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EHANCED SAFETY WITH POST-INSTALLED SHEAR REINFORCEMENT

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Abstract

The safety of existing concrete slabs against shear may be insufficient for several reasons such as design and construction errors, structural modifications or increased loads. Moreover, the knowledge about shear design has significantly increased over the last few decades and therefore, even structures correctly built according to older codes may not comply with newer codes based on the latest state of the art.
This paper presents a method to enhance the one way shear strength of RC slabs or beams by post-installed shear reinforcement. The reinforcement is bonded into inclined drilled holes from the bottom of the slab and anchored at the end by anchor heads. Compared to other methods, this has the advantages that the strengthening work can be carried out from one side of the structure and that the dimensions of slab are not modified.
A series of beam shear tests has been performed to assess the influence of the geometric layout of the reinforcement as well as the anchorage. The tests show a clear strength increase due to the post-installed reinforcement.

Keywords: Post-installed reinforcement, Shear, Strengthening,

1 Introduction

Recent research has shown that the strength of one-way slabs without transverse reinforcement is usually governed by its shear strength (Vaz Rodrigues et al.2008). In addition, design loads have also been increased in codes of practice due to heavier traffic. As a consequence, a number of bridge decks slabs, cut-and-cover tunnels and other one-way slabs show the necessity to be shear-reinforced when assessed according to current state-of-the-art.
In the following sections a method is presented to install shear reinforcement into hardened concrete. The method of post-installed shear reinforcement has successfully been implemented for strengthening of flat slabs (Kunz et al., 2008) or foundation slabs (Gonzalez, Fonseca 2009) against punching or two way shear. Research by Fernández Ruiz et al. (2010) has also led to a design concept based on the critical shear crack theory according to the fib model code (2012) design principles for punching. Similar strengthening methods used for one way shear were presented by Randl, Kunz (2009) or Valerio et al. (2009). In order to validate post-installed shear reinforcement also for the strengthening of concrete slabs or beams against one way shear, a series of beam tests was initiated. This paper shows the efficiency of the method for strengthening against one-way shear by describing four beam tests and interpreting the results.

2 Strengthening of slabs with post-installed shear reinforcement

Existing slabs can be strengthened by various means: by increasing the thickness of the slab by concrete overlays or by adding post-installed shear reinforcement. Obvious advantages of the latter method are that the original geometry can be maintained, that the installation work can be carried out from one side of the slab and that the intervention remains invisible. As opposed to concrete overlay technique, the size and weight of the structure are not increased by this method.

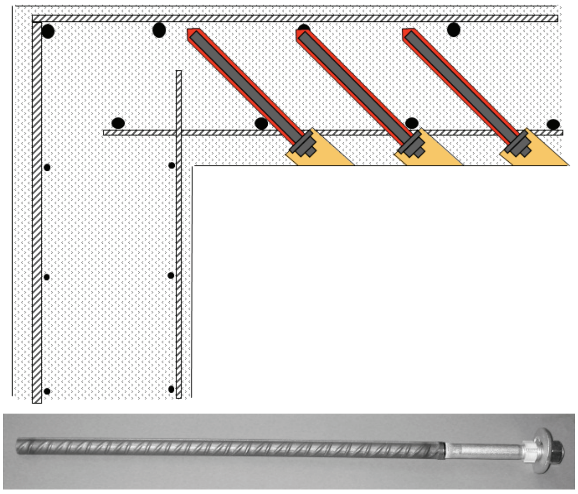

Fig. 2: post-installed shear reinforcement

Special anchors in combination with adhesive mortar are used to install the shear reinforcement into already hardened concrete, see Figure 1. Inclined holes are hammer drilled from the bottom into the concrete slab or beam under an angle of 45° and in the direction towards the wall or column. The length of the drilled holes should be at least such that they reach the lowest level of the upper reinforcement, but preferably the holes should end only at the level between the tensile reinforcement layers in the two directions. Adhesive mortar is injected into the drilled holes and the special strengthening anchors Hilti HZA-P are set into the mortar filled holes. The special anchors consist of a reinforcement bar of diameter 16 mm or 20 mm in the upper part (see Fig. 1). The lower part is a smooth shaft with a thread at the end. For the design, the strength of the reinforcement bar is decisive since the smooth shaft and thread are made of a steel of higher strength than that of the reinforcement bar.
After curing of the adhesive mortar, the lower anchor head is installed. It consists of an injection washer, a spherical washer to eliminate bending of the bar and a nut. To ensure a slip free anchorage, the annular gaps and the interface between washer and concrete surface are injected with adhesive mortar through the injection washer.
The anchor head is installed in an enlarged part of the drilled hole. The embedded anchorage has the advantage that it can be covered with a fire protection mortar and is not visible after the installation.

3 Shear tests

3.1 Test arrangement

The efficiency of strengthening concrete slabs against shear with post-installed shear reinforcement was checked by a preliminary series of tests. Beams of 4.4 m length, 0.41 m height and 0.6 m width with different arrangements of shear reinforcement were subjected to monotonically increasing shear load. The beams rested on two supports with a distance of 2.7 m and the shear load was applied by two pistons situated at 0.9 m from each support, see figure 2.
The specimens were shear-reinforced with the post-installed bonded reinforcement in the region indicated in figure 3. In the other regions, sufficient transverse reinforcement (consisting of ordinary stirrups) was provided in order to avoid shear failures outside the investigated area. The strengthening bars were installed in two arrangement types: a) all anchor heads at the bottom of the beam and b) all anchor heads on the tension side of the beam. In the latter case (b) the bonded area is always in the tensile zone of the beam (figure 3). All post-installed bars were diameter 16 mm, inclined at 45° with respect to the beam axis and spaced at a distance (along the axis of the beam) equal to the effective depth of the member.
The specified concrete quality for all tests was C25/30 (maximum aggregate size equal to 16 mm) with small variations observed over the entire series. The effective depth of the slab was 360 mm for all tests.
Measurements during the tests included the load, the vertical deformation of the beam, the strains in the strengthening bars and the opening of the shear crack.

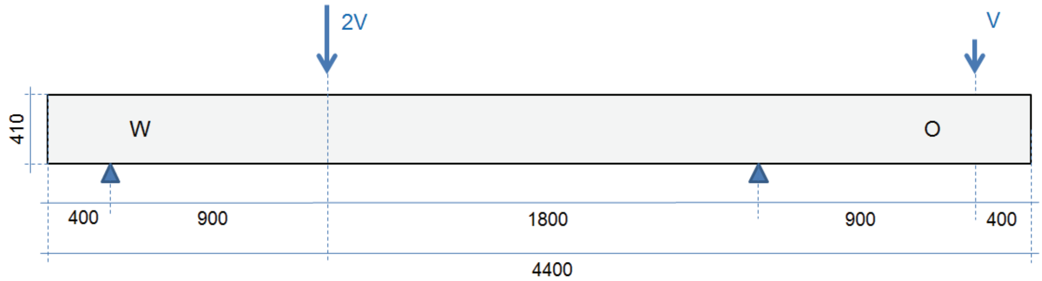

Fig. 2: dimensions of the test specimens

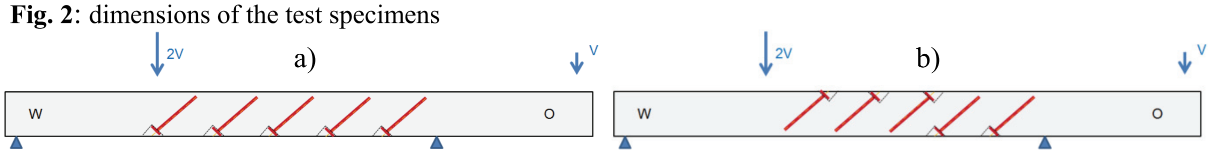

Fig. 3 Arrangements a, b of shear reinforcement

3.2 Test results

The shear loads V and $2V$ were increased monotonically. When the shear crack became clearly apparent, displacement transducers were installed across it to measure the opening as a function of the further loading. In some tests, the load was maintained at the level remaining after full opening of the first shear crack and the beam was then braced. Once the crack was braced, the beam was loaded again until a second shear crack occurred (Fig. 4)

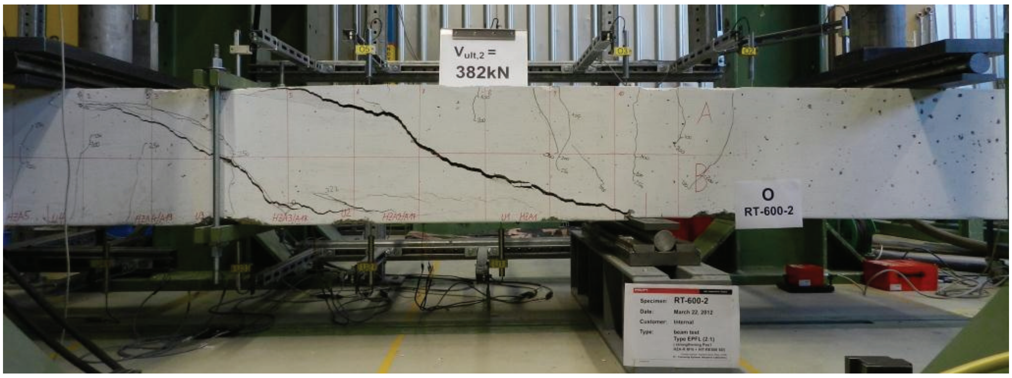

Fig. 4 Specimen RT 600-2 at second failure; first crack was braced after full opening

Table 1 summarizes the results on four test specimens. The concrete strength in the table was measured on cubes of 150 mm side length. The reference test without shear reinforcement (RT 600-0) resulted in a failure load of 246 kN. Since the concrete strengths of the other specimens were somewhat higher, the measured failure load was normalized in the last column of table 1 by the ratio of the square roots of the concrete strengths.

Table 1:
Summary of the shear tests

test	Test specimen description			Failure load	F'_{ult} =
	Width [mm]	Concrete strength f_{ccm} [MPa]	Shear reinforcement arrangement	F_{ult} [kN]	$F_{ult}*(f_{ccm}/34)^{1/2}$ [kN]
RT 600-0	600	34.0	-	246	246
RT 600-1	600	42.4	a	345	309
RT 600-2	600	41.3	a	327	297
*2nd crack**				382	347
RT 600-3	600	42.1	b	398	358
*2nd crack**				394	354

{*} shear crack occurring after bracing the specimen over the first crack (Fig. 4)

In the tests described in section 3.1 the selected shear reinforcement led to increases in shear capacity between 21% and 45% compared to a specimen without shear reinforcement. In spite of the relatively high scatter of the results this clearly shows that post-installed shear reinforcement is an effective strengthening method for structures lacking capacity against one way shear.
Based on these tests the arrangement of the post-installed shear reinforcement may have a clear influence of on the shear strength of the beam. In test 600-1 and in the first failure of test 600-2 the shear crack appeared on the side where the anchor heads were in the tension zone and the failure loads are consistent with F'_{ult} = 309 kN and 297kN. In test 600-3 all anchor heads were positioned in the compressive zone of the beam. The second shear crack of test 600-2 also occurred where the anchor heads are in the compressive zone. All three test results are consistent again with F'_{ult} = 347 kN, 358 kN and 354 kN respectively.
Further research is required to assess the influence of varying ratios of shear reinforcement and to clarify the influence of the arrangement of the strengthening anchors. From this, a consistent design concept should be derived.

4 Conclusions

This paper investigates on the beneficial influence that post-installed bonded reinforcement may have on the shear strength of one-way slabs or beams. A series of preliminary tests has been performed and confirms the following aspects:

1. Post-installed bonded reinforcement is an efficient solution to enhance the shear strength of one-way slabs failing in shear.
2. The location of the anchorage plates (tension or compression side) seems to play a significant role on the strength and performance of the system.
3. The increase on the strength is considerable for a moderate ratio of shear reinforcement (0.044%), indicating that concrete could be actively contributing to carrying shear loads. This aspect should be considered in a consistent design approach.

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