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Punching shear resistance of concrete slabs using mode-II fracture energy

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A B S T R A C T

In this paper an analytical model is presented to predict the punching shear resistance of concrete slabs using fracture energy concept. The mode-II fracture parameters are obtained by conducting the experiments on double edge notched specimens. The model predicts the force displacements resistance during punching and the stress distribution along the cracked surface. Experimental investigation on punching shear resistance of concrete slabs is also reported to compare the model. The punching shear tests showed that the thickness of slab had a strong influence on the punching shear strength and also very good agreement between the predicted and experimental results.

1. Introduction

The resistance to the transverse effects of concentrated forces acting on concrete slabs is an essential problem in design of column footings, flat slabs and bridge slabs. Punching shear is usually the governing failure mode for flat slabs. In the slab column connections, high shear stresses are developed around supporting columns, which can lead to abrupt punching shear failure. The problem with this failure mode is that it is brittle and catastrophic due to the inability of the concrete to support the large tensile stresses that develop. This failure occurs with the potential diagonal crack following the surface of a truncated cone around the column. So punching shear in concrete slabs is a serious problem in a structural system.

Most research on the punching shear strength of slabs has been concerned with the generation of experimental data on simply supported slabs and the development of empirical equations. Theoretical analysis of punching shear strength of concrete slabs have been proposed by various investigators Braestrup [1], Jiang and Shen [2], Alexander and Simmonds [3], Yankelesky and Leibowitz [4] and Theodorakopoulos and Swamy [5]. These theories do not consider the post fracture properties of concrete.

Concrete is a quasi-brittle material that exhibits softening behavior as a result of micro cracking that develops due to its low tensile strength. In the punching shear, failure occurs by slipping of a truncated cone around the column with the adjacent concrete layer. Therefore, it is assumed that the energy dissipated per unit area of cracked surface is equal to the fracture energy of concrete in mode-II. Several experimental and numerical tests were carried out to determine the mode-II fracture energy. Bazant and Pfeiffer [6] and Reinhardt and Xu [7] proposed for mode-II fracture energy values about 25 times greater than those of mode-I fracture energy. Gunneswara Rao and Naga Satish Kumar [8] have suggested method to assess the mode-II fracture energy using the size effect method based on the experiments on double edge notched specimens.

2. Research significance

Current methods for estimating the punching shear strength of concrete slabs rely on empirical formulation to estimate the contribution of concrete. This approach, in some cases, leads to very conservative estimates of punching shear strength of

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Nomenclature

τ_{max}	maximum shear stress
Δ_{max}	slip at the maximum shear stress
Δ_{cri}	critical slip
θ	the inclination of the sliding surface with vertical
σ	normal compressive stress
d_a	maximum aggregate size
d	column diameter
G_{IIf}	mode-II fracture energy
D_s	support diameter of slab
P	punching resistance of slab
h	thickness of slab
MAS	maximum aggregate size

concrete slabs, but may also overestimate the contribution of concrete. In this paper a model for estimating the punching shear strength of concrete slabs based on the post-peak fracture properties of concrete is presented. The experimental results show that post fracture properties of concrete are necessary to understand the behavior of concrete slabs under concentrated loads. This work is expected to contribute for a better comprehension of the stress transfer mechanism along the cracked surface, particularly with respect to the qualitative and quantitative definition of mode-II fracture of concrete.

3. Analytical model

Consider a circular slab being connected to circular column which is subjected to an axial force (Fig. 1). The proposed model assumes that the shape of the sliding surface to be planar and the cracked surface is continuous and starts along the column circumference. The axial displacement μ, which is the relative displacement between the two rigid bodies of the slab and the column. The slip of the sliding surface is Δ, which is the tangential component of axial displacement. The crack width is 'w', which is the normal component of axial displacement. The rough crack surface geometry is responsible for dilation, or crack opening, accompanying shear displacement. When dilation is restrained to some extent, compressive stresses are developed normal to the cracked surface. Therefore two stress components are considered on the cracked surface i.e. shear stress (τ) and normal compressive stress (σ) (Fig. 1). The shear stress (τ) and normal compressive stress (σ) are assumed to be uniformly distributed along the planar inclined fracture surface. The tangential forces along the cracked surface contribute to an increase in the resistance and the compressive normal forces act to decrease the resistance.

A differential axi-symmetric surface area dA is

$$\mathrm{d}A = \frac{2\pi r\ dy}{\cos\theta}$$

where 'r' is the radius of the sliding surface at a distance of 'y' from the top of the slab and θ is angle between the vertical and sliding surface

$$r = \frac{d}{2} + \frac{(D_s - d)y}{2h}$$

$$\mathrm{Tan}\,\theta = \frac{D_s - d}{2h}$$

where 'd' is the column diameter, 'D_s' is the support diameter and 'h' is the thickness of slab.

The vertical component of shear resultant, acting on dA is

$$\mathrm{d}P_\tau = \tau\ \mathrm{d}A\ \cos\theta$$

The vertical force component resulting from the normal stress is

$$\mathrm{d}P_\sigma = \sigma\ \mathrm{d}A\ \sin\theta$$

Total punching resistance $(P) = \int(\mathrm{d}Pt - \mathrm{d}P\sigma)$

$$P = \int_0^h 2\pi(\tau - \sigma\tan\theta)r dy = 2\pi(\tau - \sigma\tan\theta)\left(\frac{hd}{2} + \frac{(D_s - d)h}{4}\right) \quad (1)$$

3.1. Shear stress and slip relationship

The shear stress and slip relationship established experimentally i.e. by performing a test on the double edge notched specimen of different grades of concrete with varying maximum aggregate size (MAS). The experimental results of double