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STRENGTHENING OF ANCHOR CHANNELS ON THE CONCRETE SURFACE

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Abstract. *For the installation of curtain wall systems, the positions of anchor channels gradually move closer to the edge of the concrete slabs. But close to the edge of the slab, conventional supplementary reinforcements have problems to redistribute the loads to the reinforcement due to the short bond length that is available after concrete edge failure occurred. Therefore, tests have been conducted to investigate the behaviour of anchors channels, close to the edge. To achieve this, a strengthening system on the surface of the concrete with post installed fasteners was developed. First results indicate a high potential for strengthening the channels close to the edge under shear load. With these test results numerical simulations with Atena Science were performed and, after its calibration, the model was used for further investigation.*

1 INTRODUCTION

1.1 General

For anchor channels close to the edge concrete edge failure is often the decisive failure mode when loaded in shear. Therefore, the presence of supplementary reinforcement is essential for the load bearing capacity of the anchor channel. According to national codes [1] a supplementary reinforcement needs a minimum bond length of $l_{1,min} = 4 \cdot d_s$, where d_s is the diameter of the reinforcement. As an example, a reinforcement with a diameter of 8 mm would need at least 32 mm bond length within the concrete cone. For an anchor channel casted with a minimum edge distance of 50 mm and assuming a minimum concrete cover of 20 mm, the minimal possible bond length is barely obtained. A reinforcement with a diameter of 12 mm would not be able to reach this minimal bond length at all.

Therefore, a reinforcement respectively strengthening system which is not dependent of the bond length is necessary to effectively handle the loads at such small edge distances. In this study a system, preventing deformations of the anchor channel itself, was tested. The system consists of post-installed fasteners and metal lugs which are connected to the anchor channel.

The results of the tests are used to calibrate an FEM model which has been modelled with Atena Science. With the calibrated model a test program shall be conducted where the test parameters are created according to a Design of Experiments (DoE) approach. This paper is part of a research project at the Institute of Construction Materials [2]. The goal of this project is to develop a new approach of strengthening anchor channels close to the edge.

1.2 Codes and guidelines

According to DIN EN 1992-4 [1] and EOTA TR047 [3] the calculation of the characteristic concrete edge breakout strength $V_{Rk,c,re}$ for supplementary reinforced anchor channels, loaded perpendicular to the edge shall be carried out to the following equation:

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$$V_{Rk,c,re} = \psi_{cr} \cdot (V_{Rk,c,hook} + V_{Rk,c,bond}) \quad (1)$$

where:

ψ_{cr} is the modification factor for cracked or uncracked concrete. $V_{Rk,c,hook}$ and $V_{Rk,c,bond}$ are calculated according to the following equations:

$$V_{Rk,c,hook} = \psi_1 \cdot \psi_2 \cdot \psi_3 \cdot A_{S,i} \cdot f_{yk} \cdot \left(\frac{f_{ck}}{25}\right)^{0,1} \quad (2)$$

$$V_{Rk,c,bond} = \pi \cdot d_s \cdot l'_{1,i} \cdot f_{bk} \quad (3)$$

The hook and bond capacity of one stirrup depends on the factor l_1 which in case of the hook capacity is defined within ψ_2 and for the bond capacity is defined by $l'_{1,i}$. It is calculated according to the following equation for stirrups crossing the assumed failure crack with an angle < 90°:

$$l_1 = c_1 - c_c - 0.7 \cdot (e_i - b_{ch}) \geq 4 \cdot d_s \quad (4)$$

And for stirrups crossing the assumed failure crack with an angle of 90°:

$$l_1 = c_1 - c_c \geq 4 \cdot d_s \quad (5)$$

With l_1 calculated according to equation 4 or 5, $l'_{1,i}$ can be calculated through the following equation:

$$l'_1 = l_1 - 3 \cdot d_s \quad (6)$$

For stirrups crossing the assumed failure crack with an angle of 90° where:

c_1 is the edge distance of the anchor channel,
c_c is the concrete cover over the stirrup,
e_i is the distance from the loading point to the middle axis of the stirrup,
b_{ch} is the width of the anchor channel,
d_s is the diameter of the stirrup.

Equation 4 shows, that for stirrups that are not positioned underneath the anchor channel, the bond length, depending on the point of load introduction, will be further decreased. Therefore, the installation of anchor channels at a minimum edge distance of 50 mm is not possible, since according to equations 4 to 6 the supplementary reinforcement does not increase the resistance at all because the minimal bond length is not reached.

1.3 Purpose of the investigation

Since there are no test results available for strengthening anchor channels from the surface, it is necessary to determine the effectivity of such a system. Therefore, the aim of the described investigation is to get

- a first impression of the load increasing potential from surface "reinforcements"
- an understanding of the influence of the anchor channels profile
- an understanding of the crack propagation when the concrete does not need to be cracked to introduce the loads to the strengthening module
- an understanding of the influence of the positioning of the strengthening module to the loading point

2 EXPERIMENTAL INVESTIGATIONS

2.1 Introduction of the investigated strengthening module

The investigated strengthening module used to increase shear resistance of the anchor channels from the top through a metal lug which engages into the channel is shown in figure 1.

Shear loads introduced to the special screws of the anchor channel will be transferred by bending of the channel to the strengthening module. The module engages into the channel by using a hook, a bolt screw, or a comparable mechanism. Thus, the metal lug of the strengthening module will be loaded in tension.

The idea behind this concept is, that the hook engages into the anchor channel before the bending of the channel will reach its next anchor. Therefore, loads will first activate the strengthening module. After the activation of the module the lug will reach its yielding stress, and then the loads will be transferred to the anchor of the channel. This mechanism should delay the cracking of the surrounding concrete, redirecting the loads thorough the metal lug to the fastener away from the edge of the concrete member.

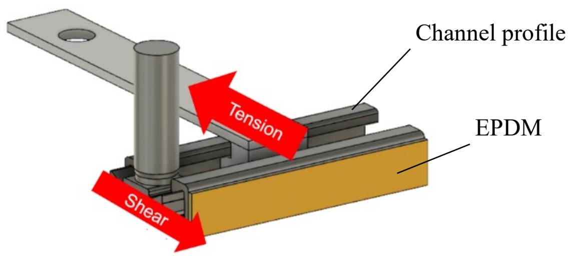

Figure 1. Illustration of the post-installed strengthening module engaging in the anchor channel profile by a hook.

The EPDM tape on the front of the anchor channel acts as a clearance of 2 mm between the concrete and the anchor channel loaded in shear. Due to this provided clearance, the strengthening module is activated before the shear loads are introduced to the surrounding concrete in front of the channel. A similar method is already used by anchor plates, where slotted holes are provided for the front anchors so that the shear loads must be transferred by the anchors far away from the edge.

The anchor channel between two strengthening modules can be idealized as a beam on two supports, as it is shown by Krause [4] for tension loading.

With this type of system, the cracking of the concrete is not a prerequisite to activate the lug, like for strengthening systems based on supplementary reinforcement. Also, the problem of providing the minimal bond length of 4 times d_s with this system is no longer a limit. An open question is, if the hook or bolt screw can be activated before loads are introduced into the concrete cover before the channel.

2.2 Test phase 1 – Investigation to determine the mechanism and effectivity of strengthening modules engaging from the top of the anchor channel

To investigate the effectivity of the strengthening module explained above, shear tests according to Table 1 were performed. Tests with and without strengthened anchor channels in unreinforced concrete are used to show the mechanism of strengthening.

The tests have been conducted in C- and V-shaped anchor channels, which are standard profile types. The used V-profile was comparable to fischer's FES 40/22 profile, because this profile type can be cast in with an edge distance of 50 mm according to its European Technical Assessment (ETA) [5].

For loading, a bolt screw with a diameter of 16 mm and a length of 80 mm, was used. The bolt screws were made of 8.8 grade galvanized steel to avoid the possibility of steel failure. In the tests, no other failure mode than concrete edge failure was aimed.

All tests were performed under the same conditions and the

- C- and V- shaped profiles
- embedment depth h_{ef}
- and anchor bolts

were kept constant for all tests. The concrete class was C20/25 with a constant edge distance c_1 of 50 mm starting from the anchors of the anchor channel. The distance of the strengthening modules to the loading point *s* was 47,5 mm to both sides of the loading point. The anchor channel length was 150 mm with a spacing of the anchors of 100 mm.

Table 1: Overview of the test program to determine the effectivity of surface elements to strengthen anchor channels close to the edge.

Test	Test series description	Support spacing	Number of tests
[-]	[-]	[mm]	[-]
Reference C	Reference tests in unreinforced, uncracked concrete, C-Profile	550	4
Reference V	Reference tests in unreinforced, uncracked concrete, V-Profile	550	4
V1	Strengthened anchor channel C-Profile	550	4
V2	Strengthened anchor channel V-Profile	550	4
V3	Strengthened anchor through rebar module	550	4

In figure 2 the spacing between the supports can be seen. The distance was fixed to 550 mm acc. to [3], so that the formation of a full concrete cone at the edge was possible. The cracks on both sides of the anchor channel and the displacement of the loading plate were monitored through three LVDTs. For the strengthened tests, also the displacement of the fasteners was monitored by two additional LVDTs.

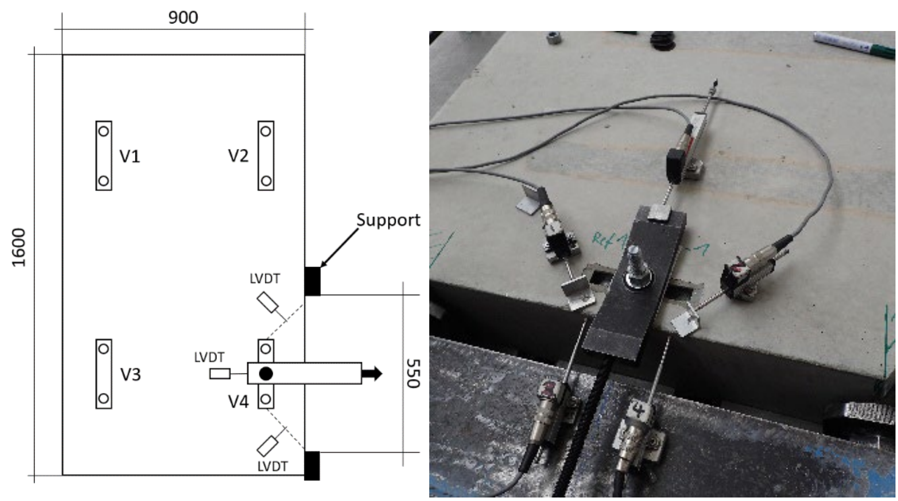

Figure 2. Schematic of the test setup of the reference tests (left) and the conducted tests (right).

The strengthened tests were performed with metal lugs having a length of 200 mm, a hole distance of 150 mm and a width of 30 mm (see figure 3). The lugs had a thickness of 4 mm and consisted of standard steel (S235). For an easy installation of the strengthening module, the same bolt screw was used as for the loading point.

Because for the tests with the C-profile, the annular gap between the fastener and the metal lug was not filled, a slipping during the loading process was possible. The annular gap of the V-profiles was filled with fischer FIS V to prevent this slipping.

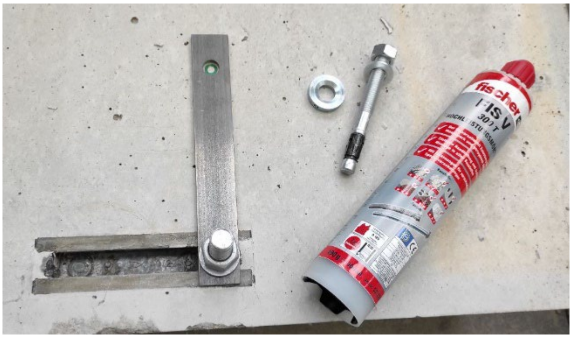

Figure 3. Installation process for the strengthening module with the fastener fischer FAZ II and fischer FIS V to fill the annular gap between the fastener and the metal lug.

To be able to compare the strengthening effect of the post installed module and a strengthening module using reinforcement according to figure 4. Additional tests with the V-profile using the module according to figure 4 were performed. The module consists of a metal plate with a width of 200 mm and a height of 50 mm. The metal plate was attached to the formwork through screws. Four rebars with a diameter of 12 mm and a spacing of 50 mm were welded to the steel plate. This module is activated when cracks in the concrete developed and a cone is restrained and held back by the plate. Therefore, the rebars can only be fully activated for larger crack widths (normally much larger than the limit of serviceability of 0,3 mm).

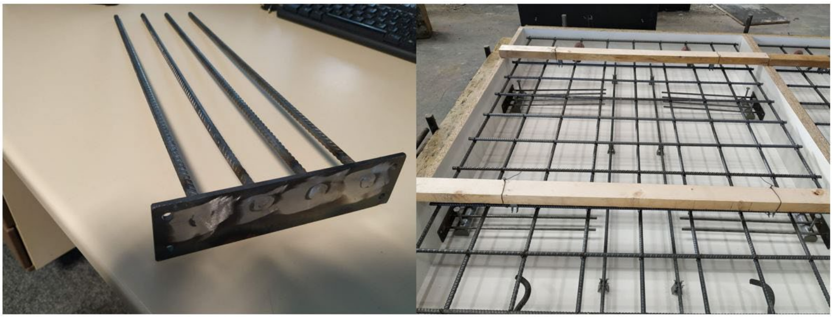

Figure 4. Strengthening module consisting of rebars welded to metal plate (left) and installed module (right).

2.3 Test phase 2 –Numerical investigation with the FE-program Atena Science to determine the influence of variable positions of the strengthening module and the effectivity with bigger channel profiles.

In the first step, the anchor channel and the concrete were modelled, using the pre processer GiD which is provided by Atena Science. For the numerical investigation only C-profiles were modelled, getting the required information from CAD files of the anchor channel profiles 40/22 and 50/30. Theses anchor channels have been embedded in the concrete as shown in figure 5. For all contact surfaces between the anchor channel and concrete, interface elements have been used. Those elements can only transfer compression stresses.

The gap of 2 mm between the front of the anchor channel and the concrete was also modelled. The connection between the anchor channel and the concrete was realized through separated interface elements which react the same way as interface elements when getting in contact after a displacement of 2 mm.

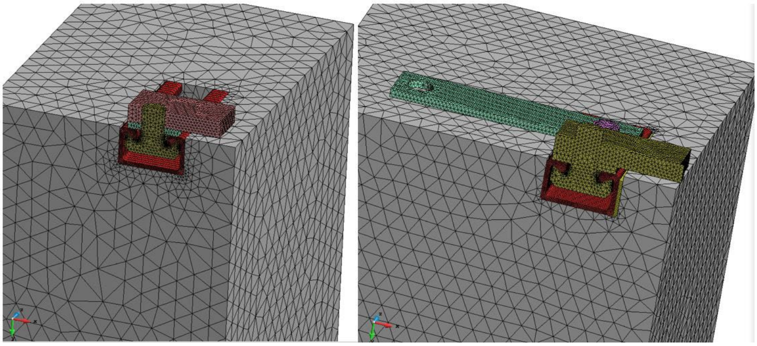

Figure 5. Half FE-model of the reference tests (left) and the strengthened anchor channel (right) with loading plate.

As given in figure 5 (right side), the fastener of the metal lug was not modelled because the tests did not show any damage of the fastener. Therefore, the clearance hole of the lug was defined as fixed in the loading direction. Using its boundary conditions, yielding or bending of the lug is still possible. For the accurate estimation of the load-deformation of the lugs some calibration tests were conducted (see figure 6).

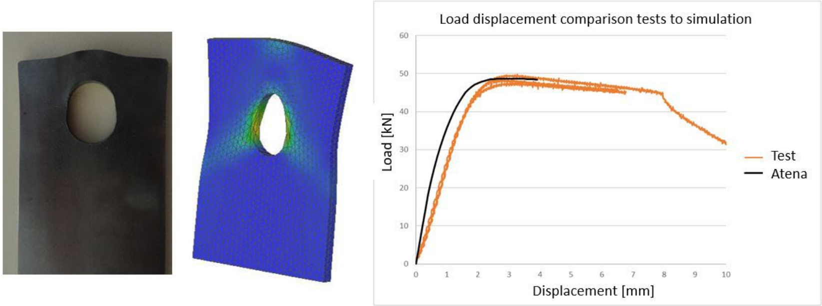

Figure 6. Calibration steps from the tested to the modelled lug with the corresponding load-displacement behaviour (from left to right).

Table 2: Overview of the numerical test program to determine the effectivity of surface elements to strengthen anchor channels close to the edge for a channel length of 150 mm.

Test	Edge distance c_1	Distance to loading plate s	Anchor channel profile p
[-]	[mm]	[mm]	[-]
Num_1	50	35	40/22
Num_2	50	50	40/22
Num_3	75	35	40/22
Num_4	75	50	40/22
Num_5	50	35	50/30
Num_6	50	50	50/30
Num_7	50	35	50/30
Num_8	75	50	50/30
Num_9	62,5	42,5	40/20
Num_10	62,5	42,5	50/30

For the test setup, presented in this paper, a full factorial 2³ test plan was carried out for the numerical part with the method DoE and the effect of the following parameters on the load bearing capacity was investigated:

- c_1: Edge distance [mm]
- s: Distance of the strengthening module to the loading plate [mm]
- p: Anchor channel profile (40/22 and 50/30) [-]

The factor levels of the full-factorial 2^3 test plan and their combination can be seen in Table 2. Additionally, points in-between where designed, to see a possible linear resp. nonlinear behaviour correlation of the parameters.

For the numerical investigation anchor channels with a length *l* of 150 and 300 mm and with a spacing of 100 mm and 250 mm were modelled. The 300 mm anchor channels were modelled to determine the maximum distance of the strengthening module to the possible loading point. The test program for the anchor channels with a length of 300 mm can be seen in Table 3.

Table 3: Overview of the numerical test program to determine the effectivity of surface elements to strengthen anchor channels close to the edge for a channel length of 300 mm.

Test	Edge distance c_1	Distance to loading plate s	Anchor channel profile p
[-]	[mm]	[mm]	[-]
Num_11	50	35	40/22
Num_12	50	120	40/22
Num_13	75	35	40/22
Num_14	75	120	40/22
Num_15	50	35	50/30
Num_16	50	120	50/30
Num_17	50	35	50/30
Num_18	75	120	50/30
Num_19	62,5	77,5	40/20
Num_20	62,5	77,5	50/30

3 INVESTIGATIONS TO DETERMINE THE MECHANISM AND EFFECTIVITY OF STRENGTHENING MODULES ENGAGING FROM THE TOP OF THE ANCHOR CHANNEL

3.1 Evaluation of the test results at failure load levels

The comparison of the reference tests shows, that this close to the edge, the difference of the mean failure load of the C- or V-profile was negligible.

Table 4: Failure loads of the reference tests.

Test	$V_{u,test}$	$V_{um,test}$	$f_{c,test}$	$V_{um,test,25}$	Variation coefficient
[-]	[kN]	[kN]	[N/mm²]	[kN]	[%]
Reference c-profile	12.84 12.58 13.50 13.41	13.06	28.62	12,.21	3.48
Reference v-profile	12.71 12.72 13.62 12.42	12.87	28.62	12.03	4.05

While the C-profile had a mean failure load $V_{um,test,25}$ of 12.21 kN, the failure load of the V-profile was at 12.03 kN which corresponds to a difference of 1.5 % with a comparable coefficient of variation under 5 % (Table 4).

A noticeable difference in the reference tests with respect to the profile type was the starting point of the crack propagation towards the edge. While the crack for the C-profiles starts from the middle to the back of the anchor channel, the cracks of the V shaped profiles start at the front of the anchor channel (figure 7).

When comparing the bending behaviour of the anchor channel profiles from the reference tests, there was no visible deformation of the channel itself, as the channel moved together with the concrete cone.

Figure 7. Comparison of the starting point of the crack propagation for the V-profile (left) and the C-profile (right).

The strengthened anchor channels showed a comparable behaviour compared to the reference tests regarding the small difference of the mean failure loads. While the mean failure load of the strengthened C-profile was at 37.58 kN, the strengthened V-profile failed at 38.89 kN. This equals a difference of 3.4% which is within the expected scattering of the concrete of 15%.

With this small difference between the failure loads, no effect of the filled or not filled annular gap could be evaluated.

In Table 5 the failure loads of each test are shown. The failure loads of anchor channels having a strengthening module, using a supplementary reinforcement are 33% higher and reach a level of 51.66 kN. This failure load is higher than the comparable strengthened tests of the V-profiles with the post-installed strengthening module. Therefore, a detailed analysis of the load behaviour considering the crack widths was performed in the following evaluation.

Table 5: Failure loads of the strengthened tests.

Test	$V_{u,test}$	$V_{um,test}$	$f_{c,test}$	$V_{um,test,25}$	Variation coefficient
[-]	[kN]	[kN]	[N/mm²]	[kN]	[%]
Strengthened c-profile	39.87 36.23 36.35 37.88	37.58	28.62	35.12	4.52
Strengthened v-profile	37.26 31.74 43.70 42.85	38.89	28.62	36.35	14.29
Strengthened V- Profile with rebars	50.51 54.01 56.15 60.40	55.27	28.62	51.66	7.48

Compared to the reference tests, the post-installed strengthened anchor channels showed a noticeable increase of their mean failure load of appr. 2.88 to 3 times of the reference loads for the C- and V-profiles.

This strengthening effect is comparable to the maximal possible strengthening effect through supplementary reinforcement $V_{Rk,re,max}$, by Schmid [6].

$$V_{Rk,re,max} = 4{,}2 \cdot c^{-0{,}12} \cdot V_{Rk,c} \quad (7)$$

For an edge distance of 50 mm equation 7 states, that the maximal effect of the reinforcement would be 2.63 times $V_{Rk,c}$, where $V_{Rk,c}$ is the possible load of the unreinforced anchor channel.

In figure 8, a deformation of the anchor channel through bending could be observed, while the failed anchor channels of the reference tests moved along the concrete cone with no bending. This indicates that the desired load transferring effect to the strengthening module by bending was achieved.

Figure 8. Failed strengthened anchor channels v-profile (left) and c-profile (right)

3.2 Evaluation of the test results at serviceability load levels

When comparing the results for defined load levels, limited by serviceability, the crack width over the loads must be considered. The test results in figure 9 show the comparison of the loads for a crack width of 0.2, 0.3 and 0.4 mm. The crack widths are chosen according to [1] as recommended maximal crack widths for prestressed concrete, limit of serviceability in normal environments, and limit of serviceability in dry environments.

C-profiles, where the annular gap between the strengthening module and the fastener was not filled, show a strengthening effect for an increasing crack width of appr. 40 % to 60 % compared to the reference values (see figure 9 left). V-profiles, where the annular gap was filled with fischer FIS V, showed a load increasing effect of 80 % to 104 % of the reference loads (see figure 9, grey scale on the right).

This difference of the load increasing effect is assumed to be caused by uncontrolled slipping of the strengthening module through the loading process. Through this slipping the C-Profile gets into contact with the surrounding concrete before the module could be fully activated, causing an earlier cracking of the concrete.

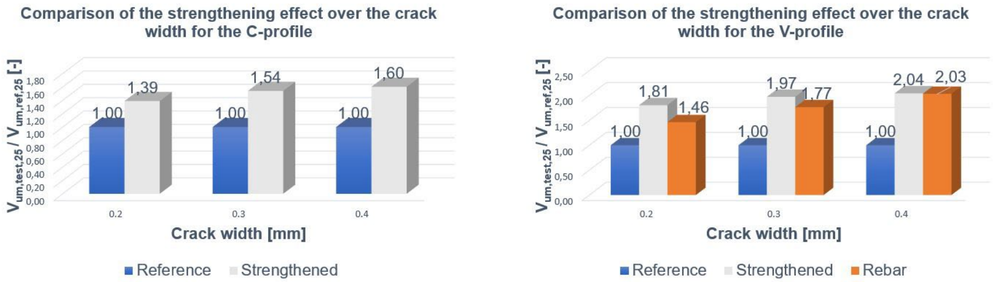

Figure 9. Comparison of the loads over the mean crack width for the C-profile (left) and the V-profile (right).

Compared to the strengthening module using reinforcement, presented in figure 4, the load increasing effect of the post-installed strengthening module for the crack widths of 0.2 and 0.3 mm is 20 % to appr. 40 % higher. At a mean crack width of 0.4 mm the loads are on a comparable level.

This indicates that the tested post-installed strengthening module prevents cracking up until yielding of the module. As expected, the failure load of the module using reinforcement is higher at larger crack widths after leaving the serviceability load level, while the post-installed strengthening module, is most effective prior to the crack opening respectively at smaller crack widths.

4 NUMERICAL INVESTIGATION TO DETERMINE THE INFLUENCE OF VARIABLE POSITIONS OF THE STRENGTHENING MODULE AND THE EFFECTIVITY OF BIGGER CHANNEL PROFILES.

4.1 Evaluation of the numerical investigation

For the numerical investigation conducted for this paper, only symmetrical cases were modelled. Therefore, the position of the strengthening module was placed on both sides of the loading point within the distance *s* according to Table 2. Therefore, only half of the system could be used in the numerical simulations to decrease the time needed for the FEM analysis.

The results of the numerical investigation were compared with the shear load resistances calculated according to equation 8 as suggested by Schmid [6].

$$V_{um,c} = V^0_{um,c} \cdot \alpha_{s,V} \cdot \alpha_{c,V} \cdot \alpha_{h,V} \quad (8)$$

The mean failure loads $V_{um,c}$ for all conducted tests of the numerical investigation given in Table 2 and 3 have been calculated with equation 8. For the following evaluation of the obtained strengthening effects those calculated loads are called V_{calc} while the results of the numerical investigation will be called V_{Sim}.

In figure 10 The influence of the anchor channel profile on the strengthening effect of the module is shown. The results of the FE investigation show, that the mean strengthening effect for the modelled profiles 40/22 and 50/30 are both by appr. 2.3 times the load of the unreinforced channels. Therefore, it can be stated that the influence of the tested anchor profiles on the effectivity of the strengthening module is neglectable.

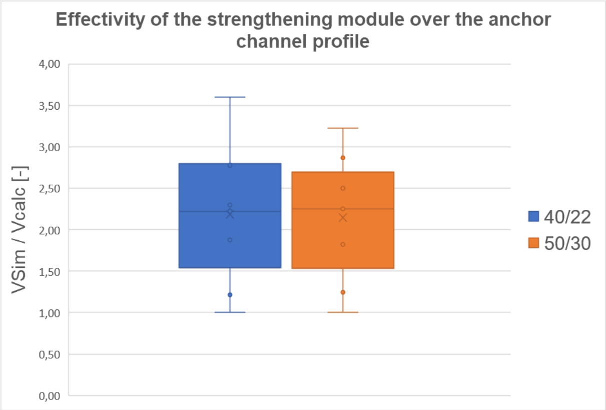

Figure 10. Influence of the anchor channel profile on the strengthening effect.

The authors assumed, that with an increasing distance *s* of the post-installed strengthening module to the position of loading, the effectivity of the system should decrease. The results of the numerical investigation confirmed this assumption. For both anchor channel profiles, the strengthening effect close to the loading plate, 35 mm to the bolt screw, was appr. 2.5 times. In contrast to that at 120 mm, the strengthening effect was neglectable. Figure 11 shows the trend of the strengthening effect depending on the distance of the module from the loading point between 35 and 120 mm.

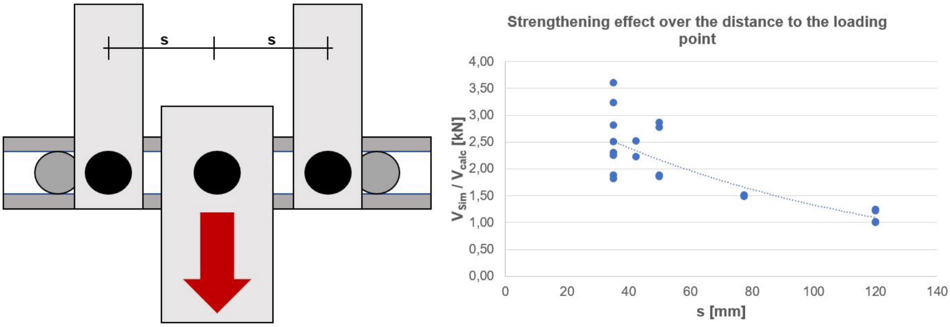

Figure 11. Influence of the distance s between the loading point and the strengthening module on the strengthening effect.

The last part of the numerical investigation was to determine the effectivity of the strengthening module with an increasing edge distance. As it can be seen in equation 7, the effectivity of normal supplementary reinforcement decreases with an exponent of $c^{-0.12}$ up to the point, where the concrete edge failure won't be the decisive failure mode anymore.

Since the post-installed strengthening module was designed for the area, where normal supplementary reinforcement would not reach the minimal bond length, the edge distance was only variated from 50 mm to 75 mm. In figure 12 the strengthening effect as a function of the edge distance, compared to the maximal possible value according to equation 7, can be seen. For this comparison, it must be considered, that the minimal bond length for normal reinforcement would most likely not be reached. Therefore, the load increasing effect according to the standards could not be used for design.

Like normal reinforcement, the post-installed strengthening module has a decreasing effect with an increasing edge distance. For this evaluation, only the strengthening modules close to the loading point, at 35 mm, for the 40/22 and 50/30 profiles were used.

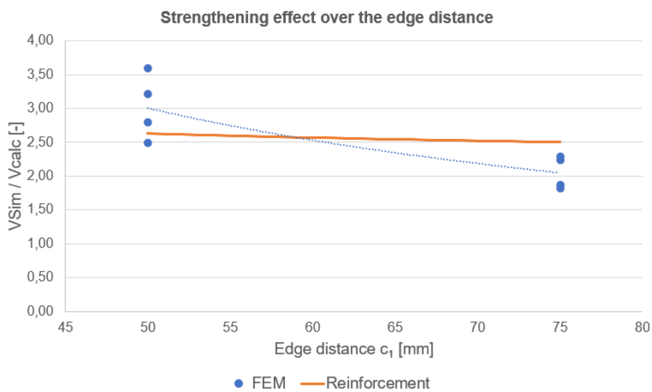

Figure 12. Comparison between the strengthening effect over the edge distance c_1 for the post-installed module (dotted line) to the maximal effect of a reinforcement (full line).

As it can be seen, the strengthening effect of the post-installed module has an effectivity of appr. 3 times at 50 mm edge distance while the normal reinforcement is at 2.63 times. Which is a difference of appr. 15 % towards the post-installed module. At a larger edge distance of 75 mm the post-installed module has a strengthening effect of 2.1 while the reinforcement would be at 2.5, which is a difference of 18 % towards the maximal effect that can be provided by reinforcement according to [5].

5 CONCLUSIONS

Experimental investigations were performed to determine the effectivity of strengthening modules for anchor channels that interact with the anchor channel. The numerical and experimental study was performed with C- and V-shaped strengthened anchor channels with an edge distance c_1 of 50 mm. The tests have been evaluated for the failure load and the cracking behaviour. For this reason, the load levels at 0.2, 0.3 and 0.4 mm crack width were determined. Also, a comparison with the strengthening method using a steel plate with welded reinforcement has been performed, to determine the effectivity of the new system compared to already existing and used systems.

In a second part, the results of the experimental tests were used to calibrate a numerical model for further investigation on the influence of the position, edge distances and larger anchor channel profiles.

Based on the results of the study, following conclusions can be drawn:

- The failure loads of anchor channels in unreinforced concrete using the post-installed strengthening module are increased by a factor of 2.6 to 3.0 times. This strengthening effect is comparable with the calculation using equation 7 that limits the maximal strengthening effect of channels using supplementary reinforcement.
- The annular gap between the fastener and the strengthening module had no significant influence on the failure load, but on the load limited by the serviceability level.
- The load evaluated over the crack width of anchor channels with the strengthening module and filled annular gap showed an increase of 20 to 40 % compared to the module using reinforcement.
- The assumption, that the load is transferred by bending of the channel could be confirmed.
- The numerical investigation indicates that the size of the profile between 40/22 and 50/30 will have no influence on the strengthening effect.
- The effectivity of the strengthening module decreases with an increasing distance to the load point at the channel. As of now it seems for $s \geq 120$ mm the strengthening effect is nearly zero.
- The effectivity of the strengthening module decreases with an increasing edge distance c_1.

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