Shear Strengthening of Existing Reinforced Concrete Slabs : an Experimental Investigation

Philippe MENETREY
Structural Engineer,
Emch+Berger AG
Bern, Switzerland

Philippe Menétrey, born 1963, received his civil engineering and doctoral degrees from the Swiss Fed. Inst. of Tech. in Lausanne and his Master of Science degree from the Univ. of Colorado at Boulder (USA). He has been involved in experimental and numerical research on punching failure in reinforced concrete.

Eugen BRÜHWILER
Professor
Swiss Federal Inst. of Techn.
Lausanne, Switzerland

Eugen Brühwiler, born 1958, received his civil engineering and doctoral degrees from the Swiss Fed. Inst. of Tech. (ETH) in Zurich and Lausanne. Post-doctoral stay at the Univ. of Colorado, Boulder (USA). Four years with the Swiss Federal Railways. Since 1995, he is Professor at ETH Lausanne.

Summary

The strengthening of existing reinforced concrete slabs with vertical posttensioned steel bolts is investigated by testing six slabs. Shear strengthening increases the failure load and leads to a more ductile behavior. By prestressing or injecting the bolts, the peak-load is only slightly increased, but the slip of the bolt inside the slab is avoided and therefore, the serviceability is improved. The prediction of the peak load for slabs with both injected and non-injected bolts is discussed.

1. Description of the experiments

The punching tests (Menétrey and Brühwiler [1]) are performed on octagonal slabs of 1.2 m in diameter and 120 mm thick, supported at its extremity by RHS steel pieces (arranged around a diameter of 1.1 m) and loaded at the center through a circular steel column (diameter 120 mm) with an hydraulic jack by controlling the vertical displacement. The concrete compressive strength on cylinder after 21 days is f_c=33.4 MPa. All slabs are reinforced with horizontal orthogonal bars (steel quality S500) at the bottom and at the top. The percentage of the bottom reinforcement is ρ=0.94%. Slab 1 is not strengthened and slabs 2 to 6 are perforated and strengthened with eight high strength steel bolts placed around a radius of 140 mm equiped with force measuring device. The strengthening system is composed of a bolt type M 10 with an ultimate tensile strength: f_u= 851 MPa, yield strength at 0.2% strain: f_y = 736 MPa. The bolts of slabs 3, 5 and 6 are post-tensioned with the nut on top of the slab. The injection around the bolts are set for slabs 4, 5 and 6 with an epoxy-resin.

2. Tests results

The test results are presented with the load-displacement curve (Fig. 1a) and the mean force in the bolts versus the vertical displacement of the slab (Fig. 1b). It follows that the punching load is increased from 280 kN up to 380 kN or 37% due to the strengthening. The vertical displacement at maximum load is significantly increased by the strengthening as it has more than doubled. It is observed that slab 1 is characterized by a punching cone inclined at an angle of approximately 30^0. For all strengthened slabs, the punching cone is formed between the column diameter and the perimeter defined by the bolts. The inclination of the punching cone is approximately 70^0 (Fig. 2). This means that all the strengthened slabs exhibit a punching failure which is characterized by a punching crack that did not cross the strengthening bolts.

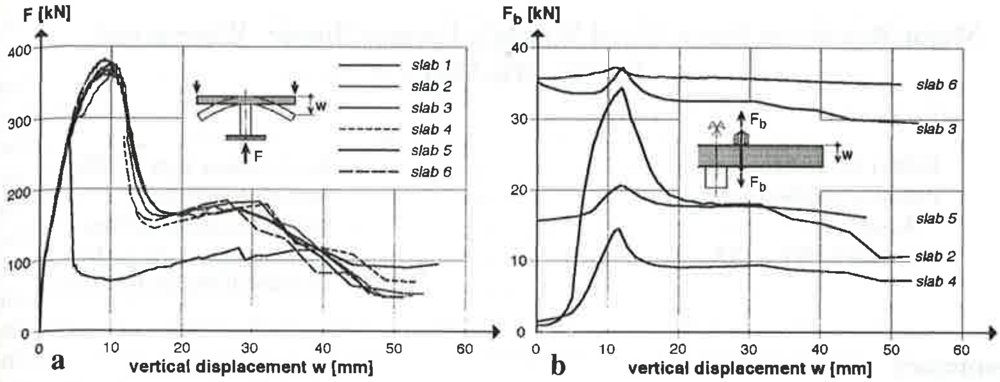

Fig. 1: Load-displacement curves and mean force in the bolts versus vertical displacement

The post-peak descending branch of the load-displacement curve is characterized by a strong reduction of the load carrying capacity with increasing displacement characterizing punching failure (Fig. 1a). After peak, the first drop of the load carrying capacity is about 200 kN for all the slabs (strengthened or not) which indicates that this decrease is due to a similar failure mechanism, that is, the concrete failure.
The present experimental results are similar to the well known characteristic of bolted joints in steel construction for which the failure load for both with and without prestressing force is the same. In addition, prestressing the bolts improves the serviceability of structures.
Injection modifies the slab mode of resistance so that it resists globally resulting in reduction of the stress level in the bolts (compare slab 2 and 4 in Fig. 1b). The injection also improves the serviceability of the slab and provides a protection against corrosion of the bolts.

3. Prediction of the punching load

The punching load for the slab without strengthening bolts is predicted with the analytical model developed by Menétrey [2] which leads to V_{pun}=250 kN. The punching load of the strengthened slabs with a punching crack inclination of 70^0 is influenced by the punching and the flexural strength (as proposed by Menétrey [3]) resulting in V_{fail}=364 kN.

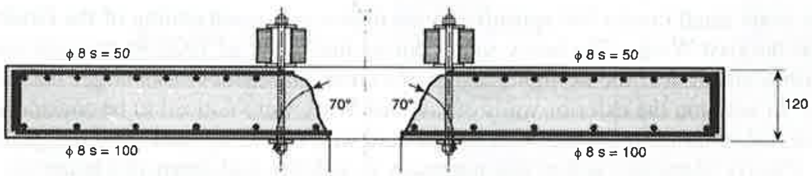

Fig. 2 : Sketch of the punching crack in the strengthened slab

The punching load of slabs strengthened with non-injected bolts is obtained by adding the dowel and the bolt strength. The punching load of slabs strengthened with injected bolts is recovered by adding the concrete, the dowel and the bolt strength.

References:

[1] Ph. Menétrey and E. Brühwiler. Shear strengthening of existing reinforced concrete slabs under concentrated loads, Report MCS-EPFL, CH-1015 Lausanne, 1996.
[2] Ph. Menétrey. Analytical computation of the punching strength of reinforced concrete. ACI Structural Journal, 93(5), 1996.
[3] Ph. Menétrey. Relationships between flexural and punching failure. Submitted to ACI Structural Journal.