InSights

new trends, new techniques and current industry issues

Punching of Slabs

A Discussion on the Development of the Delamination of Concrete Cover in the Soffit of the Slab

By Aurelio Muttoni, Ph.D., Miguel Fernández Ruiz, Ph.D., and João T. Simões

Aurelio Muttoni is a Professor at École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland. He can be reached at **aurelio. muttoni@epfl.ch**.

Miguel Fernández Ruiz is a Senior Lecturer at École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland. He can be reached at **miguel.fernandezruiz@epfl.ch**.

João T. Simões is a PhD student at École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland. He can be reached at **Joao.simoes@epfl.ch**.



unching shear behavior is a topic that has attracted much attention from engineers in the last decades because of several collapses caused by punching shear failures. Introducing transverse reinforcement is the most common solution when the geometry of the slabcolumn connection has to be maintained and punching shear resistance has to be increased. To that aim, several transverse reinforcement systems may be used, not only to increase the punching shear resistance but also to significantly increase the deformation capacity and the residual strength after a local failure. If usual detailing rules are fulfilled, the design of slabs with shear reinforcement is governed by one of the following three potential failure modes: 1) crushing of the concrete struts in the column vicinity (maximum shear strength, see Figure 1a); 2) punching within the shear reinforcement (governing the dimensioning of the transverse reinforcement, Figure 1b); and 3) punching outside the shear-reinforced region

(governing the dimensioning of the size of the zone with shear reinforcement), *Figure 1c*.

Several experimental investigations of slabs with transverse reinforcement available in the literature have

revealed the development of horizontal cracking at the height of the compression reinforcement, which can be seen as a delamination of the concrete cover in the soffit of the slab. Questions might arise whether its potential occurrence influences or even governs the punching shear behavior and whether this effect should be accounted for in the design. To investigate the influence of this phenomenon, the origin and the development of such cracking should be understood. According to the several test programs, the phenomena leading to cover delamination appear to be multiple. Several authors of experimental studies have mentioned that delamination of concrete cover in the soffit of the slab could be observed before failure, even in cases where failures were shown to be within the shear-reinforced region or by crushing of concrete struts. This has also been observed in

slabs with shear reinforcement recently tested by the authors and presenting a failure due to crushing of concrete struts (*Figure 2*). The origin of this delamination can be explained by the tangential strains developing at the column vicinity as a function of the rotation of the slab (*Equation 1*).

$$\mathcal{E}t = \frac{\Psi}{r} \cdot c$$
 Equation 1

Where Ψ is the rotation of the slab, r the radial distance from the center of the column, and c the height of the compression zone. For large rotations, tangential strains in the vicinity of the column may largely exceed the peak uniaxial strain of concrete (more than 0.5% in many cases). The concrete cover, which is not confined by any reinforcement, enters a softening stage and a strain localization (horizontal cracking) occurs at the level of the compression reinforcement. This effect becomes more pronounced for large rotations, which are normally observed in slender slabs with shear reinforcement. The delamination of the concrete cover typically occurs in the critical shear region and reduces the lever arm in both radial and tangential directions. This phenomenon may constitute a limitation of the maximum punching shear strength. The impact of this effect on the efficiency of different transverse reinforcement systems deserves further research.

Another common situation where delamination is observed occurs in a punching failure outside the shear-reinforced region. In this case, an inclined shear crack develops between the flexural reinforcement and the bottom of the last perimeter of transverse reinforcement (*Figure 1c*), together with horizontal cracking joining the bottom of the inclined shear crack and the column face. The *Model Code for Concrete Structures* 2010 (International Federation for Structural Concrete) already accounts for this phenomenon in the punching shear design for a failure outside the shear-reinforced area (considers a reduced effective depth).

Delamination of the concrete cover under transverse reinforcement can also occur when



Figure 1. Different failure modes of flat slabs with shear reinforcement: a) crushing of concrete struts; b) failure within the shear-reinforced region; c) failure outside the shear-reinforced region; d) failure by delamination.

70 June 2017



Figure 2. Specimen tested by the authors with failure due to crushing of concrete struts near the column; pronounced delamination observed in the soffit of the slab.

a large tangential distance between rows of transverse reinforcement is present in a radial and particularly in a cruciform arrangement. In these cases, inclined shear cracks might start developing first in between the rows of transverse reinforcement, followed by a tangential propagation until reaching the transverse reinforcement elements. If the amount of transverse reinforcement is low, a failure within the shear-reinforced area can occur. On the other hand, if a large amount of shear reinforcement is used, two situations can follow:

If the last perimeter of shear reinforcement is not sufficiently distant from the column to avoid a punching failure outside the shearreinforced area, the inclined cracks already formed in between the rows of transverse reinforcement will tend to propagate tangentially through the formation of a separation crack (delamination) at the level of the compression reinforcement (without crossing the transverse reinforcement elements). This will be completed by inclined shear cracks around the rows of transverse of reinforcement (*Figure 3a*).

If the last perimeter of shear reinforcement is sufficiently distant from the column, crushing of concrete struts will be the governing failure mode. In this case, the inclination of the failure surface in the areas between the transverse reinforcement rows is flatter than that developing in the regions of transverse reinforcement (*Figure 3b*).

To deal with the development of non-uniform failure surface, codes normally limit both 1) the tangential distance between rows of transverse reinforcement at the location of the control perimeter, and 2) the maximal distance of straight lines of the outer control perimeter.

Finally, when some important detailing rules are not respected, delamination may also occur (*Figure 1d*). This is the case of transverse reinforcement not embracing the flexural compression and tension reinforcement, which leads to a slab cover delamination and premature failure, although usually associated with large deformation capacities.

In conclusion, delamination of the compression zone is mostly a matter of poor detailing: transverse reinforcement units too distant in the transversal direction, and cover of transverse reinforcement too large.•

The online version of this article

contains detailed references. Please visit

www.STRUCTUREmag.org.



Figure 3. Scheme of punching shear failures with non-uniform location of the failure surface: a) failure outside the shear-reinforced region; b) failure by concrete crushing.

DRIFT. Deflection. Done.

INTRODUCING DRIFT FASTCLIP[™] SLIDE CLIP.

Need a deflection solution that also accommodates horizontal drift? Drift FastClip allows 2-inch vertical and lateral deflection, and works with FastClip screws for friction-free sliding. Get more details and data at **clarkdietrich.com**.

