UPOREDNA ANALIZA PONAŠANJA BETONSKIH GREDA ARMIRANIH ŠIPKAMA I TEKSTILOM – EKSPERIMENTALNO ISTRAŽIVANJE

COMPARATIVE ANALYSIS OF BEHAVIOUR OF REINFORCED CONCRETE BEAMS USING BARS AND TEXTIL – EXPERIMENTAL RESEARCH

*Damir ZENUNOVIĆ
Danijel RUŽIĆ*

PRETHODNO SAOPŠTENJE
PRELIMINARY REPORT
UDK:624.012.45:66.017/.018
doi:10.5937/GRMK2004087Z

1 UVOD

Dinamičan razvoj tehnologije materijala doveo je do primjene različitih novih materijala za poboljšanje svojstava nosivosti i trajnosti betonskih nosača. Jedan od pristupa jeste primjena sistema zaštite obložnog dijela betonskog nosača (zaštitni sloj betona). U ovu svrhu, razvijeni su polimerni materijali armirani karbonskim, staklenim ili aramidnim vlaknima (FRP – Fiber Reinforced Polymer). Novi pravac razvoja ovih sistema jeste primjena tekstilom armiranih sitnozrnih betona, gdje se koriste tekstili s vlaknima u više pravaca. Fabrički proizvedena ravninska tekstilna struktura sačinjena je od vlakana upletenih na razne načine, kao što su tkanje, pletenje, filcovanje ili štrikanje. Za potrebe istraživanja i razvoja ovog sistema ojačanja betonskih greda, formirana su dva istraživačka centra u kojima se sprovode projekti pod nazivom „Textile Reinforced Concrete (TRC) -Technical Basis for the Development of a New Technology” (SFB 532) RWTH Aachen University i „Textile Reinforcements for Structural Strengthening and Repair” (SFB 528) Technische Universität Dresden. U ovim istraživačkim centrima sprovode se istraživanja mehanizama trajnosti, prionljivosti i kapaciteta nosivosti. Pored dva navedena velika projekta, postoji i niz projekata koji se odnose na tekstilom armirani beton, a sprovedeni su u Izraelu, Sjedinjenim Državama, Grčkoj, Belgiji, Ujedinjenom Kraljevstvu i Kanadi [3]. Utvrđeno je da količina i raspored tekstilne strukture imaju značajan uticaj na ponašanje tekstilom armiranog betona. Istraživanja su posvećena:

1 INTRODUCTION

The dynamic development of material technology has led to the application of various new materials for the purpose of improving the load-bearing properties and durability of concrete girders. One of the approaches is the application of the protection system at the surface layer of the concrete girders (protective layer of concrete). Polymer materials reinforced with carbon, glass or aramid fibres (FRP - Fibre Reinforced Polymer) have been developed for this purpose. A new direction of development of these systems is the use of textile reinforced fine-grained concrete, where textiles with fibres have been used in several directions. The factory-produced flat textile structure is formed of interlocking fibres in various ways such as weaving, knitting, felting or knitting. Two research centres were formed for the purpose of a research and development of this system where projects entitled 'Textile Reinforced Concrete (TRC) -Technical Basis for the Development of a New Technology' (SFB 532) RWTH Aachen University and 'Textile Reinforcements for Structural Strengthening and Repair' (SFB 528) Technical University of Dresden. These research centres have carried out a research about the durability mechanisms, adhesion and load-bearing capacity. In addition to these two major projects, there are a number of projects related to textile reinforced concrete, which have been implemented in Israel, USA, Greece, Belgium, the UK and Canada [3]. It was determined that the amount and arrangement of the textile structure have

Damir Zenunović, profesor, Univerzitet u Tuzli,
Univerzitetska 2, 75000 Tuzla, damir.zenunovic@untz.ba
Danijel Ružić, magistar, Univerzitet u Tuzli

Damir Zenunovic, Professor, University of Tuzla,
Univerzitetska 2, 75000 Tuzla, damir.zenunovic@untz.ba
Danijel Ruzic, Master of Science, University of Tuzla,
danijelr@hotmail.com

primjeni tekstilnih materijala znatno većeg modula elastičnosti u odnosu na beton, kako otvaranje pukotina u betonu ne bi uzrokovalo značajnu redukciju krutosti konstruktivnog elementa, trajnosti tekstilnog materijala, ponašanju tekstilnog materijala pod dugotrajnim opterećenjem, prionljivosti s betonom, te smanjenju troškova izrade tekstilnih mreža. Istraživanjima je utvrđeno da alkalno otporna staklena vlakna, karbonska i aramidna vlakna ispunjavaju potrebne zahtjeve. U radu [13] dat je pregled fizičko-mehaničkih i deformacionih karakteristika pojedinih vlakana.

Korištenje alkalno-otpornog stakla u građevinarstvu započinje sedamdesetih godina prošlog vijeka [3]. U zavisnosti od finoće vlakana, čvrstoće su do 1.400 N/mm², linearno elastično izduženje – do 2%, a modul elastičnosti – od 70 do 80 kN/mm². U eksperimentalnom programu, predstavljenom u ovom radu, korištene su tekstilne mreže sa alkalno-otpornim, staklenim vlaknima.

Da bi se postigla stabilna forma za armiranje betona tekstilom, započeta je proizvodnja tekstilnih mreža. U radu [3] opisuje se ideja armiranja za vrijeme procesa proizvodnje tekstilnih mreža, te postizanje stabilnosti tekstilne mreže impregnacijom i ubacivanjem dodatnih oslonaca, odnosno dodatnih elemenata za ukrućenje.

U radovima [3], [7] i [12] daju se preporuke za recepture betona kako bi se osigurala prionljivost tekstilne mreže i betona, kao i ugradljivost betona kroz tekstilnu teksturu. Istraživanja pokazuju da je pogodan sitnozrni beton tečne konzistencije, te da su neophodni dodaci plastifikatora.

U radovima [15] i [16] dat je pregled utvrđenih fizičko-mehaničkih i deformacionih svojstava tekstilnih mreža, te dosadašnja iskustva primjene u građevinarstvu.

Tekstilne mreže se uglavnom koriste za spoljna ojačanja armiranobetonskih nosača. Efekti ojačanja istraženi su i prezentovani u radovima [1], [2], [4], [5], [7], [9], [10], [12] i [13]. Istraživanja su pokazala da efekti ojačanja tekstilnim mrežama zavise od orijentacije glavnih vlakana tekstilnih mreža, broja slojeva tekstilnih mreža, postupka ugradnje, u smislu ostvarenja prionljivosti tekstilne mreže i podloge, kao i adekvatnog utezanja nosača tekstilnom mrežom. Dobijena su povećanja kapaciteta nosivosti armiranobetonskih greda na smicanje i savijanje, s tim što procenat povećanja zavisi od prethodno navedenih efekata.

Numerički modeli za proračun armiranobetonskih elemenata ojačanih tekstilnim mrežama predstavljeni su u radovima [6], [8], [11], [10] i [14].

U ovom radu predstavljen je program istraživanja s ciljem utvrđivanja mogućnosti primjene tekstilnih mreža za armiranje unutar poprečnog presjeka, što bi omogućilo razvoj poluprefabrikovane armiranobetonske grede sa spregnutim poprečnim presjekom. Istraživanje sa sličnom idejom predstavljeno je u radu [9].

2 PROGRAM EKSPERIMENTA (EXPERIMENTAL PROGRAM)

S ciljem utvrđivanja mehanizma nosivosti greda armiranih armaturnim šipkama i tekstilom, eksperimen-

a significant influence on the behaviour of textile reinforced concrete. Researchers are dedicated to the application of textile materials with significantly higher modulus of elasticity compared to the concrete, so that openings of the cracks in the concrete are unlikely to cause a significant reduction in stiffness of structural element, durability of textile material, behaviour of textile material under long-term load, adhesion with the concrete and reduced costs of textile meshes production. Studies have shown that alkali-resistant glass fibres, carbon and aramid fibres meet the necessary requirements. In the paper [13], physical-mechanical and deformation characteristics of individual fibres have been presented.

The use of alkali-resistant glass in civil engineering began in the 1970s [3]. Depending on the fineness of the fibres, the strengths are up to 1400 N/mm², the linear elastic elongation is up to 2%, and the modulus of elasticity ranges from 70 to 80 kN/mm². In the experimental program presented in the paper textile meshes with alkali-resistant glass fibres were used. A production of textile meshes has begun for the purpose of achieving a stable form of reinforced concrete with textile. In the paper [3] has been described an idea of reinforcing textile meshes during production, and achieving stability of textile mesh through impregnation and adding additional support and elements for stiffening. In papers [3], [7] and [12], have been presented recommendations for concrete recipes in order to ensure the adhesion of textile mesh and concrete, as well as to embed ability of concrete through textile texture. Research demonstrated that fine-grained concrete of liquid consistency is suitable but it is necessary to add plastizers. In papers [15] and [16] have been presented physical-mechanical and deformation properties of textile meshes, as well as previous experiences of application in construction.

Textile meshes are generally used for external reinforcements of reinforced concrete structures. The effects of reinforcement were presented in papers [1], [2], [4], [5], [7], [9], [10], [12] and [13]. Research have shown that the reinforcement effects of using textile meshes depends on the main fibre orientation of the textile meshes, the number of textile layers of the meshes, the installation process when it comes to achieving adhesion textile mesh or basis and an adequate shrinkage of the textile mesh girder. Increases have been obtained when it comes to the bearing capacity of reinforced concrete beams for shearing and bending, bearing in mind that the percentage of increase depends on the previously mentioned effects. In the papers [6], [8], [10], [11] and [14] have been presented numerical models for the calculation of reinforced concrete elements reinforced with textile mesh.

This paper presents a research program with the aim of determining possible applications of textile mesh reinforcement within the cross section, which would allow the development of semi-prefabricated reinforced concrete beams with a composite cross-section. Research with a similar idea has been presented in the paper [9].

2 EXPERIMENTAL PROGRAM

In order to determine the load-bearing mechanism of reinforced beams using reinforced bars and textiles, the

talnim programom predviđeno je uporedno ispitivanje tri tipa modela:

- model grede armirane armaturnim šipkama (RC – Reinforced Concrete);
- model grede armirane armaturnim šipkama i tekstilom (CRC – Combined Reinforced Concrete);
- model grede armiran tekstilom (TRC – Textile Reinforced Concrete).

Urađeno je devet modela (3 RC + 3 CRC + 3 TRC) (slika 1).

experimental program provides comparative research of three types of models:

- model of reinforced beams using reinforced bars (RC - Reinforced Concrete),
- model of reinforced beams using reinforced bars and textiles (CRC - Combined Reinforced Concrete),
- textile-reinforced beam model (TRC - Textile Reinforced Concrete).

In the research participated nine (9) models (3 RC + 3 CRC + 3 TRC) (Figure 1).

Slika 1. Izrada modela
Figure 1. Model setup

Modeli greda su dimenzija 15/15/180 cm. Svi modeli urađeni su od betona iste recepture klase čvrstoće C 25/30, armirani armaturnim šipkama S500N. Na slici 2 prikazan je način armiranja RC modela.

Dimensions of model beams are 15/15/180 cm. All models are made of concrete with the same recipe of strength class C25/30. All models are reinforced with S500N reinforcing bars. Figure 2 shows the method of reinforcing the RC model.

Slika 2. Način armiranja RC modela
Figure 2. The method of reinforcing the RC model

Podužna armatura jeste 4Ø12, a poprečna - RØ8/17,5 cm. Za CRC modele korištena je tekstilna mreža od alkalno-otpornih staklenih vlakana proizvođača SIKA AG, komercijalnog naziva SikaWrap – 350 G Grid.

Čvrstoća na zatezanje vlakana je $f_{yt} = 2600\text{MPa}$, a modul elastičnosti $E = 80000\text{MPa}$. Kako su ispitivanja prezentovana u radovima [1], [6], [8] i [9] pokazala da je

The longitudinal reinforcement is 4Ø12, while the transverse reinforcement is RØ8 / 17.5 cm. A textile mesh used for CRC models is made of alkali-resistant glass fibres manufactured by SIKA AG, commercial name is SikaWrap - 350 G Grid. The tensile strength of the fibres is $f_{yt} = 2600\text{MPa}$, and the modulus of elasticity $E = 80000\text{MPa}$.

orijentacija tekstila značajna za konačne rezultate u pogledu nosivosti i mehanizma otvaranja pukotina, tekstilne mreže ugrađene su tako da su glavne nosive trake mreže u pravcu podužne ose modela grede, što je povoljna orijentacija iz aspekta nosivosti na savijanje. Kako bi se ostvarila što bolja prionljivost betona i tekstilne mreže, prilikom ugradnje betona, mreže su ostavljene otvorene s gornje strane. Konačan izgled armature CRC modela prikazan je na slici 1. Način armiranja CRC modela predstavljen je na slici 3. Prilikom izrade TRC modela, tekstilna mreža ojačana je uzengijama od žice prečnika 3 mm, kako bi se osigurala stabilnost tekstilne mreže tokom ugradnje betona.

Testing presented in [1], [6], [8] and [9] showed that the orientation of textiles is important for the final results in terms of load-bearing capacity and crack opening mechanism. Therefore, textile meshes were installed in such way that the main load-bearing fibres in the mesh are placed in the direction of the longitudinal axis of the beam model, which is a favourable orientation from the aspect of bearing capacity to bending. In order to achieve the best possible adhesion of concrete and textile mesh, during the installation of concrete meshes were left open from the top. The final arrangement of CRC model reinforcement is shown in Figure 1. The method of reinforcing the CRC model is presented in Figure 3. During the creation of the TRC model, textile mesh is reinforced with stirrup made out of wire diameter of 3 mm for the purpose of ensuring the stability of the textile mesh during installation of concrete.

Slika 3. Model CRC
Figure 3. The method of reinforcing the CRC model

Tokom ispitivanja, mjereni su ugibi, dilatacije (izduženja i skraćivanja) gornjeg i donjeg površinskog sloja grede i širine pukotina. Raspored mjernih mjesta prikazan je na slikama 4 i 5.

Mjerenje ugiba rađeno je sa ugibomjerima tačnosti mjerenja 0,01 mm, a dilatacije deformaterima s tačnošću mjerenja 0,01 mm i mjernim bazama 100 i 300 mm.

Intenziteti opterećenja usvojeni su na osnovu proračuna proste armiranobetonske grede datih geometrijskih karakteristika i raspona (prezentovanih na slikama 2 i 3). Puno opterećenje grede, pri kojem se dostiže kapacitet nosivosti s faktorom sigurnosti 1.0, jeste $F = 27\text{kN}$. Modeli su opterećeni u 12 faza, sa opterećenjima intenziteta $F = 2, 4, 6, 8, 14, 21, 27, 36, 45, 51, 54\text{ kN}$. Nakon dostizanja opterećenja $F = 8\text{ kN}$, rađeno je rasterećenje modela nakon svake faze opterećenja kako bi se pratilo područje razvijanja plastičnih deformacija. Opterećenje modela vršeno je hidrauličkom presom. Postavka ispitivanja modela prikazana je na slici 6.

During the testing, deflections, dilatations (elongation and shortening) of the upper and lower surface layer of the beam and the width of cracks were measured. The layout of the measuring points is shown in Figures 4 and 5. Measurement of deflection is done with the measurement accuracy of 0.01 mm, with a dilatation of deformation of 0.01 mm measuring accuracy and measuring bases 100 and 300 mm.

The load intensities of the beams were adopted on the basis of the calculation of a simple reinforced concrete beam of geometrical characteristics and spans presented in Figures 2 and 3. The full load of the beam, at which the bearing capacity is reached with a safety factor of 1.0, is $F = 27\text{kN}$. The models were loaded in 12 phases with load intensities of $F = 2, 4, 6, 8, 14, 21, 27, 36, 45, 51, 54\text{ kN}$. After reaching the load of $F = 8\text{ kN}$, the model was unloaded after each phase of the load in order to monitor the area of development of plastic deformations. The model was loaded with a hydraulic press. The model test setup is presented in Figure 6.

Slika 4. Raspored mjernih mjesta za mjerenje ugiba
Figure 4. Disposition of deflection measurement points

Slika 5. Raspored mjernih mjesta za mjerenje dilatacija
Figure 5. Disposition of dilatation measurement points

Slika 6. Postavka ispitivanja
Figure 6. Test setup

3 REZULTATI ISPITIVANJA

U radu se predstavljaju rezultati mjerenja ugiba i praćenja mehanizma otvaranja pukotina. Na osnovu tih rezultata, moguće je donijeti zaključak o ponašanju betonskih greda armiranih armaturnim šipkama i tekstilnim mrežama.

Na slikama 7 i 8 prikazani su radni dijagrami sila–progib ispitanih RC modela za mjerna mjesta U2 i U4

3 TEST RESULTS

The paper presents the results of measuring deflection and monitors the crack opening mechanism. Based on these results, it is possible to draw a conclusion about the behaviour of reinforced concrete beams using reinforced bars and textile meshes.

In figures 7 and 8 are presented the force-displacement diagrams of the tested RC models for measuring points U2 and U4.

Slika 7. RC modeli, mjerno mjesto U2
 Figure 7. RC models, measurement point U2

Slika 8. RC modeli, mjerno mjesto U4
 Figure 8. RC models, measurement point U4

Efikasnost provlačenja (fitovanja) radnih dijagrama određena je koeficijentom determinacije R^2 . Koeficijenti determinacije imaju zadovoljavajuće vrijednosti. Iz priloženih radnih dijagrama vidljivo je da je nešto veće rasipanje rezultata pri mjerenju ugiba na mjernim mjestima koja su u trećini raspona (mjerno mjesto U4), odnosno mjernim mjestima udaljenim od mjesta nanošenja opterećenja, u odnosu na mjerna mjesta u blizini nanošenja sile na polovini raspona (mjerno mjesto U2). Ovdje je vidljiv efekat heterogenosti strukture betona, odnosno stohastički promjenljivog odnosa zapremine zrna i zapremine cementnog kamena duž grede. Ujednačenost ponašanja RC modela vidljiva na slici 7. Na slikama 9 i 10 prikazani su radni dijagrami sila–progib ispitanih CRC modela za ista mjerna mjesta U2 i U4.

The fitting efficiency of the working diagrams is determined by the coefficient of determination R^2 . The coefficients of determination have satisfactory values. It is evident, as shown in diagrams, that there is a slightly higher scattering of the results during measuring the deflection at the measuring points which are in one third of the span (measuring point U4), measuring points far from the place of application of the load, compared to the measuring points near the application of force at half the span (measuring point U2). Here, the effect of heterogeneity of concrete structure, i.e. stochastically variable ratio of aggregate volume and cement stone volume along the beam is visible. The uniformity of the RC model behaviour can be seen in Figure 7. Figures 9 and 10 show the working force-displacement diagrams of the tested CRC models for the same measuring points U2 and U4.

Slika 9. CRC modeli, mjerno mjesto U2
 Figure 9. CRC models, measurement point U2

Slika 10. CRC modeli, mjerno mjesto U4
 Figure 10. CRC models, measurement point U4

Iz radnih dijagrama na slikama 9 i 10 vidljivo je da je kod CRC modela veće rasipanje rezultata, što je posljedica kompozitnosti presjeka, otežanih uslova ugradnje betona i stepena prionljivosti tekstila i betona duž grede.

Ispitivanjem TRC modela dobila se nosivost grede na savijanje približno 50% veća u odnosu na nearmiranu betonsku gredu. Na slici 11 predstavljeni su radni dijagrami TRC modela.

The working diagrams in Figures 9 and 10 show that the CRC model has a higher scattering of results, which is the consequence of the cross-sectional composition, difficult conditions for concrete installation and the degree of adhesion of textiles and concrete along the beam.

By testing the TRC model, the load-bearing capacity of the beam was approximately 50% higher compared to the non-reinforced concrete beam. Figure 11 presents the working diagrams of the TRC model.

Slika 11. Dijagrami sila–progib RC i CRC modela, mjesto mjerenja U2
Figure 11. TRC models, measurement point U2

Poređenje radnih dijagrama sila–progib RC, CRC i TRC modela prikazano je na slici 12. Iz prezentovanih radnih dijagrama RC i CRC modela vidljivo je slično ponašanje klasično armiranih greda (RC) i greda armiranih armaturnim šipkama i tekstilom (CRC). Utvrđeni prosječni intenzitet sile loma isti je kod CRC modela i RC modela.

Pored mjerenja ugiba i dilatacija, praćen je mehanizam otvaranja pukotina i način otkaza ispitanih modela. Kod RC i CRC modela, prve pukotine otvorile su se pri istom intenzitetu sile ($F=21\text{kN}$). Međutim, kod RC modela i CRC modela, registrovani su različiti mehanizmi loma (otkaza). Kod RC modela lom se desio otvaranjem dominantne vertikalne pukotine u sredini raspona, odnosno otkazom na savijanje (sl. 13), dok se kod CRC modela lom desio otvaranjem dominantne kose pukotine (sl.14).

The comparison of the force-displacement diagrams of the RC, CRC and TRC models is shown in Figure 12. The presented working diagrams of the RC and CRC models show similar behaviour of conventionally reinforced beams (RC) and beams reinforced with reinforcing bars and textiles (CRC). The determined average fracture force intensity is the same for CRC models and RC models.

Besides measuring deflection and dilatation, it has been monitored the mechanism of crack opening and the failure mode of the tested models. In the RC and CRC models, the first cracks opened at the same force intensity ($F = 21\text{kN}$). However, different fracture (failure) mechanisms have been registered in the RC model and the CRC model. In the RC model, the fracture occurred through the opening of a dominant vertical crack in the middle of the span, or by failure at the bending (Fig. 13), while in the CRC model the fracture occurred through the opening of the dominant oblique crack (Fig. 14).

Slika 12. Dijagrami sila–progib RC i CRC modela, mjerno mjesto U4
Figure 12. Force-displacement diagrams of the RC, CRC and TRC models, measurement point U2

Slika 13. Mehanizam otkaza RC modela
Figure 13. Mechanism of RC model failure

Slika 14. Mehanizam otkaza CRC modela
Figure 14. Mechanism of CRC model failure

Do intenziteta sile $F = 40\text{kN}$ registrovane su jednake širine vertikalnih pukotina u sredini raspona na RC i CRC modelu (širina 0,3 mm). S povećanjem intenziteta sile, povećavale su se širine vertikalnih pukotina na RC modelu do registrovane širine 1 mm neposredno prije loma. Na CRC modelima, s povećanjem intenziteta sile nije došlo do povećanja širine pukotine. Dakle, kod CRC modela lom se desio otkazom na smicanje. Tekstilna mreža povećala je nosivost na savijanje grede, ali orijentacija glavnih vlakana mreže u smjeru podužne osi nosača nije dala doprinos nosivosti na smicanje, što je zaključak istraživanja u radu [1], gdje se navodi da je iz aspekta nosivosti na smicanje povoljna orijentacija glavnih vlakana mreže uspravno na podužnu os.

4 ZAKLJUČAK

Ispitivanjem RC modela i CRC modela dobijena je sila loma jednakog intenziteta. Međutim, razlika u mehanizmu otkaza RC modela i CRC modela ukazuje na to da je upotrebom tekstila došlo do povećanja nosivosti na savijanje grede u odnosu na klasično armirane betonske grede. Ovo povećanje nije kvantifikovano zbog obima eksperimentalnog programa, koji je bio ograničen na određeni broj modela za inicijalna ispitivanja. Naime, nije rađena kombinacija tekstilnih mreža s različitim pravcima glavnih tekstilnih vlakana i različitim procentima armiranja poprečnom armaturom s ciljem povećanja nosivosti na smicanje. Međutim, jasna je mogućnost primjene tekstilnih mreža za istovremeno povećanje trajnosti i nosivosti.

Za intenzivniju primjenu tekstilnih mreža za armiranje unutar poprečnog presjeka betonske grede, iskustva istraživača u ovoj oblasti eksperimenta pokazuju da je potrebno riješiti tri ključna problema:

- tehnologiju ugradnje betona unutar tekstilne mreže;
- stabilnost tekstilne matrice (tekstilne mreže) tokom opterećenja;
- prionljivost betona i tekstilne mreže.

Jedan od pristupa za ostvarenje adekvatnog mehanizma nosivosti betonskih greda armiranih armaturnim šipkama i tekstilnim mrežama, promovisan i u radu [9], jeste izvođenje poluprefabrikovanih betonskih greda s prefabrikovanim obložnim dijelom grede

Equal widths of vertical cracks in the middle of the range were registered on the RC and CRC model (width 0.3 mm) by the intensity of force $F = 40\text{kN}$. As intensity of the forces increased, at the same time increased the width of the vertical cracks on RC model up to registered width of 1 mm before the fracture. On CRC models with increasing force intensity, there was no increase in crack width. Thus, in the CRC model, the fracture occurred by shear failure. Textile mesh increased the bending load of the beam, but the orientation of the main fibres of the mesh in the direction of the longitudinal axis of the girder did not contribute to shear load, which is the conclusion of the research in [1], where it is stated that the mesh is perpendicular to the longitudinal axis.

4 CONCLUSION

By testing the RC model and the CRC model, a fracture force of equal intensity was obtained. However, the difference in the failure mechanism of the RC model and the CRC model indicates that the use of textiles has increased the load-bearing capacity of the beam compared to classically reinforced concrete beams. This increase was not quantified due to the scope of the experimental program, which was limited to a number of models for initial testing. Namely, no combination of textile nets with different directions of the main textile fibres and different percentages of reinforcement with transverse reinforcement was made in order to increase the shear capacity. However, the possibility of applying textile nets to simultaneously increase durability and load-bearing capacity is clear.

For more intensive application of textile reinforcement nets within the cross section of the concrete beam, the experience of researchers in this field shows that it is necessary to solve three key problems,

- concrete placing technology within the textile mesh,
- stability of the textile matrix (textile mesh) during loading and
- adhesion of concrete and textile mesh.

One of the approaches for achieving an adequate load-bearing mechanism of reinforced concrete beams using reinforced bars and textile meshes is presented in the paper [9], and that is the construction of semi-

armiranim tekstilnom mrežom, ojačanom mrežom od čelične žice i unutrašnjim dijelom grede koji se izvodi na licu mjesta. Prijedlog poprečnog presjeka poluprefabrike betonske grede prikazan je na slici 15.

prefabricated concrete beams with prefabricated beam cladding reinforced with textile mesh, reinforced steel wire mesh and inner part on the site. The cross-sectional proposal of the semi-prefabricated concrete beam is shown in Figure 15.

Slika 15. Prijedlog poluprefabrike betonske grede armirane armaturnim šipkama i tekstilom
Figure 15. Proposal of semi-prefabricated reinforced concrete beams using reinforced bars and textiles

U nastavku istraživanja uradiće se eksperimentalni program za razvoj tehnologije izvođenja i adekvatnog sprezanja prefabrikovanog i monolitnog dijela betonske grede, te verifikovanje fizičko-mehaničkih i deformacionih karakteristika grede poprečnog presjeka na slici 15.

U savremenom građevinarstvu, tekstilne mreže primjenjuju se za povećanje trajnosti obložnog dijela armiranobetonskih greda i naknadno ojačanje greda spoljnom primjenom, oblaganjem (umotavanjem) greda. Iskustva predstavljena u radovima, pobrojanim u referencama i prezentovana ispitivanja u ovom radu pokazala su da je, uz razvoj tehnologije ugradnje, moguća primjena tekstilnih mreža unutar poprečnog presjeka.

The following studies will be carried out for the purpose of developing an experimental program, and technology of adequate coupling of the prefabricated and monolithic part of the concrete beam and the verification of the physical and mechanical characteristics and deformation parts of the beam cross-section in Figure 15.

In modern civil engineering, textile meshes are used to increase the durability of the cladding part of reinforced concrete beams and subsequent reinforcement of beams through external application, coating (wrapping) of beams. Experiences presented in the papers are listed in the references. In addition, the tests presented in this paper have shown that it is possible to use textile meshes within the cross section with the development of installation technology.

5 LITERATURA REFERENCES

- [1] Akhil A., Prabhakaran P., EXPERIMENTAL STUDY ON SHEAR STRENGTHENING OF RC BEAMS USING NYLON TEXTILE-REINFORCED MORTAR; International Journal of Innovative Research in Science, Engineering and Technology, Vol.5, Issue 8, August 2016;
- [2] Giorgia Colombo I., Colombo M., DiPrisco M., BENDING BEHAVIOUR OF TEXTILE REINFORCED CONCRETE SANDWICH BEAMS; Politecnico di Milano, Department of Civil and Environmental Engineering, Piazza Leonardo da Vinci 32, 20133;
- [3] Gries T., Roye A., Offermann P., T Engler., Peled A., TEXTILE REINFORCED CONCRETE, State-of-the-Art Report of RILEM Technical Committee 201-TRC, Report 36, RILEM Publications S.A.R.L. 2006,
- [4] Hashemi S., INVESTIGATION OF FLEXURAL PERFORMANCE OF RC BEAMS STRENGTHENED WITH CFRP TEXTILE AND CEMENT BASED ADHESIVES; Hokkaido University Japan; APFIS 2012.;
- [5] Hegger J., Zell M. & Horstmann M., TEXTILE REINFORCED CONCRETE – REALIZATION IN APPLICATIONS, Taylor & Francis Group, London, ISBN 978-0-415-47535-8, 2008,

- [6] Hegger J., Zell M., Voss S., DIMENSIONING OF TRC STRUCTURES, Institute of Structural Concrete, RWTH Aachen University, Germany,
- [7] Kok M., MASTER'S THESIS - TEXTILE REINFORCED DOUBLE CURVED CONCRETE ELEMENTS, TU Delft, Faculty of Civil Engineering and Geosciences, Department of Structural and Building Engineering, July 2013;
- [8] Mobasher B., DEVELOPMENT OF DESIGN PROCEDURES FOR FLEXURAL APPLICATIONS OF TEXTILE COMPOSITE SYSTEMS BASED ON TENSION STIFFENING MODELS, 6th Colloquium on Textile Reinforced Structures (CTRS6),
- [9] Papantoniou I.C., Papanicolaou C.G., TEXTILE REINFORCED CONCRETE (TRC) FOR PRECAST STAY-IN-PLACE FORMWORK ELEMENTS; Tailor Made Concrete Structures – Walraven&Stoelhorst (eds), 2008 Taylor & Francis Group, London, ISBN 978-0-415-47535-8;
- [10] Schladitz F., Curbach M., INCREASE IN THE TORSIONAL RESISTANCE OF REINFORCED CONCRETE MEMBERS USING TEXTILE REINFORCED CONCRETE (TRC); Concrete Repair, Rehabilitation and Retrofitting II – Alexander et al (eds), 2009 Taylor & Francis Group, London;
- [11] Voss S., Hegger J.; DIMENSIONING OF TEXTILE REINFORCED CONCRETE STRUCTURES; 1st International Conference Textile Reinforced Concrete (ICTRC);
- [12] Williams Portal N., NyholmThrane L., Lundgren K., FLEXURAL BEHAVIOUR OF TEXTILE REINFORCED CONCRETE COMPOSITES: EXPERIMENTAL AND NUMERICAL EVALUATION; Department of Civil and Environmental Engineering, Division of Structural Engineering Concrete Structures, CHALMERS UNIVERSITY OF TECHNOLOGY, Gothenburg, Sweden;
- [13] Williams Portal N., SUSTAINABILITY AND FLEXURAL BEHAVIOUR OF TEXTILE REINFORCED CONCRETE; Department of Civil and Environmental Engineering, Division of Structural Engineering Concrete Structures, CHALMERS UNIVERSITY OF TECHNOLOGY, Gothenburg, Sweden 2013;
- [14] Worner J.-D., Deußner S., OBERFLÄCHENNAHE TEXTILBEWEHRUNG IM STAHLBETONBAU, Bauen mit Textilien Heft, Masivbau 1998;
- [15] Zenunović D., Folić R.: Tekstilom armirani beton – materijali, ponašanje i osnove projektovanja, 13. DGKS Kongres, Zbornik radova, septembar 2010., str. 243-252.
- [16] Zenunović D., Folić R.: Tekstilom armirani beton – primjeri primjene u konstrukcijama, 13. DGKS Kongres, Zbornik radova, septembar 2010., str. 253-262.

REZIME

UPOREDNA ANALIZA PONAŠANJA BETONSKIH GREDA ARMIRANIH ŠIPKAMA I TEKSTILOM – EKSPERIMENTALNO ISTRAŽIVANJE

Damir ZENUNOVIĆ
Danijel RUŽIĆ

U ovom radu prezentovan je eksperimentalni program inicijalnih ispitivanja betonskih greda armiranih šipkama i tekstilom, koji je sproveden s ciljem uporedne analize ponašanja betonskih greda armiranih tekstilom u odnosu na klasično armirane grede. Za potrebe eksperimenta, korišćene su tekstilne mreže od alkalno-otpornih staklenih vlakana. Opisana je postavka eksperimenta. Predstavljani su dobijeni rezultati ispitivanja. Na kraju rada, data je analiza dobijenih rezultata, sa zaključcima. Sprovedeni eksperimentalni program pokazao je da dodatak tekstilnih mreža, pored poboljšanja trajnosti zaštitnog sloja betona, može poboljšati nosivost i duktilnost armiranobetonskih greda. Ostaje otvoreno pitanje ugradljivosti betona u tekstilom armirane grede i ostvarenja potpune prionljivosti tekstilne mreže i betona. Na kraju rada, dat je prijedlog poluprefabrikovane betonske grede armirane armaturnim šipkama i tekstilom.

Ključne reči: armiranobetonska greda, tekstilne mreže, ugradljivost, nosivost, duktilnost, mehanizam loma

ABSTRACT

INTRODUCING EUROCODES AND THE CALCULATION OF SEISMIC RESISTANCE OF THE MASONRY CONSTRUCTIONS

Damir ZENUNOVIC
Danijel RUZIC

This paper presents an experimental program of initial testing of reinforced concrete beams using bars and textiles carried out with an aim of comparative analysis of the behaviour of reinforced concrete beams using textiles in relation to conventional reinforced beams. Alkaline-resistant glass fibre textile meshes were used for the purposes of the experiment. An experiment setting is described and obtained test results are presented in this paper. An analysis of the obtained results is presented at the end of the paper. The experimental program demonstrated that adding textile mesh, besides improvement of the durability of the protective layer of concrete, can improve the load-bearing capacity and ductility of reinforced concrete beams. There is still an issue related to workability of concrete in textile reinforced beams and achievement of full adhesion between textile mesh and concrete. At the end of the paper, a suggestion was given about semi-prefabricated reinforced concrete beams using reinforced bars and textiles.

Key Words: reinforced concrete beam, textile mesh, workability, bearing capacity, ductility, fracture mechanism