3rd International Symposium on
Connections between Steel and Concrete
Stuttgart, Germany, September 27th -29th , 2017

CONCRETE SCREWS AS POST INSTALLED REINFORCEMENT

Jürgen Feix[1*], Johannes Lechner[1]

[1]Department for Concrete Construction and Bridge Design,
University of Innsbruck, Austria
*Corresponding Author Email: juergen.feix@uibk.ac.at

ABSTRACT

In the last two decades concrete screws have gained more importance as anchoring system because of their easy installation and high load bearing capacity. Motivated by this growing importance adhesive screw anchors with diameters up to 22 mm have been developed, which can be additionally installed with bond resins. Because of their ability to transmit high loads over short bond length screw anchors may also be used as post installed reinforcement, especially as shear reinforcement.

Due to growing traffic volume and more restrictive design standards, structural engineers have a requirement for post installed reinforcement to strengthen existing concrete structures. Especially the amount of calculated shear reinforcement has increased in connection with the introduction of the Eurocode standards. Based on these considerations and taking into account the fact that the age of infrastructural constructions such as bridges is also rising, methods to increase the shear strength of existing structures are needed.

Unfortunately, current structural solutions that aim to enhance the shear capacity suffer from many technical and economic problems. Therefore the unit of Concrete Structures and Bridge Design of the University of Innsbruck is developing a new shear strengthening method using post installed concrete screws. The advantages of this system are the easy installation which comes along with screw anchors and can be done from the lower surface of the structure without any disturbance of the traffic and the efficiency of the screws concerning the growth of the shear load capacity

The new method is analyzed in several series of shear tests with beams with a four point bending configuration. In several different variations of screw diameters and installation geometry all tests resulted in a remarkable increase in load capacity using concrete screws as post installed shear reinforcement. Three tests were made with dynamic loads of 1.25 million and 5 million load cycles. The results showed that this system allows a significant increase in shear strength of concrete structures under dynamic load conditions such as bridges in a very robust and economic efficient way.

1 Introduction

A large number of concrete bridges in Central Europe were built from the 1960s up to the 1980s ([1,2]) according to design codes of the 1950s and 1960s.

In the last decades traffic volume and traffic weight have been increasing remarkably and will increase furthermore according to current studies [1,3]. This is also considered in the actual load approaches in codes such as Eurocode 1 with significant higher loads to be applied in actual structural analysis, as shown in [4,5]. The application of these load approaches to aged bridges combined with new design and construction rules for concrete bridges leads to a lack of existing reinforcement in these structures. As shown in [6] especially the maximum shear load capacity without shear reinforcement calculated on basis of Eurocode 2 is up to 50 % smaller, compared to Austrian Standard B4200 which dates from 1957. On the other hand, the necessary stirrup reinforcement for shear and torsional loads calculated on basis of Eurocode 1 is up to 20 % higher compared to older standards.

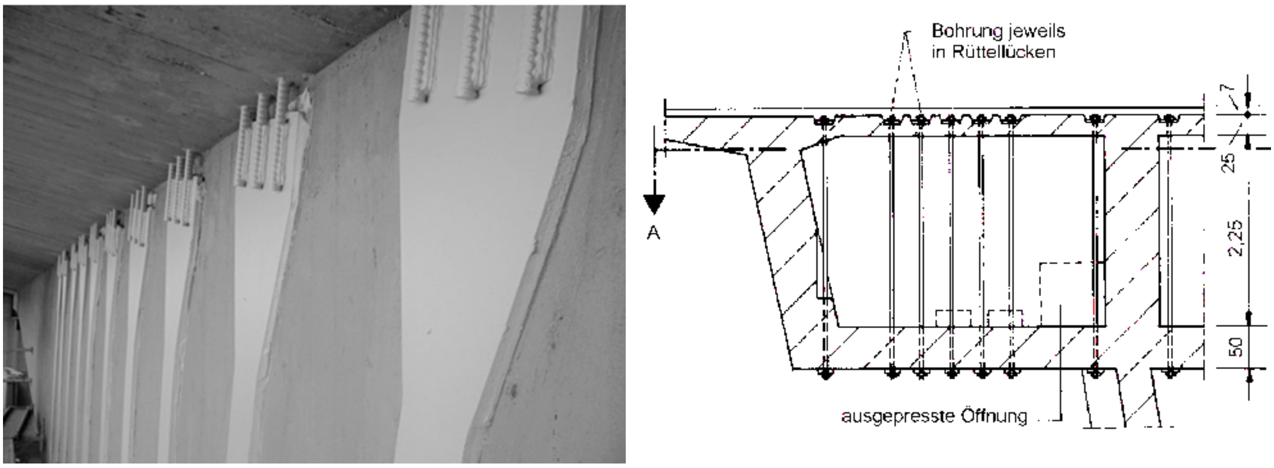

Figure 1: Attached steel plates at bridge girders and drilled through bars as examples for current shear strengthening methods, taken from [7] (left) and [8] (right)

Figure 1 shows two examples of shear strengthening systems which are currently in use. The left figure shows steel-plates that are glued to the bridge girders and attached threaded bars, which are drilled through the bridge deck to ensure a confinement of the bending compression and tension zone. Another widely used system are drilled through threaded bars as shown in the right side of Figure 1. For the installation of both examples the pavement and the sealing of the bridge has to be removed and therefore at least one lane of the bridge must be closed. On the other hand systems with glued anchors that are installed from underneath the bridge lose their strength at temperatures higher than 80°C according to Eligehausen[9].

Although several guidelines such as the “German Structural Assessment Provisions for Older Road Bridges” allow modified design approaches to assess the shear resistance of existing concrete bridges [10], based on practical experiences a need for new strengthening systems is given. Especially for shear strengthening, new methods are demanded which are cost-efficient, simple to install and based on robust force transfer mechanisms such as interlock. Since a total lock down of bridges especially for highways results in large economic losses a new strengthening system should be installed without disruption of the ongoing use.

Concrete screws as post-installed shear reinforcement can be installed from the lower surface of concrete structures since the load transfer is based on interlock between screw thread and drilled hole in the concrete structure as shown in Figure 2. Therefore this paper investigates the use of these shear strengthening elements for concrete structures with dynamic loads such as bridges.

2 Description of the post installed concrete screws

Concrete screws or screw anchors are normally used as a fastening system in cracked or non-cracked concrete. They are installed in hammer-drilled holes. The diameter of the drilled hole is given by the screw-manufacturer. At the tip of the screw a thread is provided, as shown in Figure 2 and Figure 3, larger in diameter than the drilled hole. The screws are driven in with a special impact driver and thus cut threads into the concrete surface of the drill hole as shown in the right image of Figure 2. The concrete screws used have special welded marks at the cutting thread to ensure a correct interlocking connection between concrete and anchor.

Figure 2: Load transfer mechanisms of installed, glued concrete screws on basis of interlock and adhesive

For the shear tests three different types of screws provided by the Manufacturer TOGE Dübel were used. These screws are built with a standard ISO thread at the rear end for fixing attachments with standard washers and nuts. The form-locked connection on the outside of the test-beams was accomplished with nuts, Nord-Lock elements and washers as shown in Figure 3. Additionally to the interlocking connection of the screws a two-component vinylester resin can be used to achieve a bond connection between anchor and concrete at the whole length of the screw. To ensure the correct bond properties drills with small manufacturing tolerances have to be used and the drill holes need to be cleaned by flushing and brushing several times.

The TOGE TSM-16 screw as shown in Figure 3 needs a borehole diameter of 16 mm for a correct installation and is equipped with a standard M16 ISO-thread. This screw with the shown length of 340 mm was especially developed for the shear tests. The TSM-22 screws, which need a borehole diameter of 22 mm are standardised products and are used to fasten noise barriers on railway bridges for example (see [11]).

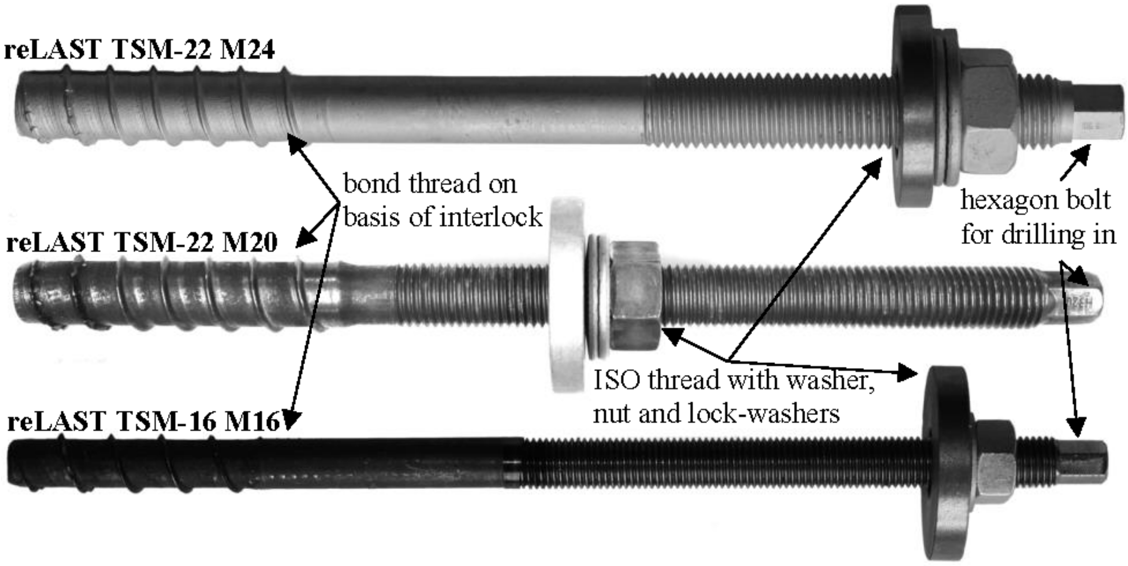

Figure 3: Used types of concrete screws as post-installed shear reinforcement for the experimental research with nominal diameters of 22 mm and 16 mm

3 Experimental research

To determine the behaviour of concrete screws as post-installed shear reinforcement, 32 test specimen in three test series were investigated at the University of Innsbruck. In each test series several different parameters were investigated. The aim of the first test series was to show the suitability of concrete screws as shear strengthening elements. Therefore the TSM-22 screw was used with and without mortar, and the installation direction was varied from the underside and from the top of the girder. These tests were performed with six and eight strengthening elements in the shear zone. On basis of the test results of the first series screws with smaller diameters (TSM-16) were investigated in the second series along to TSM-22 in different geometrical arrangements, as shown in Figure 4. To obtain smaller crack widths of the critical shear crack torque was applied at the nuts of several screws to generate axial prestress in the screws. The last test series was performed to determine the influence of the installation depth of the screws. One test of the first series and two tests of the second test series were performed with cyclic loads to investigate the dynamic behaviour of screw anchors as shear reinforcement. These test were precracked with a load of 160 kN. Afterwards 1.25 and 5 million load cycles between 70 kN and 140 kN were performed respectively. Because none of the three tests failed during cyclic loading, the ultimate load was determined by static loading afterwards. In this paper an overview of the new system will be given and several tests will be discussed in detail. Further information to all tests with static and dynamic loads can be found in [12–14].

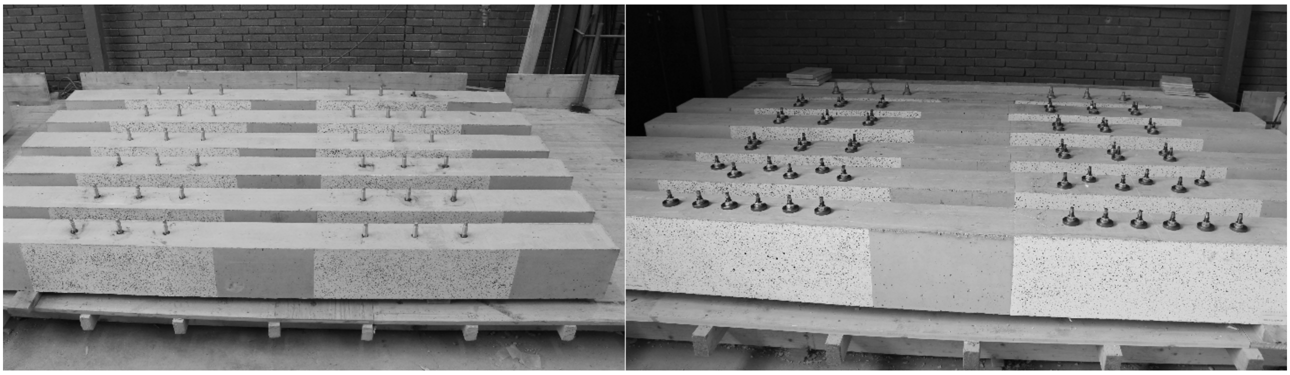

Figure 4: Geometrical arrangement of installed concrete screws in the test beams

3.1 Dimension of specimen

All tests were performed as four-point-bending tests with girders with rectangular cross-section. Figure 5 shows the geometrical dimensions and the used reinforcement for all test beams. As can be seen the total length of the specimen was 350 cm with a distance of 250 cm between the supporting points and 50 cm between the load application points. The cross-section width was 22 cm and the height 32 cm. This results in a shear span to effective depth ratio a/d of 3.45, which is similar to the test series EA performed by Leonhardt and Walther[15].

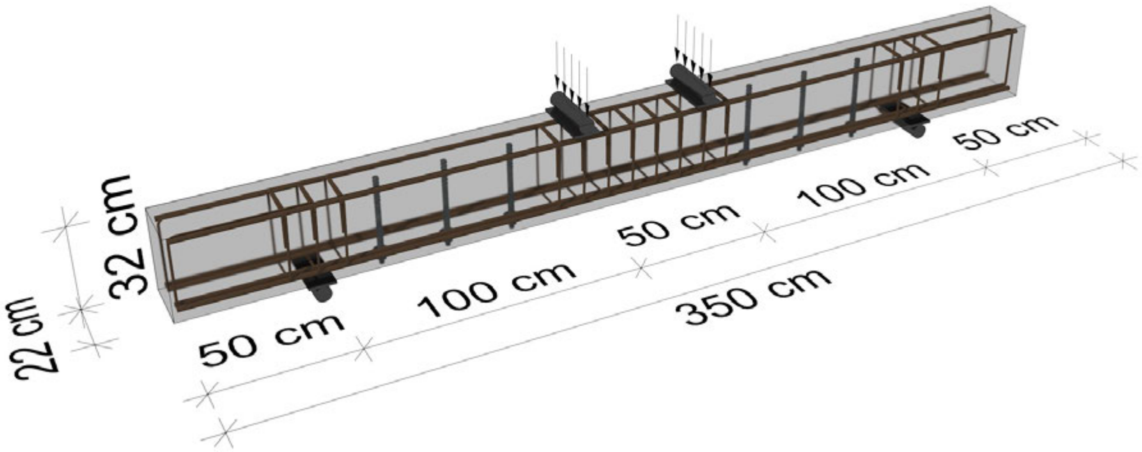

Figure 5: Dimension of the specimen for all four-point-bending tests. 4 bars ø20 mm were used as flexural reinforcement. Stirrups ø10 mm were arranged at the support and load introduction areas.

As shown in Figure 5 all test beams were reinforced with four bars of 20 mm in diameter as flexural reinforcement to avoid early bending failure. Two reinforcing bars were additionally placed in the compression zone. At the bearing points and between the points of load introduction stirrups with a bar diameter of 10 mm were installed. On this basis on both sides of the beam 80 cm could be used to investigate the shown concrete screws as post-installed shear reinforcement with several different installation parameters and geometrical arrangements of the screws.

3.2 Material properties

For both test series ready-mixed concrete of the strength-class C25/30 F45 GK16 XC1 according to the European standard EN206-1 was used. Parallel to the shear tests the compressive and tensile strength of the used concrete was determined using cubes with a side length of 150 mm, which were stored under the same conditions as the test beams.

It should be mentioned that the measured compressive strength of the second test series differs considerably from that of the first and third test series. On average the values deviate by 7.40 N/mm² and 11.8 N/mm² respectively, as can be seen in Table 1. A significant subsequent hardening could not be measured during the test periods.

Table 1: Concrete compressive and indirect tensile strength measured upon cubes with 150 mm side length and Young's Modulus of used concrete

test series	compressive strength $f_{c.cube}$ [N/mm²]	tensile strength $f_{c.sp}$ [N/mm²]	Youngs modulus E_c [N/mm²]
1	35.42	2.23	29 090
2	28.03	2.40	25 697
3	39.88	3.20	28 330

For all three types of used shear strengthening elements uniaxial tension tests were performed. With three tests of each type a mean stress-strain behaviour was determined. The tensile test diagram of the TSM-22 M24 anchor shows a highly ductile steel with an elongation after fracture of over 16 % and a maximum stress of about 650 N/mm². In comparison, the screw anchors TSM-22 M20 and TSM-16 M16 show a higher maximum stress over 700 N/mm² but a smaller elongation after fracture. The yield stress of all screws is defined as 0.2% proof stress and was determined with about 520 N/mm² for all used screws.

3.3 Procedure of shear tests

Figure 6 shows the test set-up of the shear tests. The load was applied with a computer controlled hydraulic jack with a maximum load of 630 kN. The tests were performed path-controlled with a displacement of 1 mm/min. At steps of 30, 60, 120, 200 and 250 kN the tests were stopped to manually measure the crack development and crackwidth.

The beam deformation was recorded with six inductive displacement transducers, three on each side of the beam. Two transducers were attached in the middle of the beam while the four others were applied right at the points of load application as shown in Figure 6.

To quantify the acting forces in the reinforcement elements all concrete screws of the first test series were applied with two strain gauges of type HBM LY41-6/120. In order to prevent any damage to the strain gauges and cables, the whole screw shaft was wrapped with electrical tape with the exception of those screws installed with injection mortar. In these screw anchors the cables were attached in longitudinal millings to ensure a correct bond behaviour over the full screw length. In the third test series force-measuring rings between the concrete surface and washers were used to determine the screw forces instead of strain gauges, as shown in Figure 6 too.

In the second and third test series a digital image correlation system was used to record the development and opening of the shear cracks on both sides of the test beams continuously. This system facilitates taking pictures with two high speed cameras of both shear areas of the beam every second and simultaneously records the displacement and force of the hydraulic jack as well. These photos are analysed after the tests with special software to obtain the information about crack width and propagation on the surfaces of the specimen. The used cameras, each with two lights to ensure a good illumination of the surface of the beam, are shown in Figure 6.

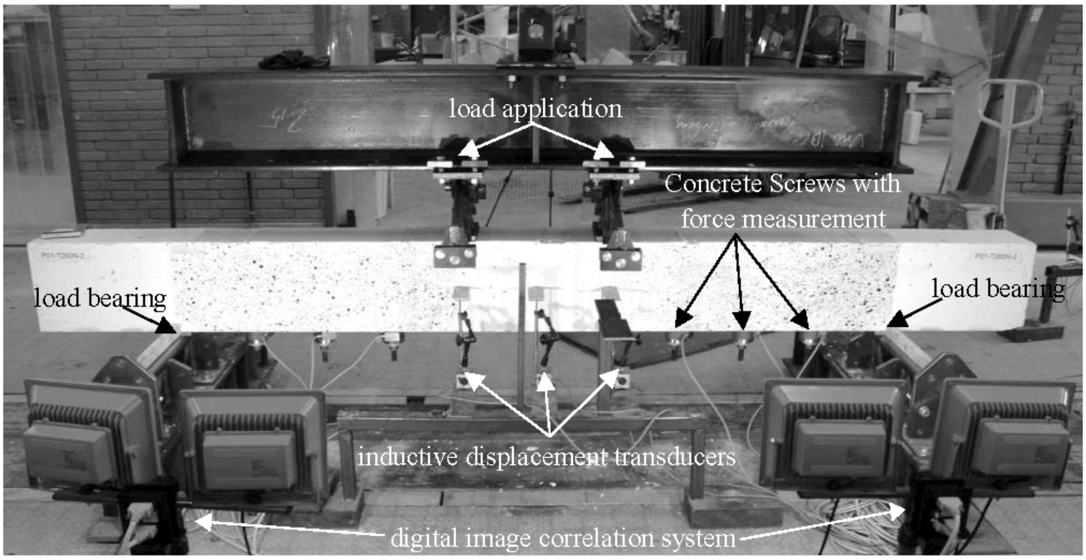

Figure 6: test setup and used systems of measurement

3.4 Test results

The following figures show some of the parameters investigated in the three performed test series. In the first test series two test were performed with 6 TSM-22 screws installed from the upper surface of test beams to determine the influence of the anchorage of the screws in the flexural tension or in the compression zone.

Figure 7 shows the force-deflection curves of the tests with 6 and 8 reinforcing elements with a nominal diameter of 22 mm installed without bond resin. The beam deflection is determined as mean value of the four displacement transducers attached under the points of load application (see Figure 6). It can be seen in Figure 7 that a significant load increase was obtained with 6 and 8 TSM-22 in unglued installation compared to the reference test without shear reinforcement. The influence of the installation direction in the maximum load is negligibly small with 5 % and 8 % for 6 screws as well as 8 screws. The beam deflection is higher for the tests with screws installed from the upper side because of the higher crack width of the bending cracks in the anchorage zone of the concrete screws.

Figure 8 shows the influence of screws installed with bond mortar compared to tests without for two different types of screws (TSM-22 and TSM-16). The amount of shear reinforcement is 15.21 cm²/m for TSM-22 and 16.75 cm²/m for TSM-16. This means a variation of the shear reinforcement ratio ρ_{sw} by 0.07 %. All tests show significant higher failure loads compared to the reference tests. The both tests with glued screws in Figure 8 reached up to 60 % higher failure loads compared to the

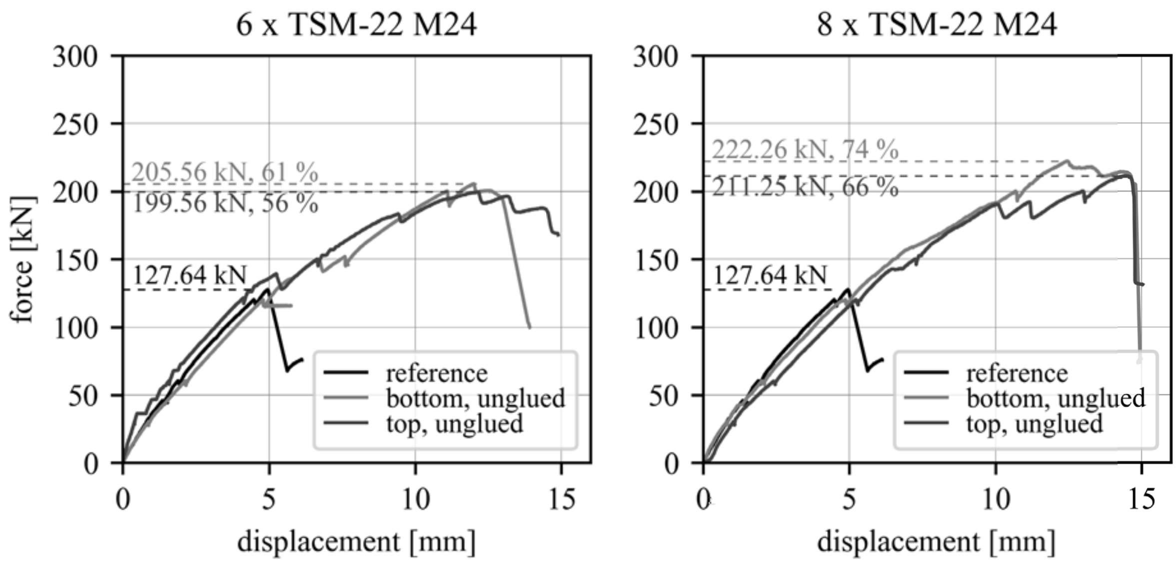

Figure 7: Force-Displacement diagrams of shear tests with installation of concrete screws from the upper side and the lower side of the beam respectively

unglued tests for TSM-22 and up to 30 % higher loads for TSM-16. It can be seen, that the tests with screws in glued installation have a higher component stiffness because of smaller crack width of the critical shear cracks. In Figure 8 a significant loss of stiffness is shown for the test with 6 unglued TSM-22 screws at a load level of around 150 kN. This is in the range of the shear load capacity of an unreinforced test beam.

In the third test series the influence of the installation depth was investigated. Three depths of the drilled hole were used. 290 mm with the top of the screw at the top level of the upper flexural reinforcement bars and 260 mm with the top of the screws at the lower level of the upper flexural reinforcement bars. Additionally 230 mm with the anchorage of the screws significantly under the flexural compression zone of 7.3 cm at maximum load, was investigated. A significant influence of

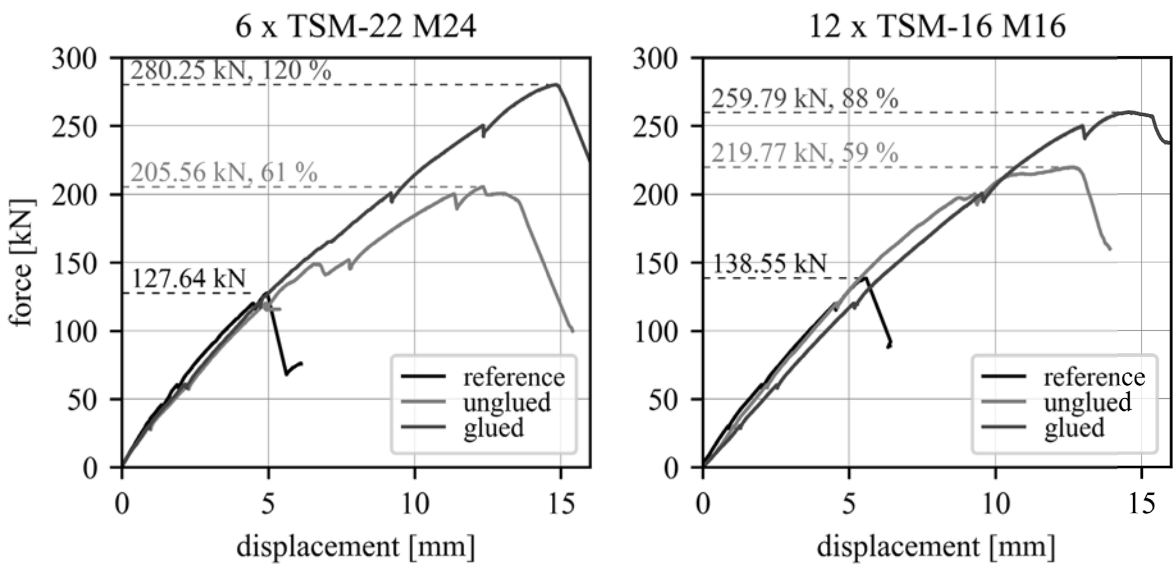

Figure 8: Force-Displacement diagrams of shear tests with and without resin of TSM-22 and TSM-16 concrete screws

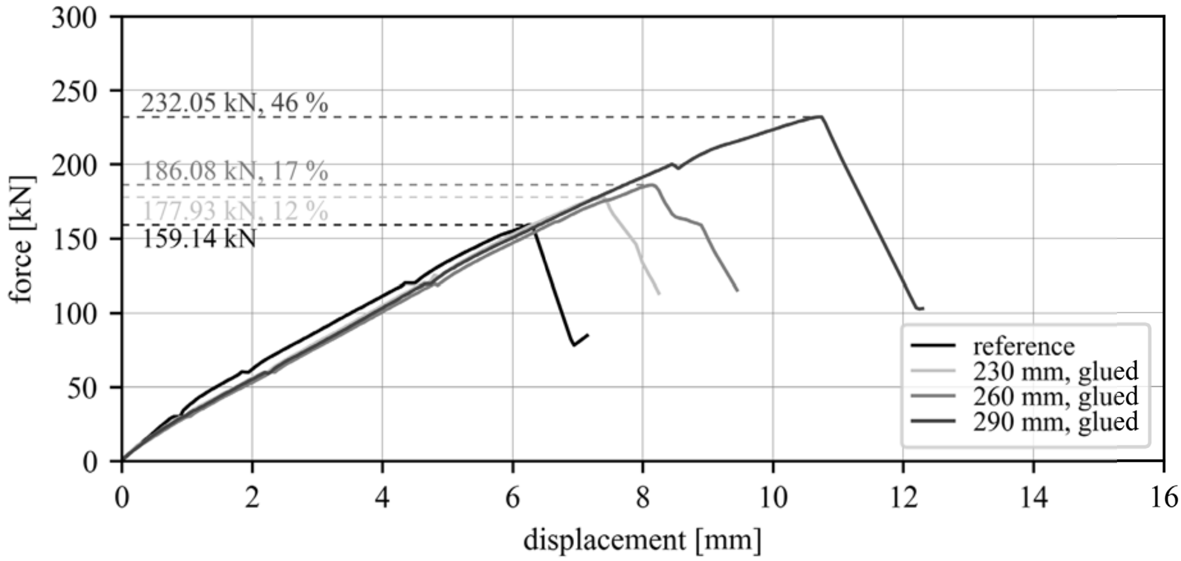

Figure 9: Influence of the installation depth of glued TSM-22 M20 to the maximum forces

the installation depth can be seen in Figure 9. All tests show higher failure loads compared to the reference test. The load increase is 46 % for the top of the screw at the upper level of the upper reinforcement bars and two times higher compared with the tests with smaller installation depths. The difference between 260 mm and 230 mm installation depth is with 5 % noticeably smaller.

Figure 10 shows the test results of the performed cyclic loaded tests compared to the static loaded reference tests with the same test setup. In the first test series one test reinforced with 6 TSM-22 in unglued installation was loaded by 1.25 million load cycles between 70 and 140 kN after precracking. The test did not fail during cyclic loading and therefore was loaded until failure statically after the dynamic load. Figure 10 shows a by 20 % higher failure load of the dynamic test

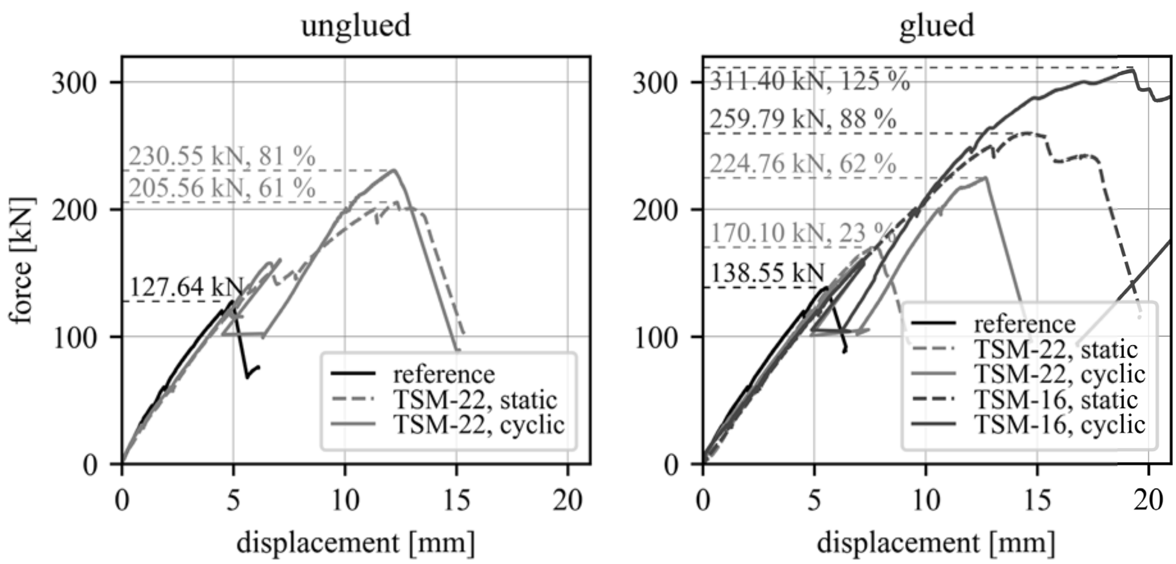

Figure 10: dynamically loaded tests compared to the static loaded comparison test and the unreinforced reference tests for TSM-22 screws in unglued and glued installation and TSM-16 screws in glued installation

and a permanent deformation of about 2 mm out of the dynamic load. The beam deflection at failure is nearly equal compared to the static test. Therefore it can be seen that the stiffness of the test beam was significantly higher after dynamic loading.

In the second test series two tests with glued screws were loaded with 5 million load cycles at same load level. None of these two tests failed due to cycling loading. The right picture of Figure 9 shows for both tests higher failure loads compared to the static tests. The permanent beam deflection resulting out of dynamic load is also smaller compared to the test of the first test series although the number of load cycles was 4 times higher. During the tests the largest growth of beam deflection and crack width was measured for the first 1.2 million load cycles. The beam deflection grew nearly linearly afterwards.

4 Conclusion

The paper presents a new system for shear strengthening of concrete structures with a lack of shear reinforcement. The new idea is to use concrete screws, known as anchoring elements. These elements have the big advantage of a very simple and fast installation and the robust force transfer mechanism based on undercut. Because of this, the system can be installed from underneath the structure and can be loaded immediately. Therefore structures like bridges can be strengthened without interruption of their usage such as closure of single lanes or of the whole bridge.

In over 30 experimental test with concrete beams the concrete screws showed their excellent suitability as post-installed reinforcing elements. In all tests a higher failure load was achieved compared to reference beams without transverse reinforcement. The used concrete screws can be used with additional bond resin, which means an additional corrosion protection too. Therefore several tests with this bond resin were performed and compared to their equal tests without resin. It was observed that the tests with glued concrete screws have higher failure loads and smaller crack widths. A test series with different installation depths of the concrete screws showed a significant influence of the screw anchoring underneath or at the upper level of the upper flexural reinforcement bars for beams with rectangular crosssection.

The tests showed, that the new system can be used as shear reinforcement system successfully. In the meantime it has already been used in several pilot projects. Before the usage as standard construction method several additional tests should be done to determine the influence of parameters like the horizontal distance of the elements or the prestressing of the screws by torque.

5 Acknowledgement

We want to thank our supporters, especially TOGE Dübel GmbH & Co. KG from Nürnberg, Germany for the excellent and ongoing collaboration and the Deutsche Bahn Netz AG for the financial support of our tests.

References:

1. Joachim Naumann. Brücken und Schwerverkehr - eine Bestandsaufnahme. Bauingenieur 85, 1–9 (2010).

2. Marzahn, G. u. a. Die Nachrechnung von Betonbrücken – Fortschreibung der Nachrechnungsrichtlinie in Beton-Kalender 2015 819–904 (Wiley-VCH Verlag GmbH, 2015).

3. BMVIT. Erhebung Alpenquerender Güterverkehr 2009 - Österreich. (Bundesministerium für Verkehr Infrastruktur und Technik, 2010).

4. Maurer, R., Arnold, A. & Müller, M. Auswirkungen aus dem neuen Verkehrslastmodell nach DIN EN 1991-2 / NA bei Betonbrücken. Beton- und Stahlbetonbau 106, 747–759 (2011).

5. Wicke, M., Maier, K. & Pichler, D. ÖNORM B 4700: Stahlbetontragwerke, EUROCODE-nahe Berechnung, Bemessung und konstruktive Durchbildung - Erfahrungen und Weiterentwicklung. Bauingenieur 76, 562–567 (2001).

6. Huber, P., Schweighofer, A., Kollegger, J., Brunner, H. & Karigl, W. Vergleich der rechnerischen Querkrafttragfähigkeit von Bestandsbrücken nach Eurocode 2 und fib Model Code 2010. Beton- und Stahlbetonbau 107, 451–462 (2012).

7. Roeser, W. & Kerkeni, N. Ertüchtigung der beiden Eisenbahnbrücken A13. Beton- und Stahlbetonbau 105, 324–329 (2010).

8. Schnellenbach-Held, M., Peeters, M. & Scherbaum, F. Sachstand Verstärkungsverfahren – Verstärken von Betonbrücken im Bestand. (2010).

9. Eligehausen, R., Mallée, R. & Silva, J. F. Anchorage in concrete construction. (Ernst und Sohn Verlag, 2006).

10. Teworte, F., Herbrand, M. & Hegger, J. Structural Assessment of Concrete Bridges in Germany — Shear Resistance under Static and Fatigue Loading. Structural Engeering International. 25, 226–274 (2015).

11. Eisenbahn-Bundesamt. Zulassung für Betonschrauben der Firma TOGE Dübel GmbH & Co. KG für durch zuginduzierte Einwirkungen dynamisch beanspruchte Verankerungen im Konstruktionsbeton von Ingenieurbauwerken. 49, (2015).

12. Feix, J. & Lechner, J. Development of a new shear strengthening method for existing concrete bridges. in 10th Japanese-German Bridge Symposium (München 2014).

13. Lechner, J. & Feix, J. Development of an efficient shear strengthening method for dynamically loaded structures. in The 11th fib International PhD Symposium in Civil Engineering (Hrsg. Maekawa, K., Kasuga, A. & Yamazaki, J.) 753–761 (The University of Tokyo, 2016).

14. Lechner, J. & Feix, J. Einfluss der Setztiefe von Betonschrauben auf die Wirkung als Querkraftverstärkung. in Innsbrucker Bautage 2017 (Hrsg. Feix, J. & Berger, J.) 57-73 (Universität Innsbruck, 2017).

15. Leonhardt, F. & Walther, R. Schubversuche an einfeldrigen Stahlbetonbalken mit und ohne Schubbewehrung zur Ermittlung der Schubtragfähigkeit und der oberen Schubspannungsgrenze. Deutscher Ausschuss für Stahlbeton 151, (1962).