Quality Festival 2019
ISSN 2620-2832

Željka Radovanović [1]

QUALITY CONTROL OF REBAR COUPLERS IN SPLICING OF REINFORCEMENT BARS

Abstract: *The method of splicing reinforcement bars by rebar couplers is specially justified in the construction of bridges piers with big quantity of the reinforcement in the cross section. The rebar couplers were used for the splicing vertical reinforcement bars in the foundations and piers of the Moračica bridge, the most demanding structure on the section Smokovac-Mateševo of the highway across the Montenegro. The bridge has total length of 960 m and very high piers. During the process of construction and supervision works on the Moračica bridge one of the issues were the choice of adequate material and the control of quality in accordance with the relevant standards. In this paper attention is paid to presented different type of the couplers, the process of controlling the rebar couplers in the plant, the control of the installation of the rebar couplers at the site, as well as the results of the stress testing carried out in the laboratory.*

Keywords: *rebar couplers, quality control, concrete bridges, standards*

1. Introduction

One of the base principle in the design of the concrete structures is that reinforcing bars shall be so anchored and splicing that the bond forces are safely transmitted to the concrete, avoiding longitudinal cracking or spalling. Rebar splicing can be done by overlapping, welding or using mechanical rebar connections (rebar-couplers).

The most important code for design concrete structures in the Montenegro is Rulebook for design concrete structures, “PBAB'87” was edited in the period of the Yugoslavia state. Yugoslavian Rulebook for design concrete structures, “PBAB`87”, and accompanynig JUS standards for quality material control, have not predicted possibilities of rebar splicing by rebar couplers. Also, the method of rebar splicing by overlapping has the most popular splicing method in construction industry of Montenegro. The rebar splicing by rebar couplers almost not been in the using.

Since August 2019, the mandatory regulations for the design of civil engineering structures are Eurocodes, more precisely the Montenegrin standards that have been aligned with European Union regulations, that are marked as MEST EN standards. In the section eight of the standards MEST EN 1992-1-1, which deals with detailing of reinforcement, has recommended that large diameter bars, diameter larger than ϕ32 should not be lapped.

Mechanical rebar splicing, representing relatively new technology in reinforced

[1] Corresponding author: Željka Radovanović
Email: radovanovic@t-com.me

concrete structures, is under fast development for the last decade. This method will be very soon in the wide using in Montenegro construction industry and region of Balkan. Therefore, it is important to presented: mechanical couplers types, their performance, methods of testing and embedding and cost analyses.

All actors in the process of the bridge construction have a many challenges in choice of the best materials, the process of testing material in accordance with appropriate standards and control of the process of the performing works. Therefore, presentation of experience from construction of Moračica bridge, one of the highest bridge in the South Europe, may be interesting for engineering society.

2. Mechanical couplers types

Large number of manufacturers as well as wide assortment of products led to wider use of this technology in contemporary structures construction. It is possible to determine locations and situations where mechanical rebar splicing is better solution than classical splicing, using appropriate technological, economic and structural analysis.

Mechanical rebar splicing using couplers could be considered more as a supplement than substitution of classical rebar splicing by overlapping or welding.

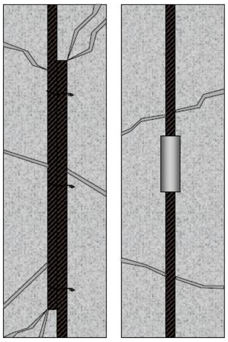


Figure 1. Reinforcing bar lap splice, on left, and reinforcing bar rebar coupler, on right, in cracked concrete, (Brungraber G. R, 2009)

Brungraber G. R. (2009), classify mechanical couplers regarding the means of force transfer between two spliced bars, as follows: Incised-Bar Threaded, Bar-Swaged, Swaged-Sleeve, Grouted Sleeve.

2.1. Incised-Bar Threaded

Threads are incised into the rebars and then two rebars are joined together with double ended coupler. Depending on the rebar coupler system the threads part of the rebars and coupler can be conical, Figure 2 or straight, Figure 3. This system requires either rebar or coupler to be rotated during installation. Incising threads into a rebar introduces stress concentrations which can weaken the bar’s fatigue resistance.

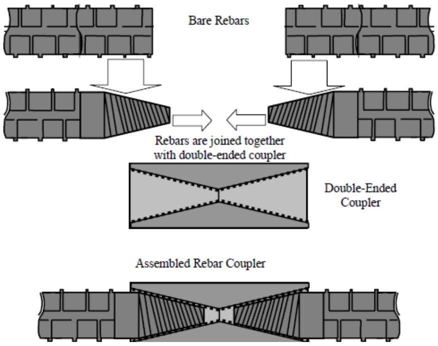


Figure 2. Assembly procedure for incised-bar conical threaded rebar-couplers

Figure 3. Straight threaded end of the rebars splicing with coupler by Dextra manufacturer

2.2. Bar-Swaged

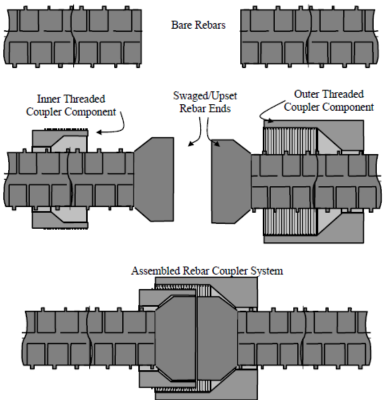


Figure 4. Bar-swaged rebar-coupler

Rebar swaging, or rebar-end-upsetting, can be used alone or with other methods to couple rebars. By deforming, upsetting, or swaging, a rebar end, the diameter is increased.

2.3. Swaged-Sleeve

A metallic sleeve can be plastically deformed, swaged, onto the outside of a rebar, engaging the rebar's deformations and enabling load transfer. Swaged sleeve couplers can either be double-ended, as shown in Figure 5.

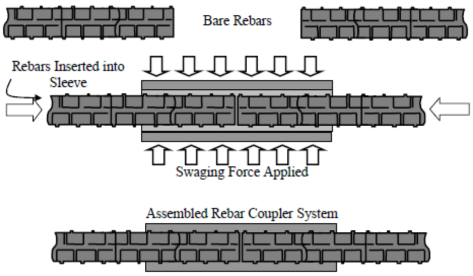


Figure 5. Assembly procedure swaged-sleeve rebar-couplers

2.4. Grouted Sleeve

Grouted sleeve rebar-couplers use the mechanism of development length, to transfer forces from the rebar to the grout, and then to the coupler sleeve.

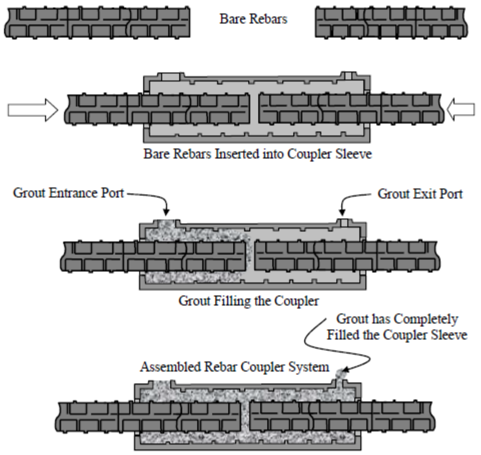


Figure 6. Assembly procedure for adhesively-bonded rebar-couplers

Grouted sleeve rebar-couplers can use cementitious, metallic, or adhesive grouts. The grout can be pumped into the sleeve after the rebars are already inserted, or the sleeve can be filled with grout before the rebars are inserted.

3. The application of mechanical rebar couplers

Mechanical rebar coupler is designed for splicing reinforcement for situations where classical rebar splicing by overlapping or welding are not applicable such as:

- Structural element with large rebar diameters and high reinforcement percentage;
- Fully loaded reinforcement in narrow structural elements or elements with small dimensions;
- It is impossible to extend bars for overlapping at joints due to building technology;
- In case of using specific building technologies, example „top-down“ building method;

- Splice reinforcement through construction joints without formwork interruption, without extending the bars through the formwork.
-

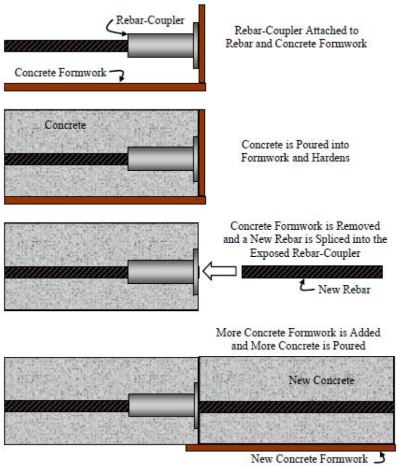


Figure 7. Rebar-coupler continuity of reinforcing across construction joint

About of the method of mechanical rebar splicing through construction joints is wrote Milosavljević B, (2014) and this method is presented at the Figure 7.
On the Moračica bridge, in purpose splicing reinforcement in the foundations and piers, the coupler presented on the Figure 3, was used.

4. Seismic performance of threaded rebar coupler system

Currently there are many uses of threaded reinforcing bars in construction fields in USA, Australia, Switzerland, Germany and Poland as presented in paper Do-Kyu H. and others, (2015). American Concrete Institute and Korea Concrete Institute prohibit the use of lap splice of reinforcement in the plastic hinge area of reinforced concrete bridge pier designed in seismicity regions but codes ACI 318-11 and KCI-2012 are only focused on the strength capacity of mechanical splice by couplers. For threaded rebar coupler system, strain could be more concentrated at the region just outside of the coupler and slip of threaded reinforcing bar within the coupler could be larger than that of conventional ribbed reinforcing bar says in their work „Assessing the Seismic Performance of Threaded Rebar Coupler System" Do-Kyu H. and other, (2015).

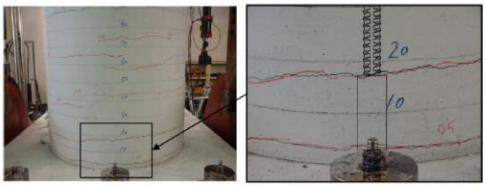


Figure 8. Flexural cracks near the end of the coupler

It is recommended that connection ratio of mechanical couplers in one section shall be below 50% in order that cracks are not concentrated just outside of the mechanical coupler. Sanada et al. (2011) researched the influence of the transverse reinforcement arrangement in the zone of the mechanical rebar splice, under high shear loading and conclude thet is possible avoid in the zone of couplers.

5. Cost analyses

Damsara P. and Kulathunga T., (2018) make a cost comparison between lapping and mechanical joint. The total cost is the sum of material cost, workmanship cost and machinery cost. It was understood that both lap splicing and rebar coupler connection take approximately the same time for making of the joint onsite. However, mechanical joint needs an extra step for thread cutting of rebars which is to be done before the making of joint onsite. For this, help of an electrician and an unskilled labour is needed along with a forging machine and a thread cutting machine. Comparison of material cost for both the methods is given in Figure 9.

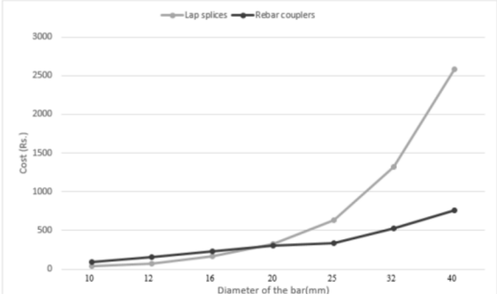


Figure 9. Material Cost Comparison of Rebar Couplers and Lap Splices

Usage of couplers is cost effective for larger diameter bars such as 32 mm and 40 mm, as shown in Figure 9.

6. Quality control of rebar couplers on the Moračica bridge

6.1. Basic information about the project and Moračica bridge

First part of the highway across the Montenegro is 41 km long section Smokovac-Mateševo. Contract about design and construction of the highway was signed at February 2014. Construction works on the bridge Moračica, the most demanding object on the section Smokovac-Mateševo of the highway, was started in May 2016. Main designer and contractor of the bridge is company China Road and Bridge Corporation, CRBC, from Chine.

Figure 10. View on the bridge Moračica

The bridge is a continuous prestressed frame structure of variable cross section. The piers P1-P5 establish rigid connection with the structure and abutments A0 and A1 are connected to the structure through bearings. Spans on the bridge are 95+170+3x190+125m and total length of the bridge is 960m. The highest pier on the bridge is pier P3 161m high.

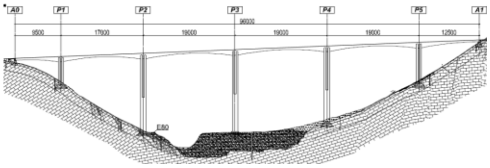


Figure 11. Layout of the structure

Middle piers P1 and P5 consist of 2 box cross
sections. The shape of the section is modified rectangular. The sections which are separated in transverse direction and aerodynamically favourable shape of side areas reduce the wind influence on the piers.

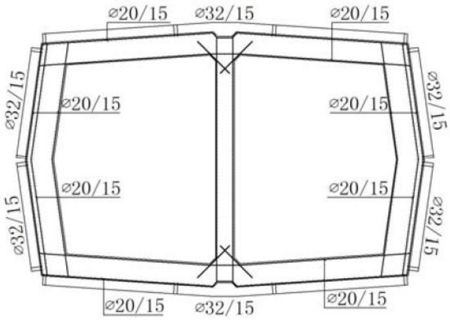


Figure 12. Cross section of the pier in the bottom part

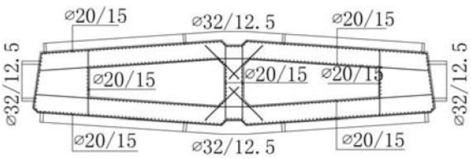


Figure 13. Cross section of the pier in the upper part

Considering the geotechnical conditions, shallow foundation is chosen. The dimensions of foundations of piers P1 and

P5 are 30x26m and the dimensions of piers P2-
P4 are 33x26m. The total height of all the foundations is 7.5m.

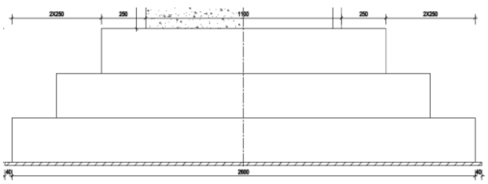


Figure 14. Moračica bridge foundation

The method of reinforcement overlapping will be used for the reinforcement whose diameter ϕ is smaller than 22 cm. Mechanical splicing method will be used for the ϕ reinforcement whose diameter is ϕ ≥22mm. On the Moračica bridge the splicing reinforcement with mechanical coupler was performed on the foundations and piers of the bridge.

Figure 15. Threaded reinforcing bars in foundation which was continued by mechanical couplers

6.2. Application of standard

In the period of the start of highway construction, our Montenegrin standards that have not been aligned with Eurocodes. Main design of the bridge Moračica has done in accordance with Yugoslavian standards and rulebooks for design structures but rebar splicing by mechanical couplers was anticipated in graphical documentations for the vertical bars in foundations and piers of the bridge Moračica.

The question of the choice of adequate materials and the control of their quality in accordance with the relevant standards has been put during the process of construction and supervision of Moračica bridge.

For the reinforcement of the concrete elements was used the reinforcement B500B, manufacturer Arcelor Mittal from Zenica, in accordance with standard MEST EN10080. Reinforcement splicing by overlapping was executed according to the required length of overlapping in the design drawings and acc. to articles of PBAB 87. The percentage of splicing in one section was higher than 50%.
Performance of the couplers were complied with the performance requirements of S12 category in Standard ISO 15838-1. For S12 category couplers, the qualification tests consist of tensile test, slip test and low cycle loading test. The manufactory, Dextra Group Company, provided the qualified results of qualification tests of couplers for each batch of couplers. One batch means that couplers are from same production batch of same manufacturer, with no limitation for total amount of couplers. The numbers of samples, for one batch of couplers, were complied with requirement of the regulation ISO 15835-1:2009.
The percentage of couplers in one section should not be higher than 50% except specified in design. The methods of tests reinforcement bars spliced with mechanical couplers should comply with the standards - ISO 15835-2: 2009 (Steel for the reinforcement of concrete – Reinforcement couplers for mechanical splices of bars – Part 2: Test methods).

6.3. Process of controlling the rebar couplers in the plant

Couplers is a parallel threaded system which produce full strength joint in the rebar connection. The ends of the reinforcing bar to be jointed are cut square and then enlarged by cold forging process to increase their core diameters to ensure that the joint is stronger than rebar.

The purpose of this quality control plan is to make sure the cutting, forging and threading bars, which will be connected by coupler, to be done with the provided requirements. The construction processing threaded couplers in splicing of reinforcement bars was presented in Figure 16.

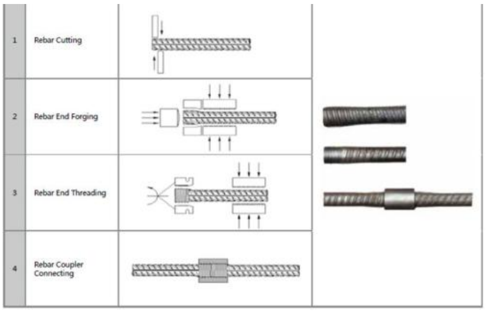


Figure 16. Construction processing of threaded couplers

6.3.1 Inspection after cutting

Quality control of bar cutting are checking with protractor to measure the angle after bar cutting. Last protractor calibration was performed within the last 12 months.

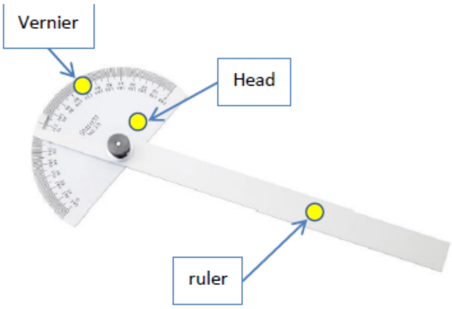
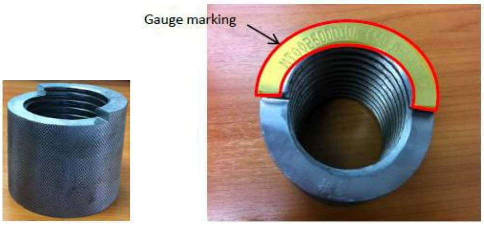


Figure 17. Protractor

Quality control of cutting was done after each change of tool, change of bar diameter or sharpening on the 3 samples. When quality control engineer measured the cut face the 90° ± 1° will be acceptance. If the angle after cut is out of the tolerance, the cutting machine needs to be re-set. Trace back all the rebars cut since the last control, re-control them and reject the rebars that need to.

6.3.2 Thread pitch diameter inspection

The operator will use the DEXTRA couplers and no-go gauge to measure the diameter of the thread. It's a directly way to check the thread good or not.



a) b)

Figure 18. NO-GO gauge

The coupler should slide all along the thread bar without forcing. The NO-GO should not go over 2 pitches. If not more than 1 thread bar fails the control, the lot is acceptable, this corresponds to an AQL of 4.0 as per ISO 2859-1. If more than 1 thread fails the control, all the threads processed since the last control must be checked. Threads that failed the control shall be cut off, and the bars re-processed.

6.3.3 Thread length inspection

Choose the set of gauges corresponding to the pitch of the processed thread. Identity of gauge is marking on the top surface, see Figure 18, b).
Engage the gauge, flat surface first, and turn it slowly and gently into the thread bar. Being checked until the gauge is naturally stopped by the rebar ribs, Figure 19.

Figure 19. NO-GO gauge

After the gauge is fully screwed, the end of the rebar should be within the limits defined on the picture below:

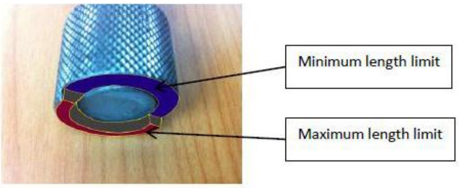


Figure 20. NO-GO gauge

If the thread length is too long or too short, the threading machine needs to be reset. Trace back all the threads processed since the last control and reject those that need to.

6.3.4 Threads handling, identification and protection

Bar threads may be cleaned by compressed air, wire brush or hand file to remove dirt and burrs. Once the bar ends have been threaded, couplers must be screwed onto them with their plastic cap on the outer end.

Figure 21. Threaded bars stored on the site

Couplers should have factory certification with diameter and type connected to reinforcement. It should be protected during transport and storage.

6.4 Type of the coupler installed on the Moračica bridge

On the Moračica bridge was installed two types of couplers. Type A in the all foundations and piers. The type C in the foundation under the piers P1 and P5.

Figure 22. Coupler type A

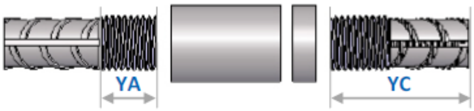


Figure 23. Coupler type C

Position of installation threads coupler type A and coupler type C in the concrete elements were presented on the figure 24.

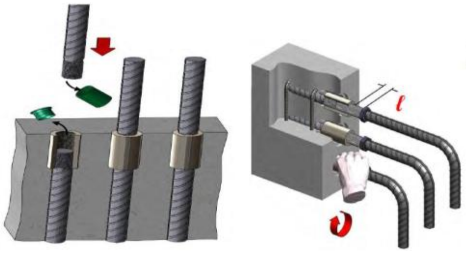


Figure 24. Position in the concrete where is used couplers type A and type C

Figure 25. Couplers type A in the pier P3

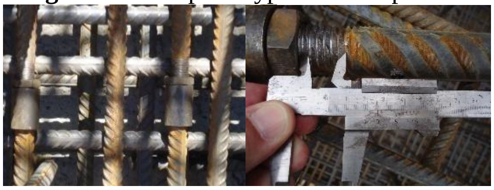


Figure 26. Couplers type C in the foundation under the pier P1

6.5 Control of the rebar couplers installation at the site

The Contractor should submit the qualification test results to the Engineer for approval before commence of installation of couplers. The checking and acceptance on site is as follows:

- The Engineer should randomly choose couplers and check the installation quality of couplers on site;
- Checking frequency is one time per 1000 pieces;
- 3 mechanical splices should be cut out every time for checking;
- Checking test consist of tensile test;
- If one pieces fails for test, another 6 pieces should cut out for checking. If one pieces still fails, the checking result is negative, the Engineer should refuse to accept it and instruct the Contractor to rectify and reform, and then checking again.

Figure 27. Three samples of rebar couplers type A prepared for tensile test

6.4. Results of the laboratory testing

Requirements for mechanical couplers is defined in the first part standard ISO15835-1. The second part of standard ISO 15835-2 defines the testing methods and procedures. The requirements for mechanical couplers relate to: slip under static forces, fatigue properties under high cycle elastic loading, properties under low cycle reverse elastic-plastic loading and strength and ductility under static forces,

The total slip value measured shall not exceed 0,10 mm.

Mechanical splices shall sustain a fatigue loading of at least 2 megacycles with a stress range, $2\sigma a$, of 60 MPa without failure.

There are two prescribed sets of low cycle fatigue requirements, one simulating moderate-scale earthquakes, and one simulating violent earthquakes.

The strength of the mechanical coupler should not be less than product of specified characteristic yield strength value of the reinforcing (R_{eH}) and the specified ratio between tensile strength, and characteristic yield strength value of the reinforcing bar (R_m/R_{eH}). The yield strength value of the reinforcing, R_{eH}, is defined at elongation of 02%. The R_m represented the maximal tension stress. Values of characteristic yield strength R_{eH} and ration R_m/R_{eH} is defined in the standard MEST EN 10080:2009 for the steel type B500B. Total elongation at maximum tensile force A_{gt} shall not be less than 70% of the specified characteristic value at maximum tensile force of the reinforcing bar, but not smaller than 3% in the absolute value.

6.4.1 Results of testing in the BAS's, research&technology laboratory

In the BAS's, research & technology laboratory mechanical splices of Ø 32 mm, type C was testing according to standard ISO 15835-2.

Tensile tests with slip measurement, low cycle loading tests (category S2) and fatigue tests were conducted on mechanical splices on behalf of China Road and Bridge Corporation d.o.o. The tensile and low cycle loading tests were performed on a class 1 Zwick Z1200 tensile/compression machine. A video extension meter was used to measure deformations during the tests. The fatigue tests were conducted on a Zwick HFP 550 machine. The settings during testing have been selected according to ISO 15835-2:2009. The tests were conducted according to ISO 15835-2:2009 (Q). The results of the tests have been evaluated according to ISO 15835-1:2009.

For all testing: Slip- and tensile tests, Fatigue tests, load cycles for S2 test the results were satisfactory.

6.4.2 Results of testing in the Contractor's, site laboratory

All mechanical splice properties tested in the Contractor's site laboratory are related to axial-tension loading. The testing was carried out the standard ISO 6892-1 method B. In the attest documentation the following values were registered: yield tensile strength value of the reinforcing (R_{eH}), maximal tensile stress (R_m) and ration R_m/R_{eH}. Total elongation at maximum tensile force A_{gt} was not presented in the attest documentation. The testing was done on the machine model TT HW2, capacity 1000kN.

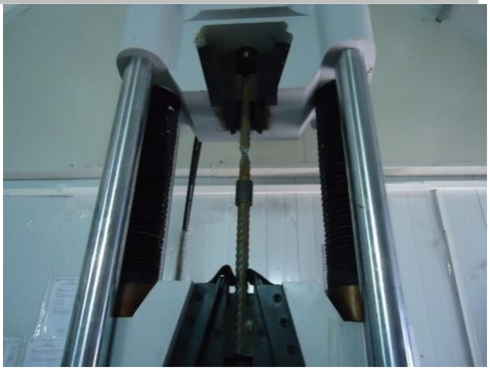


Figure 28. Mechanical couplers testing.

The total 264 testing of mechanical couplers, 88 series per 3 samples, was done during the construction of Moračica bridge piers. The breaking mechanism in the all samples, except in one, was in the bar. Only in one sample of mechanical couplers, taken from the pier P1, the breaking mechanism was registered as extracting of the bars from mechanical coupler.

Figure 29. Broken samples from pier P1, bar ϕ32, coupler type C

During the testing the working diagram was done.

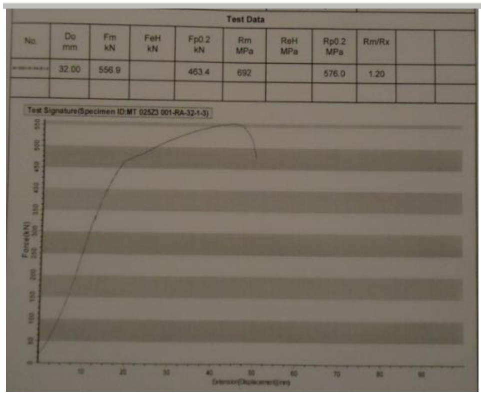


Figure 30. Working diagram of rebar coupler, bar ϕ32 coupler type A, pier P1

Figure 31. Broken 6 new samples from pier P1, bar ϕ32, coupler type C

According to the technical requirement in the Main Design of the Moračica bridge the Engineer requested that be taken the new six samples from the foundation P1, which was done on 05.05.2017. On the same day, six additional samples were tested and all samples were broken outside the zone couplers and in the all 6 testing samples the satisfactory results are registered during the test.

During the testing, executed during the construction of the Moračica bridge, it is concluded that in piers we have the following values:

- P1 - average yield tensile strength, R_{eH}, is 593.8 MPa and average ration R_m/R_{eH} is 1,25;
- P2 - average yield tensile strength, R_{eH}, is 566.7 MPa and average ration R_m/R_{eH} is 1,22;
- P3 - average yield tensile strength, R_{eH}, is 562,3 MPa and average ration R_m/R_{eH} is 1,20;
- P4 - average yield tensile strength, R_{eH}, is 564,2 MPa and average ration R_m/R_{eH} is 1,19;
- P5 - average yield tensile strength, R_{eH}, is 557.8 MPa and average ration R_m/R_{eH} is 1,16.

7. Conclusion

The examples of mechanical rebar splicing with couplers in Montenegro are rarely. In this paper experiences from the using mechanical coupler for splicing bars in the foundations and piers of the Moračica bridge was presented. It can be concluded that intensive development of construction product, like as mechanical couplers, and introduction these products and the international standards in the area of engineering’s construction can bring benefits in the in cases where large profile profiles and a large amount of reinforcement in concrete structures are required. In these situation the splicing reinforcement with couplers represent the better solution then the classical reinforcement splicing by overlapping.

References:

ACI Committee 318, (2011). Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary. *American Concrete Institute, Farmington Hills*, 503 pp.

Brungraber G. R. (2009) Long-Term Performance of Epoxy-Bonded Rebar-Couplers. *PhD thesis. University of California, San Diego*

Damsara P., Kulathunga T., (2018) Analysis on Effectiveness of Rebar Couplers in Splicing of Reinforcement Bars, *ResearchGate*

Do-Kyu H., Ho-Young K., Ho-Hyeoung C., Gi-Beom P., Jae-Hoon L. (2015) Assessing the Seismic Performance of Threaded Rebar Coupler System. *International Journal of Civil and Environmental Engineering, World Academy of Science, Engineering and Technology.* Vol:9, No:10, 1282-1288, ISNI:0000000091950263

ISO 15835-1:2009 Steels for the reinforcement of concrete – Reinforcement couplers for

mechanical splices of bars – Part 1: Requirements

ISO 15835-1:2009 Steels for the reinforcement of concrete – Reinforcement couplers for

mechanical splices of bars – Part 2: Test methods

KCI, (2012) Code Requirements for Structural Concrete. *Korea Concrete Institute, Seoul, Korea*, 342 pp.

Main designer Company CRBC Chine, (2016), Main Design of the Moračica Bridge

Main designer Company CRBC Chine, (2016), Method statement - Installation of Couplers and

Thread Preparation

Milosavljević B. (2014) Mechanical Rebar Splicing. *Building Materials and Structures* 57(2), 9-28. UDK: 624.012.45.078.4

Sanada Y. Konishi D. Khanh N. Adachi T, (2011), Experimental study on intensive shear reinforcement for RC beams with mechanical couplers. *fib Symposium Prague. Proceedings* ISBN 978-80-87158-29-6

Uday S., Dhruva S., (2015), Mechanical Splicing Couplers for Reinforcement, *The*

Masterbuilder, www.masterbuilder.co.in

www.stressteel.com/files/MUL03_27_Documents/772/sas_cat_rp_de_en_04_2013.pdf

Željka Radovanović
University of Montenegro
Faculty of Civil Engineering
radovanovic@t-com.me