Post-installed rebar connections

ROLF ELIGEHAUSEN AND HANNES SPIETH

Institute for Construction Materials, University of Stuttgart, Stuttgart, Germany

ABSTRACT

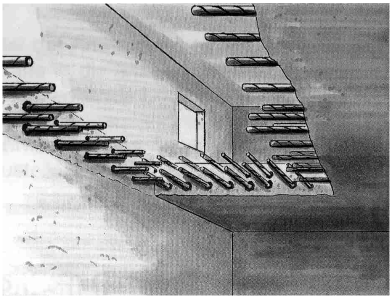
Post-installed rebar connections are increasingly used in practice. Generally accepted design guidelines are not yet available. The products are used according to the manufacturers recommendations.

The bond lengths recommended by manufacturers are much smaller than the bond length of reinforcing bars given in different international codes for reinforced concrete. Therefore pullout tests with single bars and tests with spliced bars in beams and slabs under bending moments were performed. Post-installed deformed bars and cast-in-place deformed bars were tested side by side. The results show that the bond strength of bars bonded with suitable products in well cleaned holes in uncracked concrete is as high as the bond strength of cast-in-place bars. Based on the test results the bond length of post installed rebars should be as long as the anchorage or splice length required by codes for reinforced concrete.

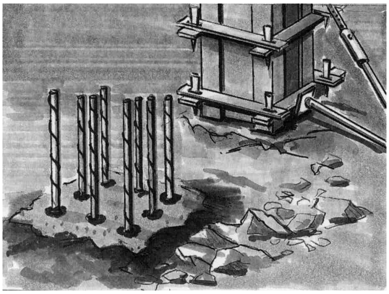
Introduction

In practice more and more connections between reinforced concrete elements are carried out by bonding deformed reinforcing bars with an adhesive mortar in holes drilled into the existing concrete. Examples are:

casting secondary floor slabs
closing of temporary openings (Fig. 1a)
casting new walls or expanding existing buildings
connecting columns with the foundation (Fig. 1b)
connecting cantilevering elements such as balconies, stairways and landing slabs with the existing structures



a) Fill in of temporary openings



b) Connection between column and foundation

Fig. 1: Examples of Applications

In these cases the reinforcing bars have to be anchored in existing reinforced elements or have to be spliced with existing reinforcing bars. Normally holes are drilled in the existing concrete with hammer or diamond drilling machines. After cleaning the hole the adhesive mortar is injected; subsequently the reinforcing bar is pressed into the filled hole.

Types of systems and installation

There are different systems on the market. They vary in the type of used mortar and the installation procedure. All systems have in common that a hole has to be drilled and cleaned. The cleaning procedure vary with each product. In most cases the hole has to be cleaned by brushing and pumping (Fig. 2).

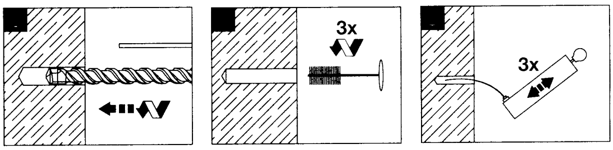


Fig. 2: Example of cleaning and drilling procedure recommended by manufacturers

With injection systems, the hole is filled with mortar using an injection tool. The two components of the mortar are mixed automatically during injection. Used are mortars based on organic compounds (epoxy, polyester, vinylester), inorganic compounds (cementious) and combinations of organic and inorganic compounds. After filling the hole the bar is pressed in with a twisting motion (Fig. 3).

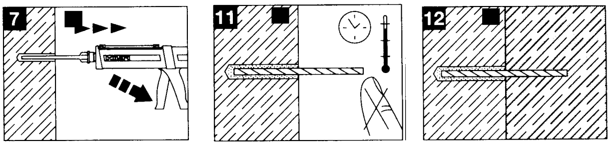


Fig. 3: Example of injection system

Furthermore glass capsule systems are used. The capsules contain the mortar which is based on the above mentioned resins. They are put into the hole. Then the bar is driven into the hole by hammer blows (Fig. 4). There by the capsule is destroyed and resin and hardener are mixed.

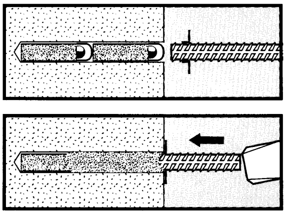
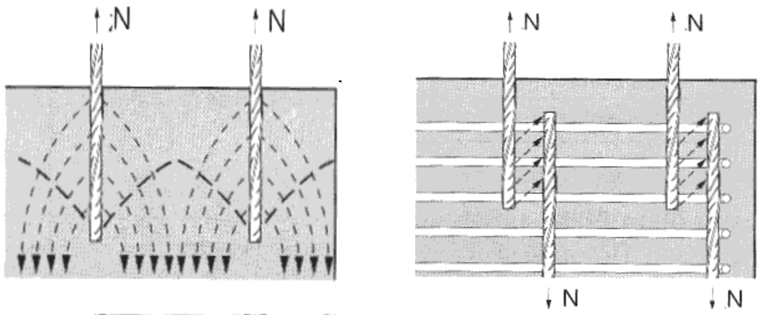


Fig. 4: Example of capsule system

Transmission of load

Bonded reinforcing bars can be separated into two kinds of applications:
Bonded bars in concrete without connection reinforcement (Fig. 5a). These bonded rebars transfer the load into the concrete in the same way as bonded anchors.
Bonded bars in concrete with connection reinforcement (Fig. 5b). These bonded rebars act in the same way as spliced reinforcement.



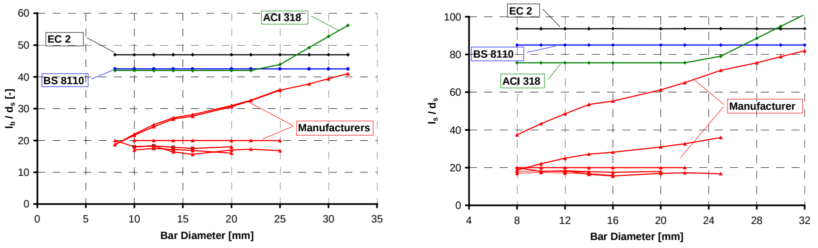
a) Without connection reinforcement b) With connection reinforcement

Fig. 5: Bonded reinforcement

In these two cases the transmission of load is totally different. In case of bars without connection reinforcement the load must be taken up by the surrounding concrete, utilizing the concrete tensile strength in a rather large volume. Failure may be caused by bar pullout or by concrete breakout. With rebars spliced with existing reinforcement the load is transferred by compression struts to the cast-in-situ reinforcing bar. The tensile strength of concrete is utilized only locally. Failure is caused usually by splitting of the concrete cover. In this paper only rebar connections are discussed, where the load is transferred to existing reinforcing bars or concrete breakout is prevented e.g. by compression forces.

Comparison of the Bond length according to reinforced concrete-codes with manufacturers recommendations

Several products are already on the market for post-installed rebar connections for which manufactures recommend the required bond length. Fig. 6a shows the bond length recommended by manufacturers to transfer the yield strength of the bar as a function of the bar diameter. For comparison the anchorage length required by the codes for reinforced concrete Eurocode 2 [1], ACI 318 [2] and BS 8110 [3] are plotted as well. It can be seen that the bond length recommended by manufacturers are in most cases significantly shorter than the bond length required by codes for reinforced concrete.



a) Bond length b) Splice length

Fig. 6: Comparison of bond length a) and splice length b) recommended by manufactures with the length required by different codes for reinforced concrete

Often post-installed rebar connection have to be spliced with the existing reinforcement. This connection must be treated as overlap splice. Fig. 6b shows a comparison of the splice length recommended by manufacturers to transfer the yield strength of the rebar with the values required by codes for reinforced concrete. The bond length recommended by manufacturers may be up to 70% shorter than the splice length required by the codes. This significant difference is due to the fact that most manufacturers recommendations do not distinguish between anchorage and splices.

Experimental investigations

To investigate the behavior of post-installed bars with large and small concrete cover under different installation conditions pullout tests with single bars were performed. Furthermore the overall behavior of rebar connections was investigated by testing spliced bars in beams and slabs. In all cases cast-in-place and bonded bars were tested side by side.

Pullout tests with single deformed rebars

Pullout tests with single deformed rebars were performed to study the bond behaviour and load transfer mechanism under different geometrical and environmental conditions. Test variables were:

- Type of mortar
- Concrete strength

- Bar diameter
- Embedment depth
- Concrete cover
- Hole cleaning
- Moister content of concrete
- Drilling system
- Temperature of mortar and base material

Two injection systems were tested. The mortar of both systems contains a mixture of vinylester resin and cement. All bars were pulled out with a hydraulic ram. The formation of a concrete cone was prevented by placing a steel plate on the concrete surface. To reduce the friction between the steel plate and the concrete two layers of teflon were placed under the steel plate. The test setup for tests with a small concrete cover is shown in Fig. 7. A similar test setup was used for the tests with a large concrete cover.

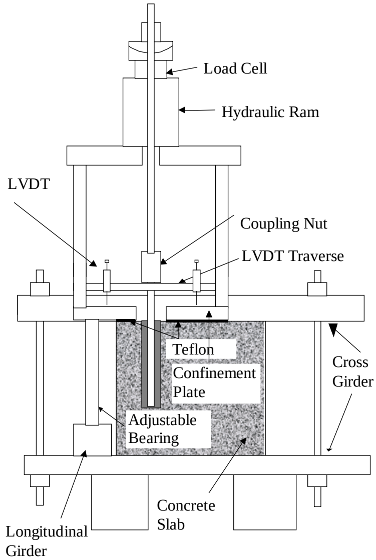


Fig. 7: Test setup for pullout tests with a small concrete cover

Influence of Adhesive Mortar

Fig. 8 shows the bond strength related to the bar diameter measured in pullout tests with cast-in-place and post-installed deformed reinforcing bars diameter d = 20 mm, embedment length h_{ef} = 300 mm as a function of the concrete cover. Tests were done with a concrete cover c = 40 mm and c = 150 mm. The cleaning of the holes was done by hand pump and hand brush until no further drilling dust could be removed (5 times blowing, 5 times brushing, 10 to 15 times blowing). The equipment is normally applied in practice. Two different injection mortars were tested. For c = 40 mm failure occurred by splitting the concrete cover and for c = 150 mm bar pullout was observed. For a reason of simplicity the average bond strengths for the concrete covers are connected by a straight line. Note that in reality the increase of bond strength with concrete cover might be different because pullout failure might be seen at c < 150 mm. The test results show an influence of the mortar type on the bond strength. While the bond strength of bars with mortar type A is as high (c = 40 mm) or higher (c = 150 mm) than the bond strength of cast-in-place bars, the bars bonded with mortar type B show a smaller bond capacity than cast-in-place bars. In [4] similar results have been reported.

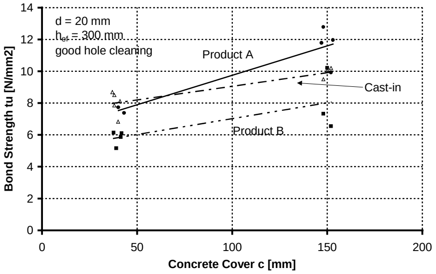


Fig. 8: Results of pullout tests with cast-in-place and bonded bars with small and large concrete cover, cleaning by hand, concrete cube strength $f_{c,200} \cong 30$ N/mm²

Influence of Cleaning Conditions and Wet Concrete

Fig. 9 shows the results of pullout tests with bonded bars d = 20 mm, h_{ef} = 300 mm. Varied are the degree of hole cleaning, the moister content of the concrete and the concrete cover.

According to the test results the bond strength is significantly influenced by the degree of hole cleaning. If in dry concrete the hole was not cleaned at all, the bond strength was reduced to less than 50 % of the value valid for a well cleaned hole. In moisture saturated concrete the holes were cleaned by using several times a hand pump and a hand brush. In spite of the large cleaning efforts the bond strength was very low. With bars installed in uncleaned holes in dry concrete or installed in well cleaned holes in wet concrete the bond strength is not much influenced by concrete cover, because in all tests failure occurred by pullout.

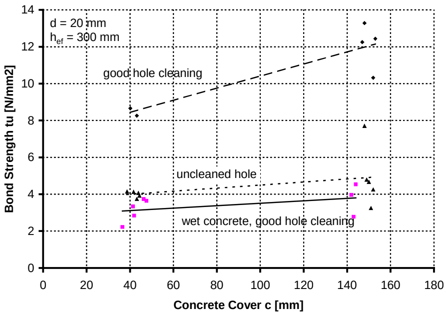


Fig. 9: Results of pullout tests with bonded bars with small and large concrete cover. Tests in dry concrete with different hole cleaning conditions and in wet concrete, Product A, concrete cube strength $f_{c,200} \cong 30$ N/mm²; hand cleaning equipment

A careful analysis of the test results revealed that in wet concrete the wall of the hole is not cleaned enough when using a hand pump and a hand brush even with extensive cleaning efforts. Therefore a new cleaning procedure was developed by the manufacturer. The blowing with a hand pump was replaced by using oil free compressed air combined with a specially developed lance. Instead of a hand brush made out of natural pristle or plastic fibers, the holes were cleaned with a wire brush driven by a drilling machine.

The results of pullout tests with bonded rebars installed into holes drilled into wet concrete and cleaned with the new equipment are shown in Fig. 10. Tests with cast-in-place bars in the same concrete slabs were performed side by side. With the new equipment the wall of the holes were cleaned well. Therefore the bond strength of the bonded rebars is higher than that of the cast-in bars.

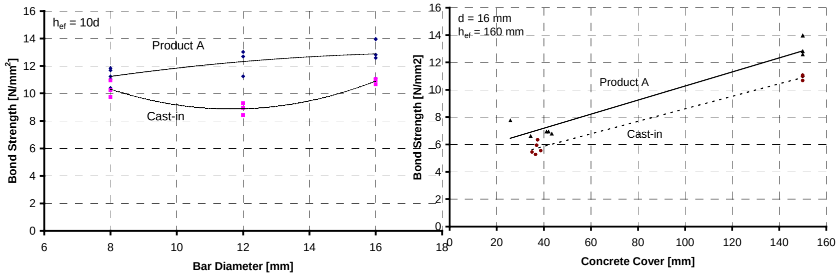


Fig. 10: Results of pullout tests with large and small concrete cover in wet concrete, Product A, concrete cube strength $f_{c,200} \cong 30$ N/mm²; new cleaning equipment

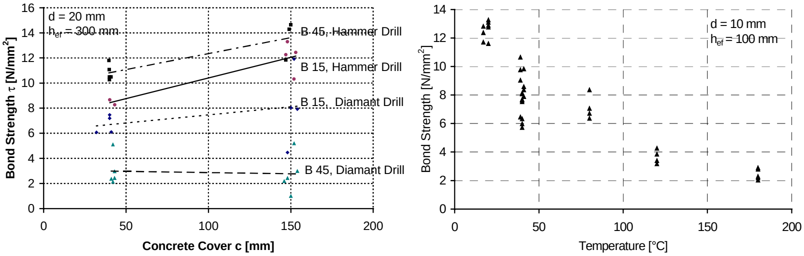
Influence of Drilling System

Fig. 11a) shows the results of pullout tests with post-installed rebars. They were installed in holes which were drilled in dry concrete by hammer drilling and diamond drilling respectively. The tests were done in specimen with a concrete compressive strength $f_{c,200} \cong 30$ N/mm^2 (B15) and $f_{c,200} \cong 55$ N/mm^2 (B45).

The test results show that the bond strength of the bars installed in diamond drilled holes is significantly lower than the strength of bars set in hammer drilled holes. This is especially valid for higher strength concrete.

Influence of Temperature

In Fig. 11b) results of pullout test under different temperature conditions are plotted. The bond strength decreases significantly with the increasing temperature. Note, that the influence of temperature on the bond strength is product dependent.



a) Influence of drilling system b) Influence of Temperature

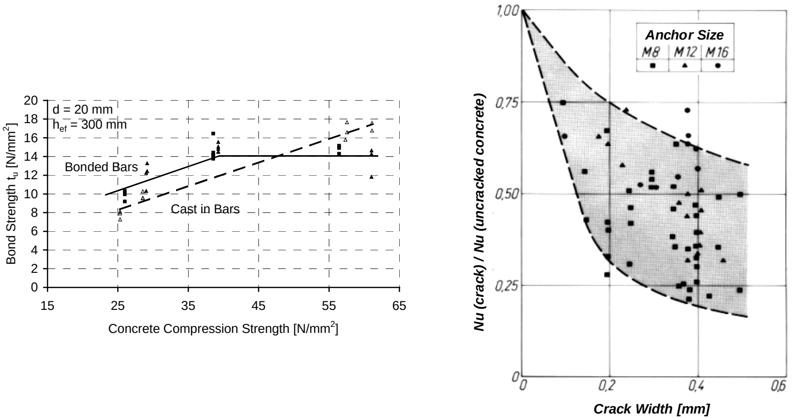
Fig. 11: Influence of drilling system a) and temperature b) on bond strength (Product A)

Influence of Concrete Strength

In Fig. 12a the bond strength of cast-in-place and post-installed rebars are plotted as a function of the concrete compression strength. While the bond strength of cast-in-place rebars increases with increasing concrete compressive strength the bond strength of post-installed bars increases only up to concrete strength $f_{c,200} \cong$ 40 N/mm². This behavior agrees with [5].

Influence of concrete cracking

In reinforced concrete structures cracks must be expected under service load. If these cracks are parallel to the bar the bond strength will be reduced. While the bond strength of cast-in-place bars anchored in cracks with a width of w ≅ 0,3 mm is reduced only by about 20 % compared to uncracked concrete [6], the bond strength of post-installed bars may be reduced by up to 70 % (Fig. 12b).

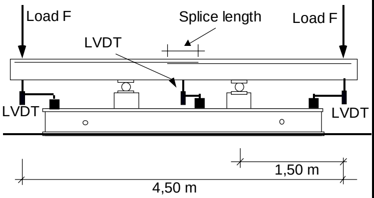


a) Influence of concrete compression strength b) Influence of crack width [7]

Fig. 12: Influence of concrete compression strength and crack width on the bond strength of bonded anchors [7]

Tests of post-installed rebar connections in beams and slabs

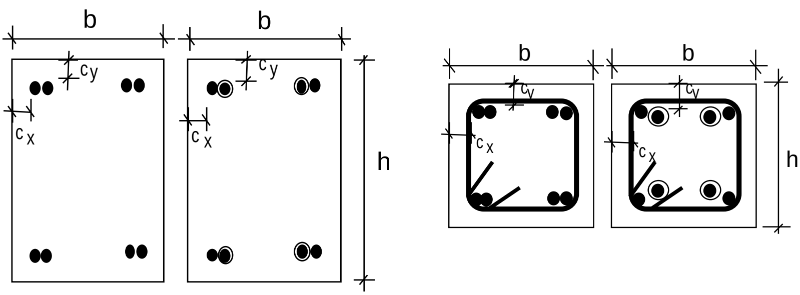
To investigate the overall behavior of post-installed rebar connections, tests with beams and slabs were performed. Tested were cast-in-place spliced rebars and rebars post-installed with product A and product B spliced with existing bars side by side. Fig. 13 shows the test setup and the main dimensions of the test specimen.



	Beam A1	Slab A2	Beam B1	Beam B2	Slab B3
Product	A	A	B	B	B
Specimen width b	320	360	256	400	840
Specimen height h	400	200	320	400	200
Rebar diameter d	20	12	16	25	12
Concrete cover c_x	40	24	32	50	120
Concrete cover c_y	40	40	32	50	24
Splice length l_s	612	292	480	500	240

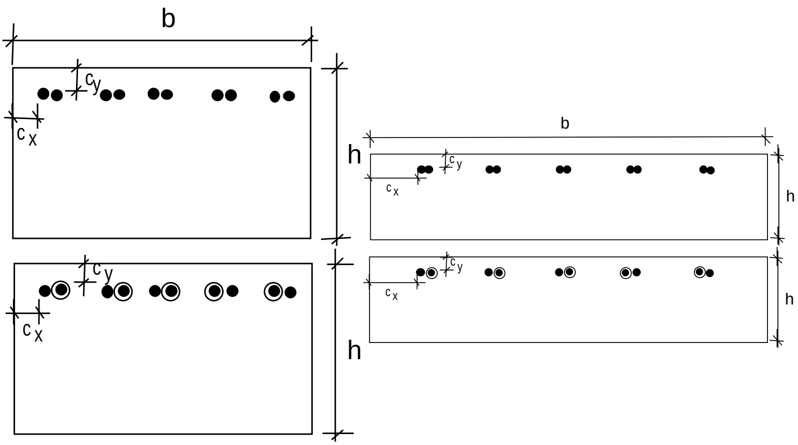
Fig. 13: Static system of bending tests and dimensions of test specimen

The specimen with the post-installed spliced bars were first cast up to the end of the spliced zone. After 28 days holes were drilled into the specimen and the connecting rebars were bonded in. Then the second part of the specimen was cast. Fig. 14 and 15 show the position of the reinforcement in the zone of the spliced bars.



a) Beam A1 and B1 b) Beam B2

Fig. 14: Section of the tested beams type A1, B1 and B2



a) Slab A2 b) Slab B3

Fig. 15: Section of the tested slabs type A2 and B3

In all tests the failure occurred by splitting of the concrete cover. In Fig. 16 the failure loads of the specimen with a post-installed rebar connection related to the values valid for the cast-in-place splices are plotted for all tests. According to the test results under otherwise constant conditions the splice strength of the post-installed rebar connections agrees fairly well with the splice strength of the cast-in-place splices.

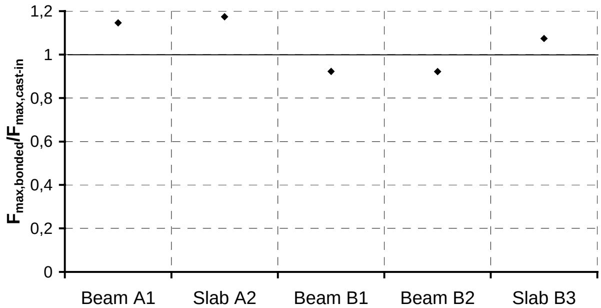


Fig. 16: Test results of beams and slabs

Summary

The bond length recommended by manufacturers for post-installed rebar connections are often much shorter than the values required for deformed bars by the codes for reinforced concrete. This may be due to the fact that often the bond

length given by manufacturers are based on the results of tests with a large concrete cover and a large bar spacing, while codes take the effect of concrete cover and bar spacing into account.

To investigate the behavior of post-installed rebars a large number of pullout tests with single bars and splice tests were performed. Cast-in-place and post-installed bars were tested side by side. The results show that in uncracked concrete the bond strength of post-installed rebars is at least as high as the bond strength of cast-in-place bars provided suitable bonding products are used and the hole is cleaned efficient. However the bond strength may be significantly influenced by installation conditions, concrete moisture, temperature and drilling procedure. Furthermore if cracks in the concrete occur parallel to the bar than the bond strength of the post-installed rebars is much smaller than the bond strength of cast-in-place rebars. Bases on these results bond length of post-installed rebars should be calculated according to the codes for reinforced concrete and may be even larger if cracks are expected parallel to the bars. Furthermore minimum values for concrete cover ($c \cong 2d$) and clear spacing ($s \cong 5d$) must be complied with to avoid damage of the concrete due to drilling of the holes. Finally the installation should be done by skilled workers to ensure the expected results.

REFERENCES

[1] DIN V ENV 1992 Teil 1-1, June 1992, Eurocode 2 Planung von Stahlbeton- und Spannbetontragwerken, Beuth Verlag GmbH, Berlin, Germany

[2] ACI 318M-89, Building Code Requirements for Concrete, American Concrete Institute, Detroit, USA

[3] British Standard, Structural Use of Concrete, BS 8110: Part 1:1985, British Standard Institution

[4] Darwin, D.; Salamizavaregh, S.: Bond Strength of Grouted Reinforcing Bars. ACI Structural Journal, V. 93, No. 4, July – August 1996

[5] Cook, R.; Bishop, M.; Hagedoorn, S.; Sikes, D.; Richardson, D.; Adams, T.; Zee, C.: Adhesive-Bonded Anchors: Bond Properties and Effects of In-Service and Installation Conditions, Report No. 94-2A, University of Florida Gainesville / USA, 1994

[6] Eibl, J.; Idda, K.; Lucero-Cimas, H.-N.: Schlußbericht zum Forschungsvorhaben “Verbundverhalten bei Querzug”. Institut für Massivbau und Baustofftechnologie, University of Karlsruhe / Germany, 1997.

[7] Eligehausen, R.; Mallee, R.; Rehm, G.: Befestigungstechnik, Beton-Kalender 1997, Teil 2, Verlag Ernst Sohn, Berlin / Germany, 1997