. This operation is risky, because if the specimen is placed in the wrong position the results can be totally wrong. For this reason, different ways to place the specimen have been tested. The technique which provides better results consists of a steel plate located at the face of the specimen. On this plate, a steel piece is fixed and allows the specimen sliding. When the specimen is in the correct position another steel piece is placed. Over this face, the load cell is included so, the boundary conditions are similar in both the faces of the specimen. During this phase, both crack width and slip along the shear plane are measured using Linear Variable Differential Transformer (LVDT) was used to measure the displacement of the bar (Mattock 1972 Specifications). Load was applied to the reinforcing bars monotonically. The loading was continued until the specimen failed. The recordings of loads and deformations were carried out.

Testing of Push off Specimen

Formation of Cracks under Loading

Interface Shear Faiure in Specimen

The results obtained from the evaluation of strength and shear bond characteristics of Self compacting geopolymer concrete are listed as follows.

1. The ultimate load of monolithic self compacting geopolymer concrete 1 (SCGC-M1) was 150 KN and deflection was found to be 0.67 mm.
2. The ultimate load of monolithic self compacting geopolymer concrete 2 (SCGC-M2) was 152 KN and deflection was found to be 0.52 mm.
3. The ultimate load of self compacting geopolymer concrete 1 with cold jont (SCGC-C1) was 145.3 KN and deflection was found to be 0.26 mm.
4. The ultimate load of self compacting geopolymer concrete 2 with cold jont (SCGC-C2) was 134.7 KN and deflection was found to be 0.22 mm.
5. The ultimate load of self compacting geopolymer concrete (SCGC1)30 Days was 136.4 KN and deflection was found to be 2.87 mm.

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