Shear and moment transfer at column-slab connections

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Abstract

The Strip Model describes a load path for the transfer of vertical shear between a slab and column. The model is easily adapted to design but its application to the analysis of specimens tested under combined shear and moment is less clear. This paper provides a brief description of the Strip Model, updates the model to include size effect, and shows how it can be applied to interior and edge column-slab connections transferring combinations of shear and moment.

Keywords

Columns, connections, punching shear, reinforced concrete, shear strength, slabs, structural design.

1 Introduction

The Strip Model for slab punching shear, originally called the Bond Model (Alexander and Simmonds, 1992), describes an internal distribution for the transfer of vertical load between a two-way slab and column. The model may be considered an extension of the Strip Method of Design (Hillerborg, 1975). The Strip Method allows a designer to define a load distribution that rigorously satisfies equilibrium at all points in a slab and to reinforce the slab for the bending moments that are the consequence of that load distribution. The Strip Method as developed by Hillerborg does not address shear strength.

The Strip Model for slab punching shear is consistent with the Strip Method for flexural design but is focused on a particular problem: the development of an internal load distribution for shear transfer at concentrated loads that does not violate either shear or flexural strength limits at any point. This internal load distribution is derived from subdividing the slab into regions dominated by slender flexural behavior (B-regions) and regions dominated by deep beam behavior (D-regions). The result is a model for shear transfer that can be verified by direct measurement (Alexander et al., 1995).

The distinguishing characteristic of a B- or D-region is the predominant mechanism of moment gradient (i.e. shear transfer). In a slender beam, moment gradient is mostly the result of a varying flexural tension force acting on a more or less constant moment arm. Such behavior is called **beam action**. In a deep beam, moment gradient results from a constant tensile force acting on a varying moment arm. This behavior is called **arching action**.

It is appropriate to describe shear transfer by beam action in terms of an average shear stress acting on the cross-section. A reasonable design strategy for slender members is to limit the average shear stress to some critical value; however, an average shear stress does not model the behavior in a D-region. D-regions are more correctly modeled using strut-and-tie.

Column-slab connections exhibit the characteristics of both B- and D-regions. Tests show that radial arching action is an important mechanism of shear transfer between a slab and a column, suggesting that column-slab connections should be considered D-regions. In the circumferential direction, however, column-slab connections behave more like B-regions.

This paper provides a brief summary of the mechanics of the strip model and extends the model to account for size effect. It then introduces the concepts of non-proportional loading and shows how these are used to describe the transfer of shear moment at a column-slab connection.

2 Strip model for concentric punching

2.1 Internal load distribution

The Strip Model divides the slab into radial strips and plate quadrants, as shown in Fig. 1. No load can reach the column without passing through one of the radial strips. Within each radial strip shear is carried to the column by arching action. This is visualized as a curved arch, with ma[illegible] drants of two-way slab are f[illegible] sfer across the boundary betw[illegible] wo-way plate equivalent of beam action.

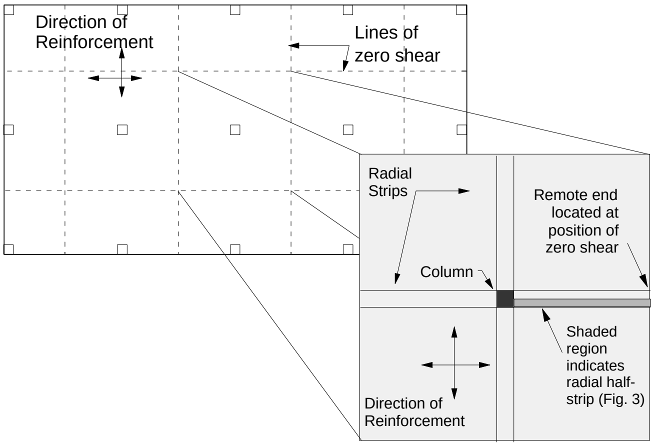

Figure 1: Geometry of Strip Model.

Consider the compression arch shown in Fig. 2. The compression force in the arch is approximately constant throughout. At the column face, the vertical component of the arch accounts for the shear transferred to the column; the horizontal component provides a flexural compression.

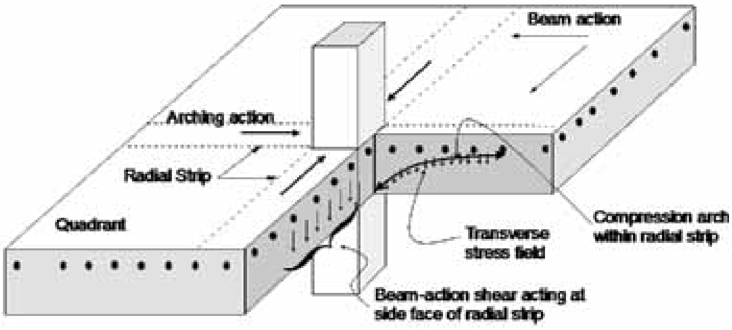

Figure 2: Beam and arching action at column-slab connection.

Moving away from the column, the slope of the arch decreases. Vertical equilibrium of the arch requires that there be a transverse stress field. The transverse stress field is internal and is generated by the two-way plate equivalent of beam action shear acting in a direction perpendicular to the arch. Thus, the model is of the interaction between the slender quadrants of plate and the radial strips acting as deep beams.

Figure 3 shows a free body diagram of half of a radial strip. The half-strip is loaded on its side face by a combination of plate bending moment, m_n, torsional moment, m_t, and shear, v. The strip is supported by a vertical reaction, P_s, at the column-supported end and bending moments, M_{ne}

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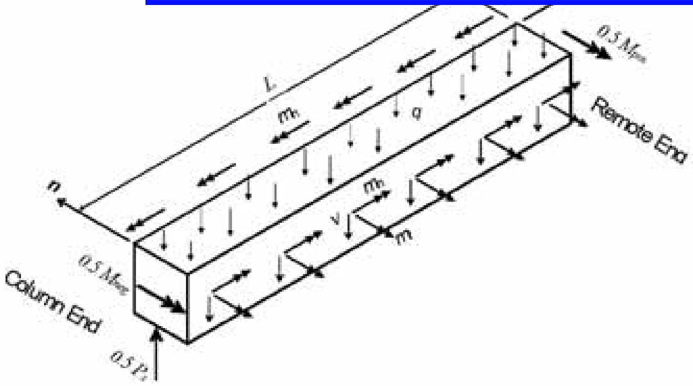

Figure 3: Forces on radial half-strip.

The internal vertical shear at any point along the side face of a radial strip is a function of the gradients of bending and torsional moments at that point. Alexander and Simmonds (1992) and Afhami et al. (1998) examine the various components of this internal shear in some detail to justify the simplified free body diagrams of radial strips at ultimate load, shown in Fig. 4. The loading term, w, is the limiting one-way shear that can be carried by the slab. An internal radial strip, such as those shown in Fig. 1, is loaded on two faces; hence the total distributed line load on the strip is $2w$. At an edge column, a spandrel strip running parallel to the free edge of the slab would be loaded on only one side and so would be subject to a line load of w.