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REPAIR OF DAMAGED STRUCTURAL CONCRETE AFTER CONTACT DETONATION ACTION BY GROUTING

Dipl.-Ing. Dipl.-Wirtsch.-Ing. Maximilian Fuchs [1]
Univ.-Prof. Dr.-Ing. Manfred Keuser [2]
CPT Dipl.-Ing. Richard Wensauer [2]

[1] Ingenieurgesellschaft Haumann & Fuchs mbH
Sonntagshornstraße 4, D-83278 Traunstein
e-mail: mfuchs@haumann-fuchs.de - web: http://www.haumann-fuchs.de

[2] Institute for Structural Engineering
University of the German Armed Forces Munich
Werner-Heisenberg-Weg 39, D-85577 Neubiberg
e-mail: massivbau@unibw.de - web: http://www.unibw.de/massivbau

Abstract:

High dynamic loads like impacts or contact detonations lead to local damage in reinforced concrete structures. This damage - consisting of perforations and craters caused by spalling and scabbing - is characterized by a central target zone, which is visually recognizable and also an invisible damage in the surrounding material caused by the shock wave running through the concrete. This obvious invisible damage is mainly characterized by cracks in the reinforced concrete structure. These cracks are often concentrated along the axes of the reinforcement bars and lead to a weakened bond between concrete and reinforcement. Consequently stiffness and load bearing capacity are reduced.

A well suited method to repair the structure and to increase its stiffness is to close the cracks friction-locked by grouting them with powder cement suspension or epoxy based adhesives. As a consequence, the concrete's meso structure and the bond behaviour between concrete and reinforcement are affected. This improves the structural behaviour of the whole RC-structure.

This paper focuses on the repair of damaged structural concrete after contact detonation action. Therefore fundamental investigations concerning the use of different repair methodologies have been carried out with respect to the obviously invisible damage in the surrounding material mentioned above. The grouting techniques which have been used focus on the repair of concretes meso structure and the weakened bond between reinforcement bars and concrete in the surrounding damage zone. This contribution includes fundamental experimental investigations concerning the repair of reinforced concrete components by grouting as well as investigations concerning practical application.

1. INTRODUCTION

High dynamic loads - for example a vehicle impact or blast and shock waves due to detonations - lead to damages in reinforced concrete structures. These damages are characterized by a central zone, which is visually recognizable and also an obvious invisible damage in the surrounding material caused by shock wave propagation through the concrete (surrounding zone, see figure 1). This damage in the surrounding zone is characterized by a deterioration of the concrete's microstructure as well as bond failure between reinforcement bars and concrete.

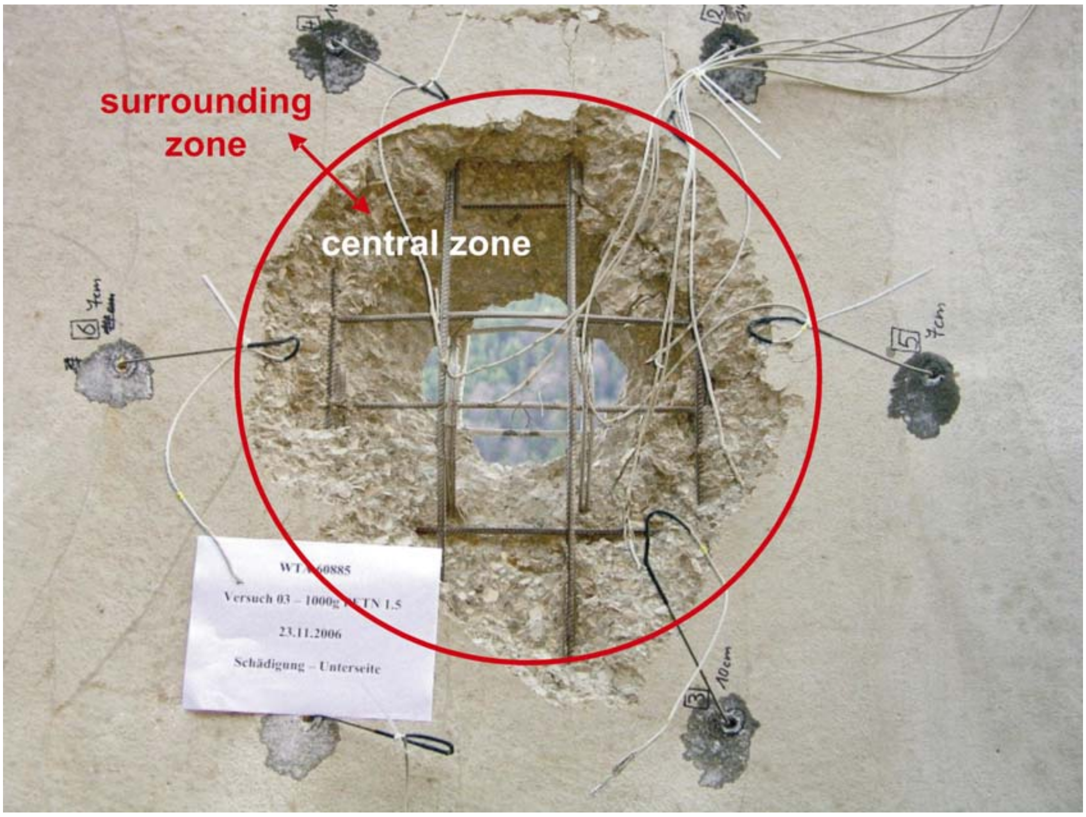


Figure 1: Zones of damage after contact detonation action

Both the damage assessment as well as the repair of damaged reinforced concrete are important topics with respect to a durable use of infrastructure. After damage assessment (see [1] and [2]) a further step focuses on the repair of damaged structural concrete (see [3]). Therefore fundamental investigations concerning the use of different repair methodologies have been carried out with respect to damage after accidental action. The grouting techniques focus on the repair of cracks, the concretes microstructure and the weakened bond between reinforcement bars and concrete in the surrounding damage zone.

Furthermore this contribution includes application-oriented experimental investigations concerning the repair of reinforced concrete components by grouting and a discussion of the appropriateness for repairing RC-structures damaged by accidental action such as a contact detonation.

2. GROUTING TECHNIQUES USED

2.1 Materials

The materials used for friction-locked closing of cracks are either powder cement suspension (ZS) or epoxy-based resin (EP). With other grouting materials such as polyurethane-based materials a friction-locked joint of crack edges could not be guaranteed. According to German guideline for repair and retrofitting of structural concrete [4] epoxy resin can be used for grouting cracks with a crack width larger than ca. 0,10 mm. Powder cement suspension needs stable crack widths larger than ca. 0,25 mm to guarantee grouting success and thus a friction-locked joint of crack edges.

Therefore powder cement suspension as well as epoxy resins have been used for the experimental fundamental investigations. For the application-oriented tests epoxy resins have been used due to the small crack widths existent in the surrounding zone after contact detonation (see figure 1).

2.2 Techniques

RC-slabs after contact detonation action are characterized by a high grade of damage in the surrounding zone consisting of radial and widespread cracking [1, 6] (figure 2). Because of this high grade of damage with almost loose parts it is necessary to choose a smart grouting method for repairing. Therefore no high pressure techniques (pressure more than 10 bar) have been used.

Figure 2: Damage after contact detonation [7]

The techniques used is mainly low pressure grouting (pressure lower than 10 bars) by using an automatic mixing equipment for powder cement suspension and a manually operated injector for epoxy resin (figure 3 left). Another technique used for cracks with larger crack widths and for the pull-out tests (see section 3.1) is soaking (figure 3 right). This technique is not explicitly appropriate to get a friction-locked joint between the crack edges according to the German guideline [4]. Although with soaking – which means the capillary absorption of epoxy resin into the crack – a friction-locked joint between the crack edges can be achieved because of using the same material (EP) as for low pressure grouting.

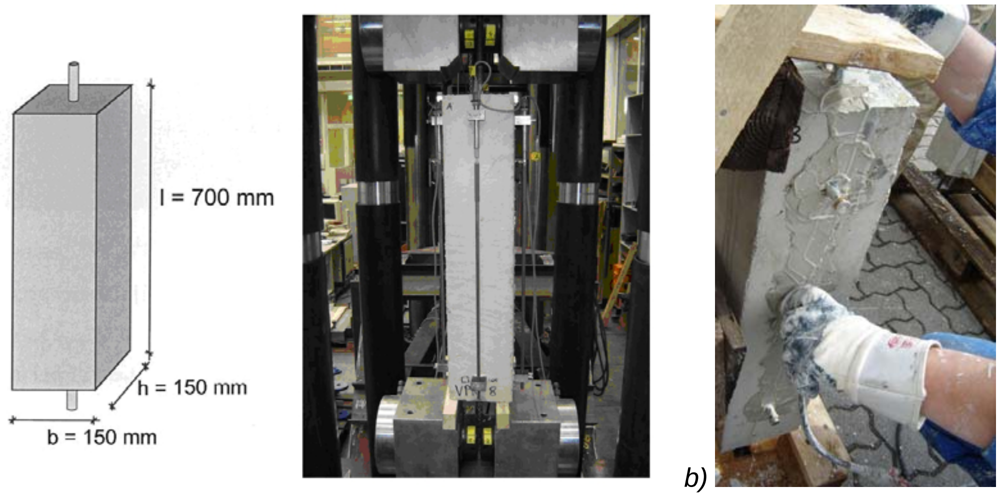
Figure 3: Injector for low pressure grouting (left) and repair by soaking (right)

Detailed information concerning grouting techniques, grouting materials and the correct application is exemplarily given by ESSER [5]. The techniques and materials used for the investigations shown in this paper are comprehensively pointed out in [3].

3. FUNDAMENTAL INVESTIGATIONS

3.1 Tests for bond behaviour

To investigate the effect of grouting concerning the bond behaviour, pull-out tests and uniaxial tension tests have been carried out (see [8]). The specimens and the test setup for the uniaxial tests have been designed in accordance to [9, 10] and are shown in figure 4a. The longitudinal crack of the specimen representing the damaged tensile member has been induced by a preceding splitting load. After damaging the specimen they have been repaired by grouting using powder cement suspension (see figure 4b).



a) b)

Figure 4: a) Test specimen and test setup for uniaxial tensile test b) Injecting the specimen

The tests show that the bond behaviour of reinforced concrete repaired in this way depends mainly on the success of the injection and this in turn is dependent on the existing crack width. In general it is to state that the greater the crack width, the greater the success of injection. The highest increase of bond stiffness could be achieved at a crack width of about w = 0,5 mm. If the crack width is very large (w > 0,5 mm), the increase in bond stiffness is only small even the success of injection is high. A possible reason for this behaviour at large crack widths may be the non-existence of an interlocking effect of the steel ribs and the concrete at crack widths greater than 2 h_f (height of ribs). To achieve a recognizable interlocking effect, the powder cement suspension itself has got a too low Young's modulus in comparison to concrete. The effect is comparable to the minor bond stiffness of post-tensioning tendons embedded into injected mortar within ducts.

Pull-Out tests with cube specimen repaired with epoxy resin showed also good appropriateness even for smaller crack widths. As the crack width has been identified as the most significant parameter for the improvement of the bond behaviour, a construction to adjust the crack width of the pull-out specimen have been designed (figure 5).

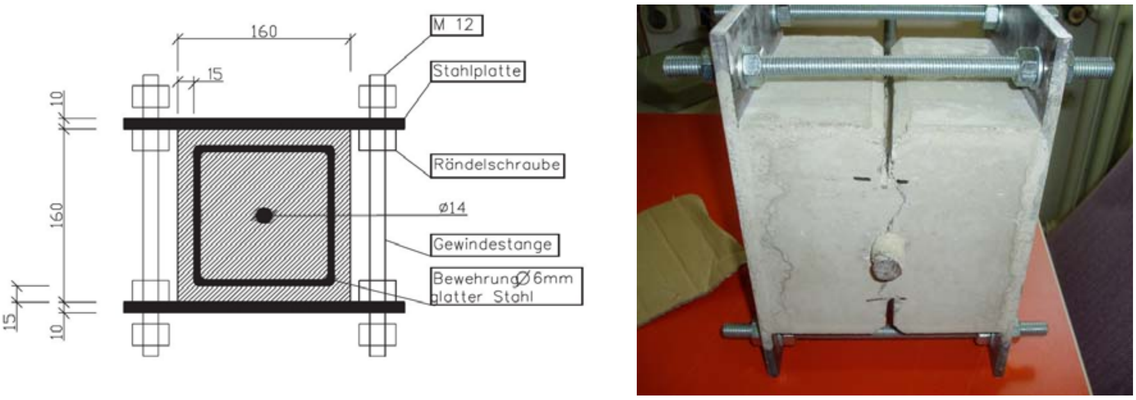


Figure 5:Construction to adjust crack width

The cracked specimen (figure 5 right) have been repaired by soaking epoxy resin with very low viscosity. After repairing and hardening of the epoxy resin the classical pull-out test according to RILEM recommendations [11] have been carried out to get information concerning the bond behaviour. This is expressed by the relationship of bond stress [MPa] and slip [mm] as showed in figure 6. The increase of bond stiffness in comparison to damaged concrete is considerable.

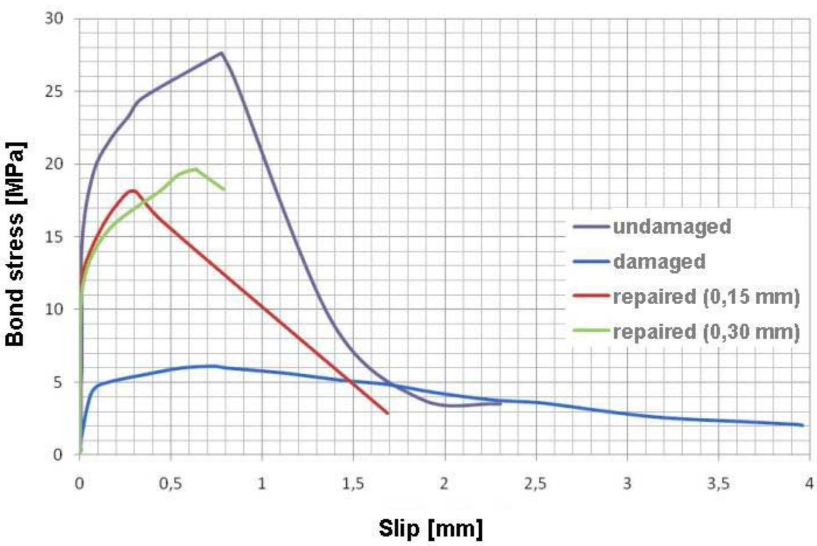


Figure 6: Comparative result of pull-out test

3.2 Compression tests

The compression tests carried out with cube specimen (edge length 20 cm) and a varied angle between load and crack as main parameter. The specimens have been repaired by grouting with epoxy resin using low pressure injector (figure 7). The results of the subsequently carried out uniaxial compression test show a very similar behaviour of all repaired cubes and reference specimen. This can be explained by epoxy's high strength and high stiffness. In fact a good appropriateness of EP for curing a compressive zone cracked of a RC-member can be stated.

Figure 7: Grouting of cracked cubes with low pressure injector

4. PRACTICAL APPLICATION TESTS

The application-oriented practical tests have been carried out at reinforced concrete slabs (size 200 cm by 200 cm) and thicknesses of 30 cm. They consist of standard concrete C 30/37 according to the German code DIN 1045 and are reinforced with two layers of orthogonal steel reinforcement. The slabs have been loaded either with a contact or with a near field detonation consisting of different amounts of explosives. The slabs have already been used for a parametric study concerning the impact of the amount of explosives to the resulting crater volumes (see [7]). The loading of the slabs has been carried out by the Technical Center for Protective and Special Technology (WTD52) in Oberjettenberg, Germany.

The specimens have been repaired by grouting with epoxy resin low pressure injector after sealing the superficially cracks and filling the crater (figure 8). The main result is a large uncertainty concerning the grouting success because of the wide variation of damage symptoms mentioning widespread cracking, crack width and branching cracks

The success of the grouting has only be verified by the injected amount of epoxy. No experimental tests concerning load-deflection behaviour have been carried out because of the large amount of parameters influencing the load-deflection behaviour of RC-structures damaged by high explosives (e.g. scale effect, material's properties, bond behaviour, anchorage of reinforcing steel,…). Hence research concerning these items have to be done in future.

Figure 8: Use of epoxy grouting with low pressure injector for slabs loaded with contact detonation

5. CONCLUSION AND ACKNOWLEDGEMENTS

The fundamental experimental investigations of repaired cracked RC-structures by using grouting with powder cement suspension or epoxy based resin with low pressure show good results in improving materials' stiffness and strength as well as bond behaviour between reinforcement bars and concrete. For the grouting a low pressure technique has been used to get a save repair and not to damage the structure once more.

The repair tests with full-scale RC-slabs loaded with contact detonation show the applicability of the grouting methods used. The quantification of improvement of RC-members by repair with grouting as well as the identification of parameters concerning the load bearing behavior of repaired RC-structures are future research topics at the Institute for Structural Engineering at the University of the German Armed Forces Munich

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REFERENCES

[1] FUCHS, M. and KEUSER, M.: Stahlbetonbauteile nach außergewöhnlicher Einwirkung – Schadensquantifizierung mittels zerstörungsfreier Echo-Verfahren, Bauingenieur, Vol. 83, No.4, pp. 176-185, 2008.

[2] FUCHS, M. and KEUSER, M.: Assessment of Structural Concrete after Contact Detonation Action, Proceedings of 13th International Symposium on interaction of the Effects of Munitions with Structures (ISIEMS 13), Brühl, Germany, 2008.

[3] FUCHS, M. and KEUSER, M.: Instandsetzung von Rissen in Stahlbetonbauteilen nach einer außergewöhnlichen Einwirkung, Beton- und Stahlbetonbau, Vol. 103, No.12, pp. 807-818, 2008.

[4] Deutscher Ausschuss für Stahlbeton: Richtlinie des DafStb: Schutz und Instandsetzung von Betonbauteilen, Edition October 2001, Beuth Verlag, Berlin, 2001.

[5] ESSER, A.: Füllen von Rissen und Hohlräumen in Betonbauteilen, Deutscher Ausschuss für Stahlbeton (DAfStb), issue 527, Beuth Verlag, Berlin, 2006.

[6] RANDLES, P.W. and METCALF, J.G.: High explosive damage in rock and concrete. Proceedings of 18th International Symposium on Military Aspects of Blast and Shock (MABS 18), Bad Reichenhall, Germany, 2004.

[7] LANDMANN, F: Dokumentation der Parameteruntersuchungen des Schädigungsverhaltens von Stahlbetonplatten unter Kontaktdetonation. Zwischenbericht, Wehrtechnische Dienststelle für Schutz- und Sondertechnik, Oberjettenberg, Germany, 2001.

[8] FUCHS, M.; Keuser, M. and Sendzek, S.: Injektion von Feinstzementsuspension - Verbundverhalten instand gesetzter Stahlbetonbauteile, beton, No. 10: p. 468, 2006.

[9] PURAINER, R. and KEUSER, M.: Versuche an Stahlbetonscheiben und –platten unter Zugbeanspruchung, Reports of the Institute for Structural Engineering, No. 06/3, University of the German Armed Forces Munich, Germany, 2006.

[10] KEUSER, M.; PURAUINER, R. and BRUNNER, S.: Bauteile aus Stahlbeton unter Zugbeanspruchung, Beton- und Stahlbetonbau, Vol. 99, No.7, pp. 552-560, 2004.

[11] RILEM: Recommendations for bond test of reinforcing steel. Materiaux et Constructions, Vol. 6, No. 32, pp. 97-105, 1973.