SMAR 2019

Influence of multiple anchors´arrangement in the behaviour of FRP-to-concrete anchored joints

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ABSTRACT: The effectiveness of FRP externally bonded reinforcements is limited by its premature delamination from the substrate. In recent years, various anchoring systems have been developed for FRP sheets. Among these, FRP anchors stand out as their effectiveness has been demonstrated in numerous experimental campaigns. Multiple anchors will be required when the unit strength of a connector is insufficient. In this campaign, single shear tests were performed on CFRP anchored sheets in concrete substrates. Narrow sheets (100 mm width) were installed with just one anchor for comparison with wide sheets (200 mm width). Wide sheets sheets were tested with one anchor and with two anchors distributed transversally covering the entire width of the sheet, with the aim of evaluating the influence of multiple anchors.

1 INTRODUCTION

The design of the FRP anchors has to be adjusted to the needs of the reinforced element, so it is not possible to determine whether it is best to use one single anchor or multiple anchors. Multiple anchors will be required when the unit strength of the connector is insufficient to properly enhance the adherent strength of the reinforcement, and their use might be considered as the best alternative when an optimized designed anchor fails by fibre rupture after reaching its maximum capacity.

The influence of multiple anchors in terms of strength and ductility of the anchored joint mainly depends on: distribution and alignment, transverse spacing and longitudinal spacing. Three different arrangements can be found in the bibliography: longitudinal, transversal and scattered. An important parameter to take into account is the width of the sheet, as the anchor fan must cover it completely in order to get a better performance of the joint according to Niemitz et al. (2010). In relatively wide sheets, locating two anchors transversally is crucial since it allows the anchors to work similarly to in longitudinal distributions. The most accurate arrangement for wide sheets can be claimed to be that of Niemitz et al. (2010) and McGurik and Breña (2012), who located two anchors in the transversal direction of the reinforcement.

An important scatter of the behaviour of multiple anchors can be found in the bibliography, making it difficult to determine the improvement when compared to a single anchor. Orton et al. (2008) and Niemitz et al. (2010) observed a nonlinear increase with the number of connectors, concluding that the strength increase is not just the addition of capacities of individual anchors.

Present research is based on some conclusions drawn from the literature and seeks to complement the existing information on the influence of multiple anchors´ arrangement in the behaviour of FRP-to-concrete anchored joints.

2 EXPERIMENTAL CAMPAIGN

Forty specimens were tested to compare at least two results for each configuration. Two different widths of the FRP sheet were studied; 100 mm width (narrow) with a single anchor, and 200 mm width sheets (wide) with both single and multiple anchors.

Figures 1 and 2 show specimen configuration and test series. For all specimens, the embedded length of anchors was 100 mm, inserted into a 20 mm diameter perforation with a dowel angle of 135 ° and a bending radius of 35 mm. Different series were tested in which the free section of the anchor (anchor fan) was splayed onto the reinforcement and between two reinforcement plies forming a 60° and 75° angle in the 100 mm and 200 mm width sheets respectively. These angles were set in order to cover all the width of the FRP sheets.

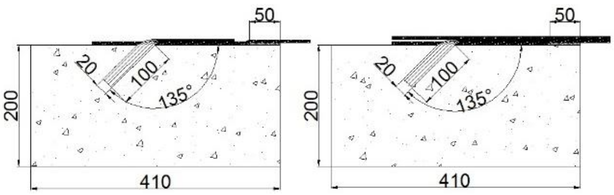

Figure 1. Specimen configuration.

Most authors in previous research located the anchors near the loaded end of the reinforcement. This follows the improvement observed when the anchors are included within the stress transfer zone of the reinforcement. In this study, three different spacing alternatives of the anchor from the unloaded end were studied. The anchors were installed on the unloaded end of the joint, at 50 mm and at 100 mm from it. Figure 2 shows the anchor located at the unloaded end of the joint in narrow FRP sheets and in the last two positions mentioned for single anchors in wide FRP sheets and for multiple anchors distributed transversally on the reinforcement.

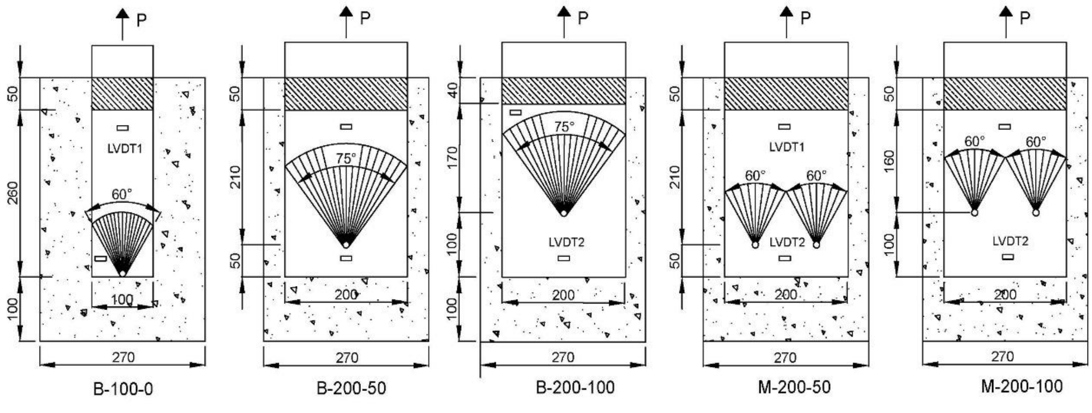

Figure 2. Anchor position with respect to the loaded end of the joint

2.1 *Material properties*

The anchors were installed in concrete specimens with dimensions of 410x270x200 mm with a compressive strength of 26.90 MPa at 28 days obtained according to standard UNE-EN 12390-3. Sika Wrap-230 C unidirectional carbon fibre fabrics with a nominal width of 300 mm were used as reinforcement. According to the manufacturer, the fibres have an elasticity modulus of 240 GPa, a tensile strength of 4800 MPa and a rupture strain of 2%. The fibres were cut to the require width of 100 mm and 200 mm for the reinforcement. Anchors were made from ropes having a diameter of the impregnated connector of 10 mm and, according to the product data sheet their fibre section is 27.3 mm2 with a tensile strength of the impregnated ropes of 1900 MPa.

2.2 *Instrumentation and loading*

The single shear test set-up was chosen in this research mainly because it is simple, repeatable and the specimens can be relatively easily handled and assembled. For the tests, the concrete block was completely restrained by a steel holding frame. Two linear variable differential transformers (LVDTs) were installed as show in Figure 3 to measure the relative displacement between the concrete and the composite in two different places, one in front ($LVDT_1$) and one behind the anchor ($LVDT_2$).

Figure 3. Single shear test set up.

3 EXPERIMENTAL RESULTS

The tables below show the results obtained in the different experimental series. In the series' name, the first letter refers to the position of the anchor fan with respect to the reinforcement being C control (unanchored specimens), O for the specimens with the anchor fan expanded onto the reinforcement and B for the specimens with the anchor fan expanded between two reinforcement plies. The first number that follows represents the reinforcement width, and the last number below is the positon of the anchor with respect to the unloaded end.

3.1 *Single anchors in narrow sheets*

In this series four different failure modes were observed. The first one, plate debonding (DB), occurred at the interface of the plate and the concrete substrate with a thin layer of concrete attached to the plate. The other three failure modes began with the plate debonding followed by plate or anchor failure. The second failure mode observed was plate debonding followed by plate rupture (DPR). The third failure mode observed was plate debonding followed by anchor rupture at the bending zone (DAR) mainly due to stress concentration in that zone. And the last failure mode observed was plate debonding followed by anchor pull out (DAP), which was a considerably more ductile failure.

Table 1 summarizes the maximum load and failure modes presented in the specimens tested, including the strength increase with respect to the control series for all the configurations. The maximum load collected in Table 1 (P_{max}) is the average of the results from at least two specimens. In some series it was possible to observed more than one failure mode as can be seen.

Table 1 Maximum loads and failure modes for 100 mm width FRP sheet specimens

SERIES	P_{max} Average (kN)	Failure Mode	P_{max}/P_{db} Average
C-100	20,94	DB	-
O-100-0	34,92	DPR	1,67
O-100-50	38,91	DPR-DAP	1,86
O-100-100	38,05	DPR-DAP	1,82
B-100-0	41,45	DAR-DAP	1,98
B-100-50	54,64	DAP-DAR	2,61
B-100-100	53,85	DAP	2,57

In the results shown in Table 1 it is possible to observe that anchoring a narrow FRP sheet with a single spike anchor enhances the joint strength reaching peak loads up to 261% the ones of the control series. It can also be concluded that both anchor position with respect to the loaded end and anchor fan position with respect to the reinforcement influence the maximum load that the joint can resist and its failure mode. The highest loads, also with more ductile failures, occurred in specimens with the anchor fan expanded between two reinforcement plies.

3.2 Wide FRP anchored sheets

In the series with wide FRP sheets the only position considered for the anchor fan was between two reinforcement plies, for single and multiple anchors, following results from the narrow series where it was possible to observe a better behavior of the anchored joint for that arrangement. The load-slip responses of all the wide FRP sheet specimens tested are shown in Figures 4 to 7. In most of the specimens it was not possible to register the slips measured by both LVDTs until the complete failure of the joint because the progress of the debonding produced premature failure of some of them. All tested anchored joints presented similar behavior; similarly to the results of Zhang and Smith (2012), the load slip responses of all the specimens tested have three defined zones. The limits between zones are defined by loads and slips corresponding to the beginning of plate debonding (P_{db};S_{db}), the moment when the plate is completely detached from the substrate (P_{max1},S_{max1}), and the maximum load and its corresponding slip achieved after that (P_{max2},S_{max2}).

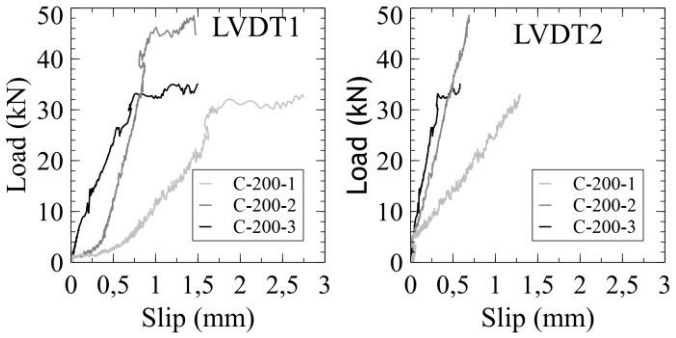

Figure 4. Load-slip responses for Control series.

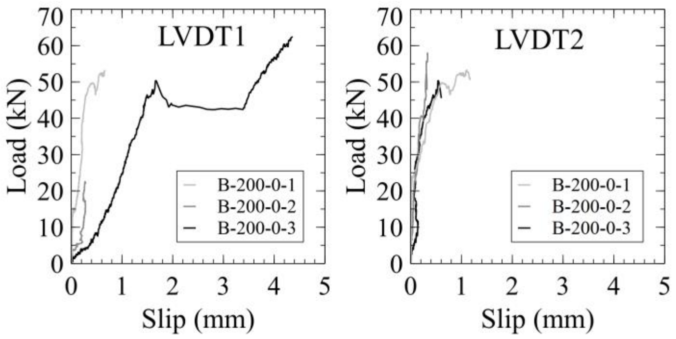

Figure 5. Load-slip responses for B-200-0 series.

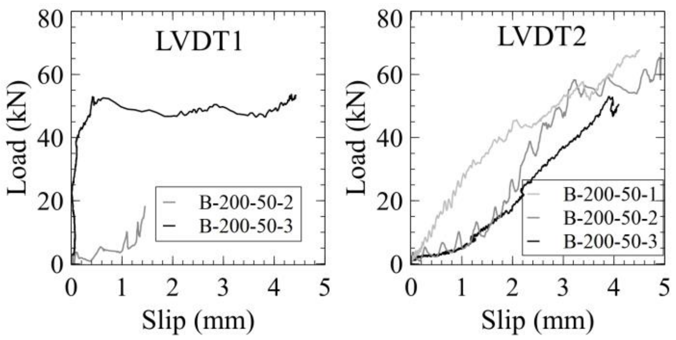

Figure 6. Load-slip responses for B-200-50 series.

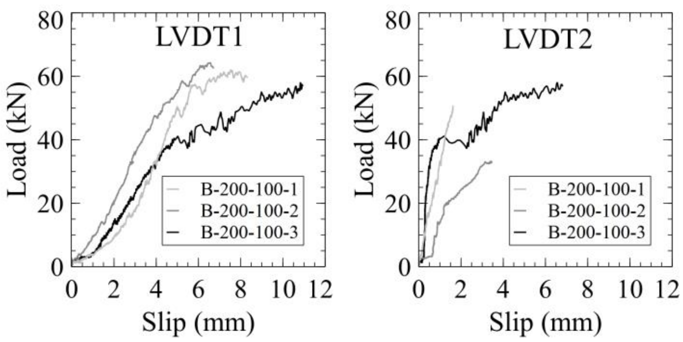

Figure 7. Load-slip responses for B-200-100 series.

3.2.1 Single anchors in wide FRP sheets

Two main aspects can be observed in the results of wide sheets with one single anchor from Table 2. The first one is that the failure mode of all the anchored specimens is related to the anchor, and in most cases it is due to anchor rupture at the bending zone. The second thing to observe is that the anchor effectiveness decreases compared to the behavior evidenced in narrow sheets, which leads us affirm that there exists a maximum width of the reinforcement that a single connector can optimally anchor.

Table 2 Maximum loads and failure modes for 200 mm width FRP sheet specimens with one single anchor

SERIES	P_{max} Average (kN)	Failure Mode	P_{max}/P_{db} Average
C-200	38,85	DB	-
B-200-0	61,36	DAR	1,58
B-200-50	62,74	DAR	1,61
B-200-100	61,50	DAP-DAR	1,58

3.2.2 Multiple anchors wide sheets

In the last series, two anchors distributed transversally in the width of the FRP sheet were tested and the results obtained are summarized in Table 3. All the specimens failed by plate debonding followed by anchor rupture. An important improvement of the anchors efficiency can be seen reaching peak loads of 260% the ones of the control series, a behavior similar to the one observed in narrow FRP sheets with one anchor.

Table 3 Maximum loads and failure modes for 200 mm width FRP sheet specimens with multiple anchors

SERIES	P_{max} Average (kN)	Failure Mode	P_{max}/P_{db} Average
M-200-50	93,96	DAR	2,42
M-200-100	100,95	DAR	2,60

4 DISCUSSION

Figures 8 and 9 show the main differences between single and multiple anchors in narrow and wide FRP sheets. Figure 8 shows the resistance increase compared to the unanchored joint for single and multiple anchors with the anchors located at 50 mm and 100 mm from the unloaded end. It shows a clear decrease in the anchors efficiency with an increase of the FRP width, supporting the previous affirmation that there exists a maximum width of reinforcement that a single connector can optimally anchor. This may be due to the fact that anchors contribution to the strength is reduced in the outer limits of their fans as observed by Niemitz (2008), being this behaviour more evident in wide reinforcements. The use of multiple anchors (two for this case) in wide sheets reduces the influence area of the connector improving its capacity until reaching the strength increase obtained with single anchors in narrow sheets.

On the other hand, Figure 9 shows the joint strength of the control series (with the two widths considered) and the series with single and multiple anchors located at two different positions with respect to the unloaded end. It can be seen that the FRP sheet width and the number of anchors employed are directly related to the maximum resistance of the anchored joint.

The use of single anchors in narrow FRP sheets and multiple anchors in wide sheets, allows the anchored joint to resist loads of more than twice the ones of the unanchored specimens.

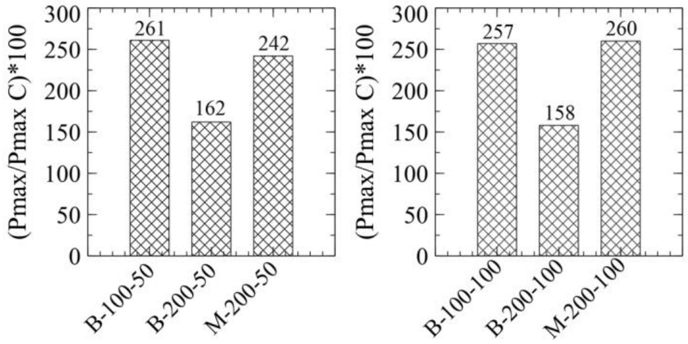

Figure 8. Resistance increase.

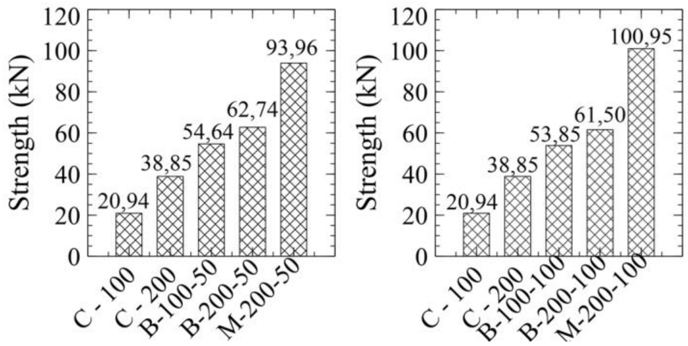

Figure 9. Resistance comparison.

5 CONCLUSIONS

Based on the results obtained in this campaign, the following conclusions can be drawn:

-The presence of FRP anchors enhances joint behavior, with anchored joints reaching peak loads up to 261% the ones of the control series for single anchors in narrow FRP sheets and 260% for multiple anchors in width FRP sheets.

-The effectiveness of multiple anchors depends on their optimal spacing, which defines the optimum sheet width that can be anchored with a single connector.

-Using one single connector in narrow FRP sheets can be equivalent to use multiple (two in this case) connectors in width FRP sheets with the adequate configuration (anchor position with respect to the loaded end and anchor fan position with respect to the reinforcement).

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