

Strengthening of concrete slabs by bonded reinforcement to increase punching resistance

R. Suter & L. Moreillon
University of Applied Sciences of Fribourg

ABSTRACT: Strengthening of concrete slabs to increase punching resistance with bonded reinforcement is currently not allowed by the majority of codes because of the lack of specific theoretical and experimental studies. For this reason, the University of Applied Sciences (UAS) Fribourg carried out a theoretical and experimental research on strengthening of concrete slabs by bonded reinforcement to increase punching resistance. The experimental studies include nine load tests on concrete slabs of 2.40 m x 2.40 m and a thickness of 200 mm. These slabs were strengthened by high performance composite material: CFK laminates, prestressed or not prestressed; CFK laminates with or without a mechanic anchor system; carbon, aramide and glass fiber sheets. A significant increase of punching resistance has been proved, in particular on slabs strengthened by prestressed CFK laminates and laminates with mechanic anchor systems. On the basis of these experimental studies, the proposed strengthening technique could be applied for cases which are similar to the tested examples. However, the establishment of general recommendations for the design of bonded reinforcement requires additional studies.

1 INTRODUCTION

Concrete slab punching is a complex process which is still not completely resolved. Many research projects have been dedicated to punching, and many scientific and technical papers have been written [1,3,4]. Different technical solutions have been developed to ameliorate concrete slab punching resistance. For new constructions there are many solutions which go from the amelioration of the concrete's quality to the integration of metallic punching heads. For the reinforcement of existing slabs, the possibilities are limited to a much more restrictive choice.

Various tragic accidents that have happened in Switzerland and abroad have highlighted the problem concerning concrete slab punching. They have also shown that such destruction can happen without any warning signs over a few seconds and in a chain reaction. An analysis carried out in Switzerland following the collapse of an underground car park showed that a large number of slabs no longer respected the prescribed security codes. This report is particularly relevant for underground car parks which have been covered with a layer of earth thicker than that initially planned, in order to favour plant growth.

According to national codes the owners are responsible for the security of their property. They are under obligation to control the state of their underground car parks. The engineer determines the security of the existing structure and, where necessary, advises on measures of reinforcement. It is therefore urgent for the building industry to develop methods of reinforcement against punching of concrete slabs.

The construction standards generally allow taking into account the flexural reinforcement of a slab for the punching dimensioning [1]. Therefore it is possible to increase the calculation value of punching resistance by increasing the flexural reinforcement of the slabs. The addition of a bonded reinforcement, in the form of plates or fabrics made of composite or steel material could be an elegant and non-destructive way of reinforcement.

Currently the bonded reinforcement technique against punching is restricted by certain national standards [1,2]. These standards are based on the state of knowledge at the time of their drafting, where reliable theoretical and experimental research was still lacking. What's more, punching causes oblique cracks concentrated in the zone of the column head. Such cracks can have very unfavourable consequences for the thin CFK composite laminates, from partial separation of the plates to the sudden rupture of the connection.

Between 2005 and 2006, the University of Applied Sciences of Fribourg carried out a vast research project on the reinforcement of concrete slabs by means of bonded reinforcement. This project includes several studies one of which is punching reinforcement. The aims of the theoretical and experimental studies consist in:

- the increase of the resistance in punching and bending of the slabs according to the various reinforcements applied,
- the analysis of the behavior of the different slabs at ultimate and serviceability limit states,
- the establishment of a resistance model in order to allow the dimensioning of the punching reinforcement of concrete slabs.

2. EXPERIMENTAL STUDIES

The experimental studies were carried out on nine slabs, including seven with bonded reinforcement. The test slabs are mainly differentiated by their specific reinforcements. Two slabs with different internal reinforcement are tested as references. The load tests are carried out in the laboratory at the UAS of Fribourg, on the punching test bench which has a capacity of 4000 kN. This device includes a hydraulic actuating cylinder placed at the center of the slab, whereas the slab is retained in eight places by steel bars fixed to the ground (fig.1,2).

The test elements have a surface of 2.40 m x 2.40 m and a thickness of 200 mm. The main reinforcement consists in bars which have diameter 10 mm, separated by 150 mm, in both directions. For the reference slab II, this reinforcement consists in bars which have diameter 9 mm, separated by 75 mm, in both directions. The load is applied to a surface of 240 x 240 mm.

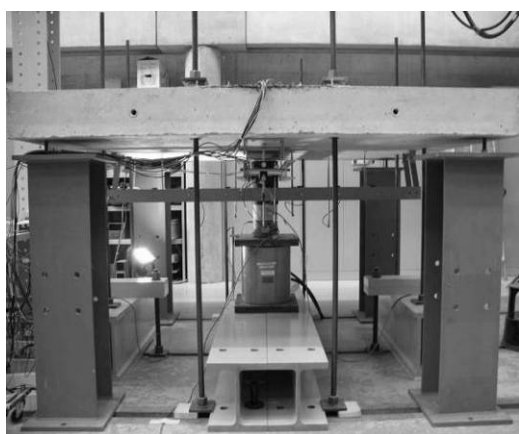


Figure 1 : Punching test bench

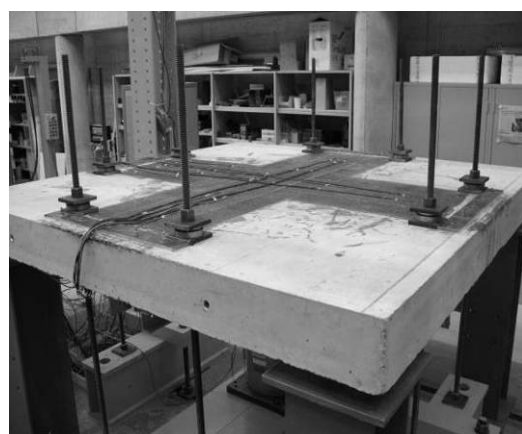


Figure 2 : Slab retaining device

The slabs are characterized by the type and material of reinforcement used. The design features of the elements are described in table 1.

Table 1 : Summary of the slab test elements and the test results

Element	Reinforcement	Denomination	Maximal force	Force difference	Maximal deflexion	Deflexion difference
DA-01	Steel bars	Reference I	470 kN	Reference	36 mm	Reference
DA-02	Steel bars	Reference II	527 kN	+ 12,1 %	23 mm	-36.1 %
DA-03	Steel	Plates	487kN	+ 3,6 %	38 mm	+5.5 %
DA-04	Carbone	Anchored laminates	498 kN	+ 6,0 %	24 mm	-33.3 %
DA-05	Carbone	Prestressed laminates	606 kN	+ 28,9 %	24mm	-33.3 %
DA-06	Glass	G Sheet 90/10-800	488 kN	+ 3,1 %	20 mm	-44.4 %
DA-07	Aramide	A Sheet 120-320	512 kN	+ 8,9 %	22 mm	-38.9 %
DA-08	Carbone	C Sheet 240-300	564 kN	+ 20,0 %	22 mm	-38.9 %
DA-09	Steel	Anchored plates	620 kN	+ 31,8 %	26 mm	-27.8 %

3. TEST RESULTS

For each test, observations were made during stage I (not cracked), stage II (cracked) and in the plastic range (stage III). In general, all the means of reinforcement tested allowed an increase in load before punching destruction. This increase varies from 3 to 30% according to the type of reinforcement, plates, laminates or sheets, as well as the nature of material used.

The reference slab DA-01 undergoes an important plastic deformation of the reinforcement followed by punching rupture located at the end of stage III (fig. 3,4). The reinforced slabs all suffer a sudden punching rupture at the beginning of stage III. This is shown by a reduction in the vertical deflections with an increase of the force at the moment of rupture.

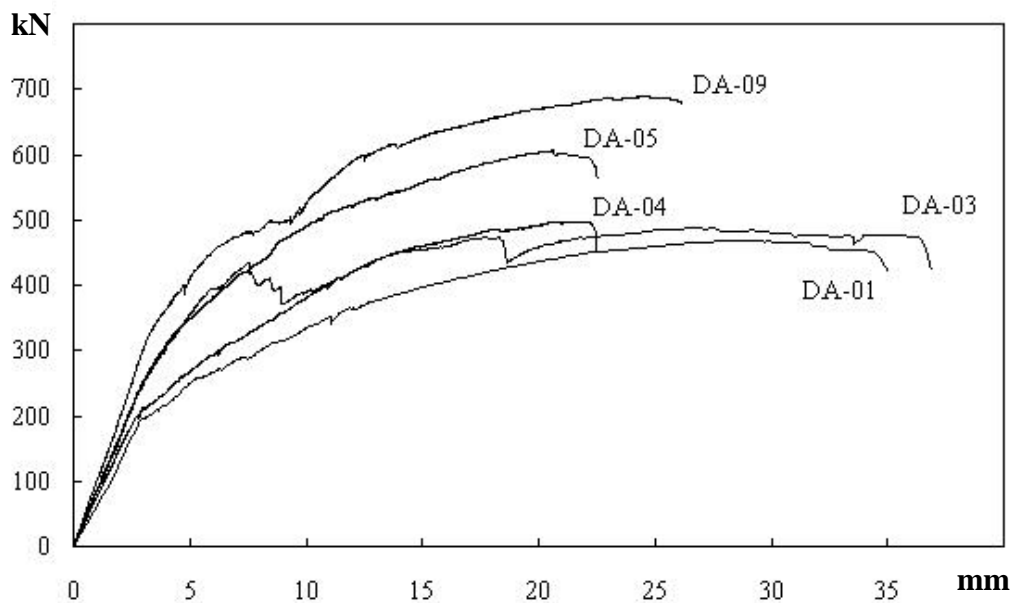


Figure 3 : Evolution of the deflection : slabs reinforced by laminates

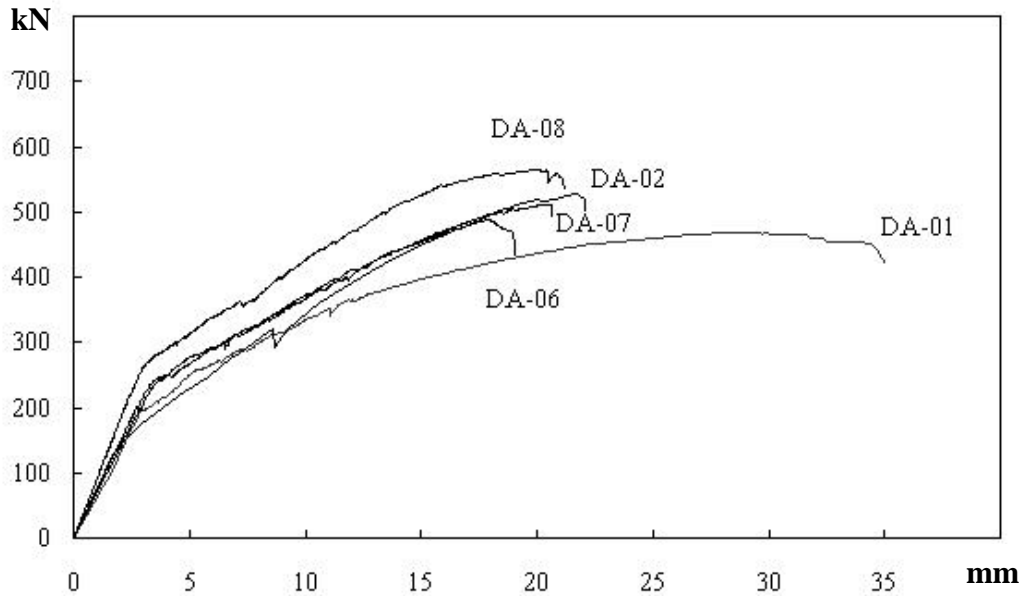


Figure 4 : Evolution of the deflection : slabs reinforced by sheets

Slab DA-03, reinforced by non anchored steel plates, shows a much higher rigidity on the first part of the loading process. The bondage between the glue and the concrete gives way with the plastic deformation of the plates. The end of the test corresponds to that of the reference slab. The steel plates have an important effect on stages I and II but they quickly detach and therefore require suitable anchoring. Slab DA-09 was provided with anchors which were mechanical sealed on the edges. The increase in resistance obtained is approximately 32%.

Reinforcement by CFK anchored laminates (DA-04) shows an increase in resistance of only 6% whereas, for the same section, the pre-stressed laminates (DA-05) allow an increase of 29%. The normal force due to the pre-stressing has an important effect on the punching resistance by limiting cracking of the slab in the critical zone.

Slab DA-06, reinforced with glass fibre sheets has a rather weak increase in resistance for a relatively high degree of reinforcement. The modulus of elasticity of glass being weak, the reinforcement has little effectiveness. Slab DA-07 reinforced with aramide fiber sheets has an increase in resistance of about 9%. Slab DA-08 reinforced with carbon fiber sheets shows better behaviour in stage I and II. The rigidity is clearly improved compared to slabs DA-06/7, because of the higher Young's modulus of carbon fibers. The increase in resistance is 20%.

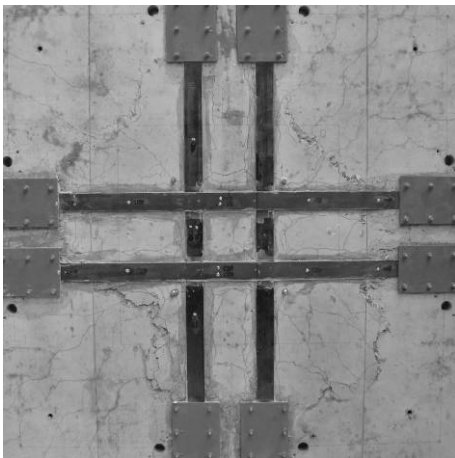


Figure 5 : External cracks of slab DA-05

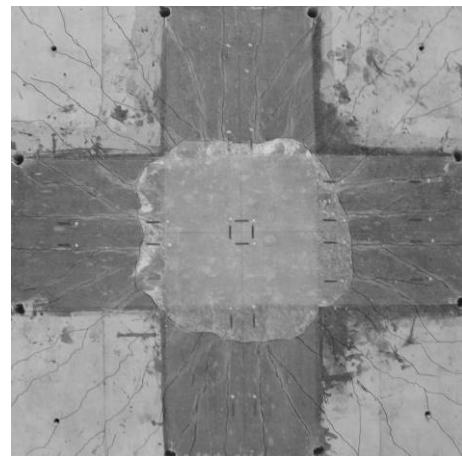


Figure 6 : External cracks of slab DA-06

Destruction by punching is negatively influenced by the propagation of flexural cracks. These flexural cracks are directly related to the deformations to the top point of the columns. The tests show two types of cracks, cracks parallel to the reinforcement (fig. 5) and the radial cracks (fig. 6). Parallel cracks are much more evident on the slabs reinforced with plates. This is explained by an increase in local rigidity due to the plates.

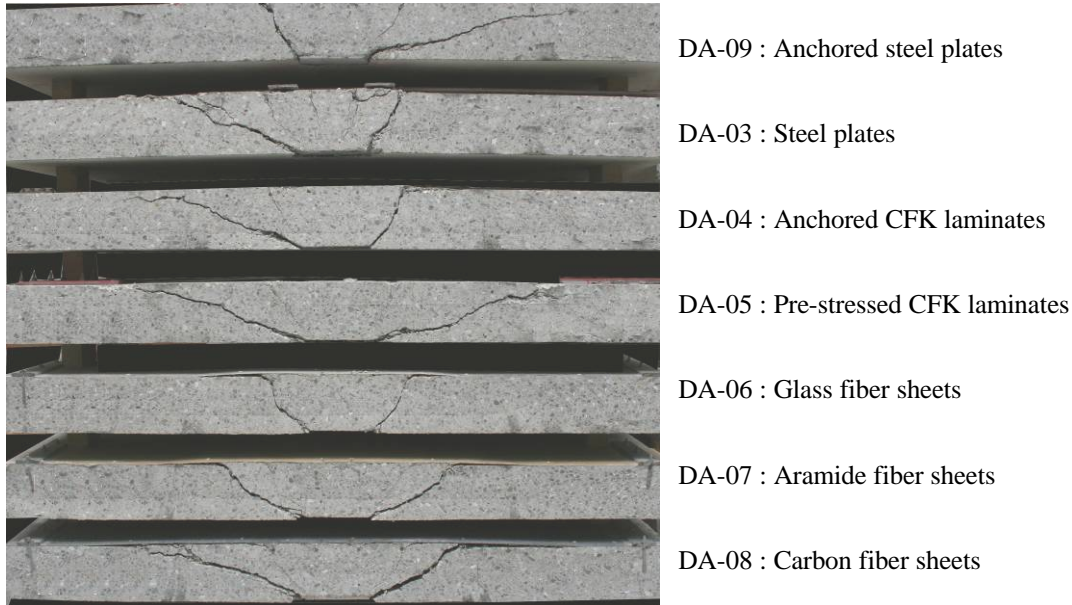


Figure 7 : Comparison of internal cracks

By sawing the reinforced slabs it was possible to observe the state of internal cracking after rupture (fig 7). The position and the diffusion of the cracks strongly depends on the reinforcement characteristics. All the elements present, inside their punching cone, two symmetrical cracks. This is the first punching cone which, depending on the type of reinforcement, is interrupted. With the exception of the slab reinforced with glass fibers, a second punching cone appears where the rupture occurs. The inclination of the internal cracks is related to the type of as well as the Young's modulus of the material.

The introduction of a normal force is effective in the case of the pre-stressed plates in that it is possible to delay and limit the opening of the cracks. Additionally, their internal inclination is weak. On the contrary, a material like glass having a weak Young's modulus does not avoid the formation of the first punching cone.

4. CONCLUSIONS

Concrete slab punching is a complex process which is still not completely resolved. For new constructions many technical solutions have been developed to ameliorate concrete slab punching resistance. For the punching reinforcement on existing slabs, the possibilities are limited to a more restrictive choice. There is in fact a need to develop methods of reinforcement against punching in concrete slabs.

The standards of construction generally allow to take into account the rate of flexural reinforcement with the right of the columns to determine punching resistance. The addition of a bonded reinforcement, in the form of plates or sheets of composite material proves to be an elegant and non-destructive means of reinforcement. Currently the bonded reinforcement technique is restricted by certain national standards. These standards are based on the state of

knowledge at the time of their development, where reliable theoretical and experimental research was still lacking.

In response to this need, the University of Applied Sciences of Fribourg undertook a vast research project on punching strengthening by means of bonded reinforcement. The theoretical and experimental studies related to the analysis of nine slabs of which seven were strengthened by means of reinforcements bonded in the form of plates or of sheets. These tests showed that the bonded reinforcement allows an increase in load of 6 to 30 % before punching destruction.

Generally this resistance is influenced directly by the rigidity of the reinforcement. The introduction of a normal force proves effective in the case of the pre-stressed plates while making it possible to delay and limit the opening of the cracks. The anchoring conditions of the plates have a great importance. After their detachment they act as pretension ties. On the contrary, the reinforcements by means of sheets, due to their great contact surface, only detach in the central part of the slab.

The reinforcement by pre-stressed CFK laminates, anchored steel plates, and carbon fiber sheets showed the best results and have an interesting development potential. However, the establishment of recommendations for the design of bonded reinforcement concerning dimensioning requires additional studies. These studies must, specifically, be completed by tests on slabs with a higher flexural reinforcement rate in order to quantify with more reliability the contribution of the bonded reinforcement against punching resistance. The combination of various types of sheets or the application of CFK laminates placed in cuts in the concrete could be new routes to follow.

ACKNOWLEDGEMENTS

The theoretical and experimental studies were carried out within the research project UAS Fribourg no 14'105 "Strengthening of structures by means of composite materials". They benefit from research funds laid out by strategic reserve of the University. The studies were also sponsored by S&P Clever Reinforcement Company in Brunnen (Switzerland). This sponsorship is gratefully acknowledged.

REFERENCES

- [1] *fib* Bulletin 12/2001, *Punching of structural concrete slabs*, Technical Report, International Federation for Structural Concrete *fib*, Lausanne-CH, 2001.
- [2] Swiss Society of Engineers and Architects, *Code SIA 262 Concrete Structures*, 2003.
- [3] Swiss Society of Engineers and Architects, *Code SIA 166 Armatures collées*, 2003.
- [4] Muttoni A. , *Schubfestigkeit und Durchstanzen von Platten ohne Querkraftbewehrung*, Beton- und Stahlbetonbau, 2003.
- [5] Guandalini S. , *Poinçonnement symétrique de dalles. Thèse 3380/2005* : EPF Lausanne.
- [6] Suter R., Nicolet J. , *Renforcement de dalles en béton au moyen de têtes de poinçonnement collées*, Rapport d'essais, EIA Fribourg, 2007.
- [7] Suter R., Moreillon L. , *Renforcement de dalles en béton contre le poinçonnement au moyen d'armatures collées*, Rapport d'essais, EIA Fribourg, 2007.