

# OBEZBEDENJE LOKALNE DUKTILNOSTI ARMIRANOBETONSKIH ELEMENATA PREMA EVROKODU 8 – KOEFICIJENT UTEZANJA

## THE DESIGN OF LOCAL DUCTILITY FOR REINFORCED CONCRETE ELEMENTS BY EUROCODE 8 - CONFINEMENT EFFECTIVENESS FACTOR

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### 1 UVOD

Nivo seizmičkog opterećenja, pri elastičnom odgovoru konstrukcije, može biti izuzetno visok i zato ga je veoma teško konstrukcijski prihvatiti. Jedan od načina smanjenja intenziteta seizmičkog opterećenja jeste dopuštanje kontrolisanih neelastičnih deformacija (oštećenja) elemenata konstrukcije, uz zadržavanje integriteta cele konstrukcije, kao i njenih delova. Ovaj tradicionalni koncept prihvatanja seizmičkog opterećenja podrazumeva obezbeđivanje duktilnog ponašanja konstrukcije – globalne duktilnosti, kako bi osnovni zahtev, koji podrazumeva da konstrukcija mora da izdrži pomeranja pri dejstvu zemljotresa, bio ispunjen. Za procenu nelinearnog ponašanja i kapaciteta pomeranja novih i postojećih konstrukcija usled dejstva zemljotresa, moguće je primeniti čitav niz metoda u okvirima linearne i nelinearne analize konstrukcija [1]. Nivo složenosti svake metode zavisi od nivoa aproksimacije uticaja ključnih faktora na ponašanje armiranobetonskih konstrukcija pri dejstvu zemljotresa, što se odnosi, pre svega, na modeliranje opterećenja od zemljotresa, interakcije konstrukcije i tla, nelinearnog ponašanja materijala i prigušenja. Međutim, imajući u vidu jednostavnost i robusnost koje podrazumeva, u praksi se najčešće koristi linearno-elastična analiza, prema kojoj se proračun konstrukcije vrši „prema silama” (*force-based seismic design*).

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### 1 INTRODUCTION

The level of the seismic load, at an elastic response of the structure, can be extremely high and as such, it can be very difficult for a structure to sustain it. One option for reducing seismic loads on structure is to allow controlled inelastic deformations (damages) to structural elements while maintaining the integrity of both the entire structure and all of its parts. This concept of sustaining seismic loads presumes that the ductile behaviour of the structure i.e. global ductility is provided in order to fulfil the basic requirement in seismic design – the structure must withstand displacements at seismic ground motions. To evaluate the non-linear behaviour and displacement capacity of new and existing structures due to seismic effects, a variety of methods can be applied using linear or non-linear structural analysis [1]. The level of complexity of each method depends on the approximation level of the influence of key factors on the behaviour of reinforced concrete structures during the earthquake. It relates to the modelling of seismic loads, soil-structure interaction, non-linear material behaviour and damping. However, given the simplicity and robustness it entails, linear elastic analysis is most commonly used in practice, with design of structure based on seismic forces (so-called *force-based seismic design*).

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Koncept projektovanja novih konstrukcija primenom linearne analize zasniva se na dimenzionisanju elemenata prema proračunskoj (redukovanoj) seizmičkoj sili  $F_y$ . Pretpostavlja se linearno ponašanje konstrukcije sve do dostizanja pomeranja na granici tečenja  $d_y$ , dok se povećanje pomeranja do pomeranja usled projektnog seizmičkog dejstva  $d_m$  realizuje nelinearnim ponašanjem konstruktivnih elemenata – pojavom plastičnih zglobova u elementima, uz nepromenjeni nivo proračunskog seizmičkog opterećenja. Potrebna ili ciljana globalna duktilnost definisana je faktorom duktilnosti pomeranja  $\mu\delta = d_m/d_y$ .

Dokaz postignute globalne duktilnosti prema Evrokodu 8 sprovodi se na lokalnom nivou, obezbeđivanjem zahtevanog faktora duktilnosti krivine poprečnih preseka primarnih seizmičkih elemenata [2] i zasnovan je na neelastičnom spektru odgovora sistema s jednim stepenom slobode – predložili su Vidic i ostali [9]. Iz izraza koji su predloženi u [9], očigledno je da globalna duktilnost direktno zavisi od faktora ponašanja. Faktor ponašanja jeste koeficijent kojim se elastičan spektar odgovora deli i koji zavisi od klase duktilnosti konstrukcije (DCL – niska, DCM – srednja, DCH – visoka), tipa konstrukcijskog sistema za prihvatanje seizmičkih uticaja i regularnosti sistema po visini. Klasa duktilnosti, iako se odnosi na globalnu duktilnost, zapravo dominantno zavisi od obezbeđene lokalne duktilnosti, kao i od načina oblikovanja detalja armiranja zona elemenata u kojima se ostvaruju plastične deformacije – plastični zglobovi. Dakle, prema proceduri proračuna saglasno Evrokodu 8, veza između globalne i lokalne duktilnosti ostvaruje se putem koeficijenta  $q$  i niza zahteva za armiranje plastičnih zglobova u kojima on figuriše. Plastični zglobovi projektuju se na krajevima horizontalnih elemenata konstrukcije – gredama, kao i u uklještenju vertikalnih elemenata – stubovima i zidovima. Poželjni, pouzdani plastični mehanizam, prema proceduri programiranog ponašanja, obezbeđuje se pojavom plastičnih zglobova u gredama pre pojave plastičnih zglobova u stubovima i zidovima.

Nekoliko primera armiranja i oblikovanja detalja greda, stubova i zidova za njihovu lokalnu duktilnost prema Evrokodu 8 prikazao je Milev [5]. Milićević i Ignjatović [6] ukazali su na razlike u armiranju AB stubova i greda u slučajevima njihove klasifikacije kao primarnih odnosno sekundarnih seizmičkih elemenata prema Evrokodu 8, sa akcentom na potrebnu količinu poprečne armature za obezbeđivanje duktilnog ponašanja konstrukcije pri dejstvu zemljotresa.

U radu je analiziran koncept obezbeđivanja lokalne duktilnosti vertikalnih armiranobetonskih elemenata prema Evrokodu 8 [2], iz aspekta ostvarivanja zahtevanog faktora duktilnosti krivine poprečnog preseka. Posebna pažnja posvećena je mehanizmu utezanja AB stubova odnosno faktoru efikasnosti utezanja preseka u kritičnim oblastima poprečnom armaturom – uzengijama i poprečnim vezama. Objasnjeno je praktično značenje faktora efikasnosti utezanja i analizirane su različite varijante armiranja iz prakse.

The concept of designing new structures using linear analysis is based on the dimensioning of the elements according to the design (reduced) seismic force  $F_y$ . The linear behaviour of the structure is assumed until reaching the displacement at yielding  $d_y$ , while the increase of displacement to displacement due to design seismic action  $d_m$  is achieved by the non-linear behaviour of structural elements - the appearance of plastic hinges in the elements, with the unchanged level of design seismic load. The required or targeted global ductility is defined by the displacement ductility factor  $\mu\delta = d_m/d_y$ .

The proof of achieved global ductility according to Eurocode 8 is conducted locally, by providing the required curvature ductility factor of the cross-sections of primary seismic elements [2] and it is based on the inelastic response spectrum of a single degree of freedom system (SDOF), proposed by Vidic et al. [9]. From the equations proposed in [9] it is obvious that global ductility depends directly on the behaviour factor. The behaviour factor is the coefficient by which the elastic response spectrum is divided and depends on the ductility class of the structure (DCL - low, DCM - medium, DCH - high), the type of structural system for accepting seismic impacts and the regularity of the system in height. The ductility class, although related to global ductility, is in fact predominantly dependent on the provided local ductility, as well as the reinforcement detailing of the zones of elements in which plastic deformations occur - plastic hinges. Thus, according to the calculation procedure in Eurocode 8, the connection between global and local ductility is realized through the coefficient  $q$  and a series of requirements for reinforcing the plastic hinges in which it appears. Plastic hinges are designed at the ends of horizontal structural elements - beams, as well as in the base of vertical elements - columns and walls. A desirable, reliable plastic mechanism, according to the principle of capacity design, is provided by the appearance of plastic hinges in beams before the appearance in columns and walls.

Several examples of reinforcement detailing of beams, columns and walls for their local ductility according to Eurocode 8 were presented by Milev [5]. Milicević and Ignjatović [6] pointed out differences in reinforcement of RC columns and beams in cases of their classification as primary or secondary seismic elements according to Eurocode 8, with emphasis on the required amount of transverse reinforcement to ensure ductile structural behaviour under seismic loads.

This paper analyzes the concept of providing local ductility of vertical reinforced concrete elements according to Eurocode 8 [2], from the aspect of achieving the required curvature ductility factor of the cross-section. Special attention was paid to the mechanism of confinement of RC columns, i.e. the confinement effectiveness factor of cross-section in critical areas with transverse reinforcement - stirrups and cross-links. The practical significance of the confinement effectiveness factor was explained and various reinforcement details common in practice were analyzed.

## 2 LOKALNA DUKTILNOST AB STUBOVA

Da bi se osiguralo duktilno ponašanje u lokalizovanim zonama konstrukcije (plastičnim zglobovima), materijali moraju da budu u stanju da postignu odgovarajuće deformacije. Lokalna duktilnost armiranobetonskih elemenata, na nivou poprečnog preseka, postiže se povećanim izduženjima čelika ( $\epsilon_s$ ), kao i skraćenjima pritisnutog betona ( $\epsilon_c$ ), odnosno odgovarajućom duktilnošću krivine preseka. Faktor duktilnosti krivine definisan je kao odnos granične krivine i krivine pri tečenju  $\mu_\varphi = \varphi_u / \varphi_y$ , gde je  $\varphi_y$  krivina AB preseka pri tečenju (armature), a  $\varphi_u$  granična krivina AB preseka.

Prema [3], krivina preseka pri tečenju AB stubova opterećenih aksijalnom silom pritiska definiše se za sledeća dva moguća slučaja:

a) krivina pri dilataciji na granici razvlačenja zategnute armature ( $\epsilon_s = \epsilon_{yd}$ );

b) krivina pri velikim dilatacijama pritiska na gornjoj (pritisnutoj) ivici betonskog preseka.

Prema Panagiotakosu i Fardisu [3], usled velike normalne sile, može doći do nelinearnog ponašanja pritisnute zone betonskog preseka, pre pojave tečenja zategnute armature. Autori su za proračun krivine pri pojavi tečenja, u slučajevima visokog nivoa normalne sile u stubovima, predložili gornju granicu dilatacije na pritisnutoj ivici betonskog preseka jednaku  $1,8 \cdot f_c / E_c$ , gde je  $f_c$  čvrstoća betona pri pritisku, a  $E_c$  – modul elastičnosti betona.

Granična krivina AB preseka  $\varphi_u$  definisana je odnosom granične dilatacije pritiska uteguto betona i odgovarajuće visine neutralne ose. Određivanje krivine preseka pri lomu zavisi od nivoa opterećenja, količine armature, kao i toga da li je dostignuta granica loma betona ili armature, i tako dalje. U zavisnosti od vrednosti pomenutih parametara, pri određivanju krivine preseka razmatra se ukupni poprečni presek betonskog elementa ili samo utegnuti presek (ukupni presek umanjen za neutegnuti zaštitni sloj betona).

Raznim eksperimentima je ustanovljeno da duktilnost betona znatno raste kada se dovede u stanje triaksijalne kompresije [7]. Ovakvo stanje može se postići utezanjem elementa poprečnom armaturom u vidu zatvorenih uzengija ili spiralne armature. Na taj način, sprečava se bočno širenje elementa usled aksijalne sile. Posledice toga su povećanje čvrstoće betonskog elementa i razvijanje većih graničnih dilatacija  $\epsilon_{cu,c}$ , znatno većih od 3,5%, čime se ostvaruje veća granična krivina preseka  $\varphi_u$ . Parametri koji utiču na stepen utezanja jesu: količina poprečne armature ( $\rho_w$ ), čvrstoća čelika (oblik dijagrama napon–dilatacija), čvrstoća betona na pritisak (oblik dijagrama napon–dilatacija), razmak, oblik i broj uzengija, kao i podužne (vertikalne) armature.

Bočne sile, koje se javljaju kao posledica sprečenog širenja betonskog elementa, deluju u nivou uzengija. Prema Fardisu [3], smatra se da efekti utezanja dolaze do izražaja pri dostizanju aksijalnog napona pritiska približno jednakom čvrstoći betona pri pritisku, kao i da ne dolazi do ojačanja armature za utezanje nakon dostizanja granice tečenja, već se za graničnu vrednost usvaja napon pri tečenju. Najveći bočni pritisak može se razviti samo na onom delu betonskog elementa gde se nalazi armatura za utezanje. Zbog ovakvog delovanja bočnog pritiska maksimalna vrednost mora biti korigovana koeficijentom utezanja. Ovaj koeficijent utiče

## 2 LOCAL DUCTILITY OF RC COLUMNS

In order to ensure ductile behaviour in the localized structural zones (plastic hinges), materials must be able to achieve appropriate deformations. Ductility of the reinforced concrete elements, at the cross-sectional level, is achieved by the increased elongation of the steel ( $\epsilon_s$ ), as well as by corresponding concrete compression deformation ( $\epsilon_c$ ), i.e. appropriate cross-section ductility curvature. The curvature ductility factor is defined as the ratio of the ultimate curvature and the curvature at yielding  $\mu_\varphi = \varphi_u / \varphi_y$ , where  $\varphi_y$  is the curve of RC cross-section at yielding (of reinforcement) and  $\varphi_u$  is the ultimate curve of RC cross-section.

According to [3], the yield curvature of cross-section is defined for two possible cases:

a) The curvature with strain at yielding of the tensioned reinforcement ( $\epsilon_s = \epsilon_{yd}$ ),

b) The curvature with large pressure strains on the upper (pressed) edge of the concrete cross-section.

According to Panagiotakos and Fardis [3], due to the large normal force, a non-linear behaviour of the compressed zone of the concrete cross-section may occur, before steel yielding. The authors proposed to calculate the curvature at yielding, in cases with large normal forces in columns, by limiting the strain of compressed fibre of the concrete cross-section to a value of  $1,8 \cdot f_c / E_c$ , where  $f_c$  is the compressive strength of concrete and  $E_c$  is the modulus of elasticity of concrete.

The ultimate curvature of the RC cross-section  $\varphi_u$  is defined by the ratio of the ultimate strain of the compressed confined concrete and the corresponding depth of the neutral axis. Determination of the cross-sectional ultimate curvature depends on the load level, the amount of reinforcement, the failure of the section due to rupture tension reinforcement or compressed concrete, etc. Depending on the values of the mentioned parameters, failure of the section can be achieved before spalling of the concrete cover or curvature at the spalling of the concrete cover.

Various experiments have shown that the ductility of the concrete significantly increases when it enters the state of triaxial compression [7]. This condition can be achieved by confining the element with a transverse reinforcement in the form of hoops and ties or spiral reinforcement. This prevents the lateral expansion of the element due to the axial compression force. As a result, the strength of the concrete element increases and the development of higher ultimate strain of cross-section compression fibres  $\epsilon_{cu,c}$ , significantly greater than 3.5%, which results in a larger ultimate curvature of cross-section  $\varphi_u$ . The parameters that affect degree of confinement are: quantity of transversal reinforcement ( $\rho_w$ ), steel strength (stress-strain diagram), concrete compression strength (stress-strain diagram), distance, shape and number of stirrups as well as longitudinal (vertical) reinforcement.

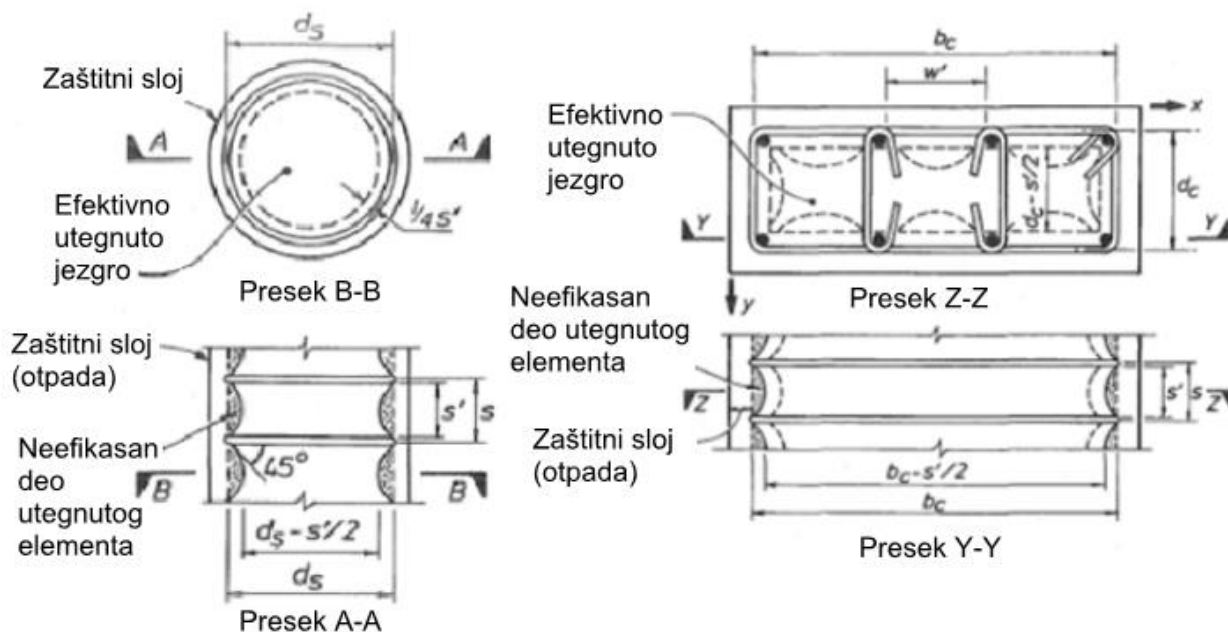
The lateral forces, which occur as a result of the prevented lateral expansion of the concrete element, act at the level of the stirrups. According to Fardis [3], it is considered that the confinement begins at achieving the approximate compression strength of the concrete, and that the stirrups fail to go into hardening when reaching the ultimate stress and hence the value of stress at yielding is adopted as the limit value. The highest lateral

na čvrstoću betona, naravno, u zavisnosti od oblika i količine poprečne armature.

Kako bi se obezbedila minimalna duktilnost kritičnih zona armiranobetonskih elemenata koje prihvataju seizmičko opterećenje, Evrokod 8 propisuje minimalne vrednosti količine poprečne i podužne (vertikalne) armature, njihove prečnike i međusobna rastojanja. Ispunjavanjem ovih uslova, te dobrim oblikovanjem i konstruisanjem položaja plastičnih zglobova, konstrukciji se omogućava da prihvati redukovane seizmičke sile, sa odgovarajućim nelinearnim deformacijama.

### 3 KOEFICIJENT UTEZANJA

Na slici 1 prikazana je teorijska pretpostavka oblika efektivnog dela betonskog elementa, kako pokazuju Sheikh i Uzumeri [8], a kasnije i Mander i ostali [4], u poprečnom preseku (B-B i Z-Z) i duž visine samog elementa (A-A i Y-Y). Pretpostavljeni oblik efektivno utegnutog preseka betona smanjuje se na mestima na kojima nema uzengija. Oblik promene je parabola s tangentama u krajnjim tačkama od  $45^\circ$ , sa žižom od četvrtine dužine.



Slika 1. Efektivno utegnuto presek s kružnim i pravougaonim uzengijama [4]  
Figure 1. Effectively confined cross-section with circular and rectangular stirrups [4]

Koeficijent utezanja ( $\alpha$ ) predstavlja faktor efikasnosti utezanja poprečnom armaturom. Ovaj faktor, prema propisima Evrokoda 8, sadrži dva činioca  $\alpha_s$  i  $\alpha_n$ . Prvi član definiše odnos površina preseka 1 i 2 označenih na slici 2 – izrazi (1) i (3). Presek u ravni 1 predstavlja minimalni poprečni presek koji se može javiti prilikom otpadanja neefikasno utegnute zone betonskog elementa, dok drugi predstavlja presek u kojem se nalazi

pressure can be developed only on the part of the concrete element where the confinement reinforcement is located. Due to this effect of lateral pressure, the maximum value must be reduced by confinement effectiveness factor. This coefficient affects the strength of concrete, depending on the shape and quantity of the transversal reinforcement.

With the aim of the confined zones to be ductile, Eurocode 8 suggests minimum values of the quantity of transversal and longitudinal (vertical) reinforcement, their diameters and their mutual distances. Complying with these conditions, designing good reinforcement details and distinguishing the places of plastic hinges throughout the structure allow the structure to accept seismic forces with certain inelastic deformations.

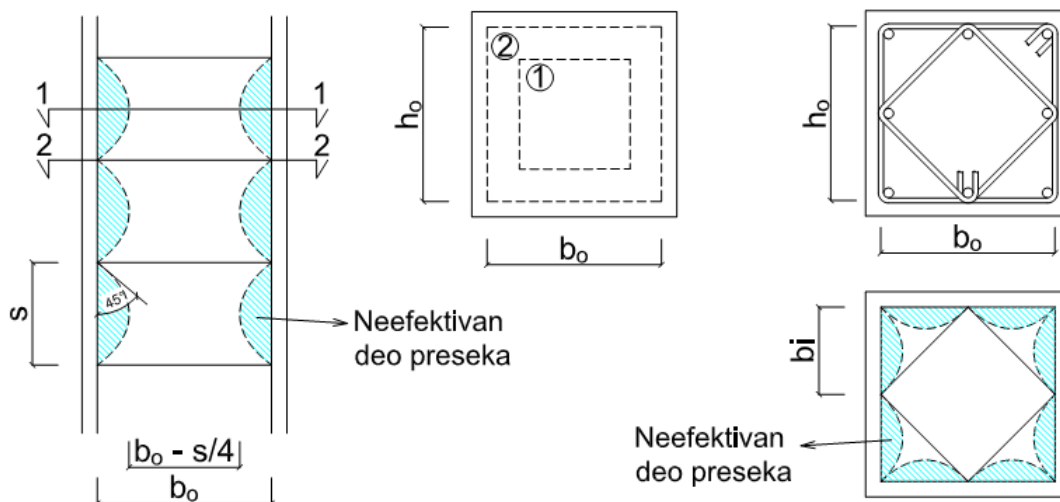
### 3 CONFINEMENT EFFECTIVENESS FACTOR

In Figure 1 the theoretical assumption of the shape of concrete element effective area is shown by Sheikh and Uzumeri [8], and later Mander et al. [4], in the cross-section (B-B and Z-Z) and along the height of the element itself (A-A and Y-Y). The assumed form of the effective cross-section of concrete is reduced in places without hoops or ties. The shape of the assumed volume of effective confined element is a parabola with tangents at the endpoints of  $45^\circ$ , with apex of a quarter of length between hoops or ties.

Confinement effectiveness factor ( $\alpha$ ) represents the efficiency factor of the transversal reinforcement. This factor, according to Eurocode 8, is defined as a product of two factors  $\alpha_s$  and  $\alpha_n$ . First one defines the ratio of the surfaces of sections 1 and 2 shown on Figure 2 - equations (1) and (3). The cross-section at level 1 represents the minimum cross-section which can occur after spalling the ineffective area of concrete element,

armatura za utezanje. Ovim članom uzima se u obzir efikasnost utezanja po visini elementa, koja zavisi od relativnog odnosa razmaka uzengija ( $s$ ) i dimenzija utegnutoh betonskog preseka (širine i visine označene sa  $b_o$  i  $h_o$  respektivno). Drugim članom umanjuje se efektivna površina betona za zbir svih neefektivnih delova između podužnih šipki armature prikazanih na slici 2 – izrazi (2) i (4). Ovim članom uzima se u obzir efikasnost utezanja na nivou poprečnog preseka.

while the other is cross-section in which the stirrups are located. First factor takes into account the confinement efficiency along the element that depends on relative ratio of the stirrups distance ( $s$ ) and the dimensions of the concrete cross-section (width and height indicated by  $b_o$  and  $h_o$  respectively). The second factor reduces the effective surface area of concrete for the sum of all ineffective parts between longitudinal rebar shown in Figure 2 - equations (2) and (4). With this factor the efficiency of confinement at the cross-sectional level is taken into account.



Slika 2. Definisiranje koeficijenta utezanja  
Figure 2. Defining of confinement effectiveness factor

Za pravougaoni poprečni presek:

For rectangular section:

$$\alpha_s = \left(1 - \frac{s}{2 \cdot b_o}\right) \left(1 - \frac{s}{2 \cdot h_o}\right) \quad (1)$$

$$\alpha_n = 1 - \sum_{i=1}^n \frac{b_i^2}{6 \cdot b_o \cdot h_o} \quad (2)$$

Za kružni poprečni presek:

For circular section:

$$\alpha_s = \left(1 - \frac{s}{2 \cdot D_o}\right)^2 \quad (3)$$

$$\alpha_n = 1 \quad (4)$$

Prilikom dostizanja graničnih dilatacija, odlama se zaštitni sloj betona, pa – shodno tome – efektivni presek, za takva stanja dilatacija, inicijalno postaje umanjen za debljinu tog sloja, odnosno dobijamo dimenzije utegnutoh preseka:

a) Pravougaoni presek

$$h_o = h_c - 2 \cdot (c - d_{bh}/2) \quad (5)$$

$$b_o = b_c - 2 \cdot (c - d_{bh}/2) \quad (6)$$

b) Kružni presek

b) For circular section:

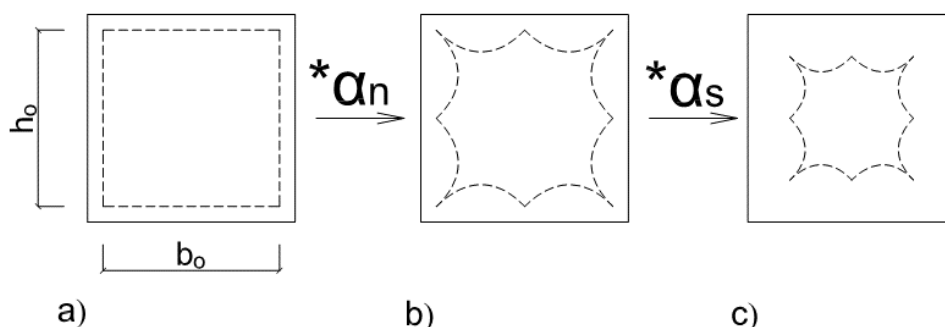
$$D_o = D_c - 2 \cdot (c - d_{bh}/2) \quad (7)$$

gde su  $b_c$  i  $h_c$  dimenzije pravougaonog betonskog poprečnog preseka,  $D_c$  prečnik kružnog preseka, a  $d_{bh}$  prečnik armature za utezanje – uzengija i poprečnih veza.

Redukovanjem površine ograničene spoljnim uzengijama koeficijentima određenim prema propisima Evrokoda 8, došli smo do koeficijenta utezanja, odnosno do efektivno utegnute površine (slika 3). Ako uporedimo interpretacije koeficijenta utezanja prikazane na slikama 1 i 3, tj. prema teorijskoj pretpostavci i izrazima Evrokoda 8, zaključujemo da je veoma teško ustanoviti fizički smisao izraza. Postavlja se pitanje kako izrazi Evrokoda 8 dobijenu efektivnu površinu interpretiraju i po visini elementa, odnosno koji deo stuba se smatra efektivno utegnutim.

#### 4 ANALIZA REALIZOVANOG KOEFICIJENTA UTEZANJA

Kako bismo shvatili oblik efektivno utegnuto elementa duž visine stuba prema izrazima (1)-(4), a imajući u vidu da koeficijent utezanja predstavlja odnos efektivne utegnute površine (slika 3c) i površine utegnuto preseka (slika 3a), pretpostavljamo da to, takođe, može biti odnos zapremine efektivno utegnuto i uteguto dela elementa. Pretpostavljamo da izrazi Evrokoda 8 efektivnu zapreminu interpretiraju kao „prizmu” s bazom površine sa slike 3c, tj. da promene efektivne površine po visini elementa nema.



Slika 3. Interpretacija koeficijenta utezanja skaliranjem preseka sa  $\alpha_n$  i  $\alpha_s$

Figure 3. Interpretation of the confinement effectiveness factor by scaling cross-section with factors  $\alpha_n$  and  $\alpha_s$

Analizu prvo sprovodimo na jednostavnijem obliku stuba, odnosno na stubu kružnog poprečnog preseka, prečnika utegnuto preseka  $D_0=40$  cm i razmaka uzengija  $s=20$  cm. Prvi parametar za analizu predstavlja koeficijent utezanja prema izrazima Evrokoda 8, tj. izrazima (3) i (4), koji nazivamo  $\alpha[EC8]$ . Dalje, konstruišemo tri trodimenzionalna elementa, od kojih je prvi stub prečnika  $D_0$  (slika 4a). Drugi element predstavlja efektivnu zapreminu prema teorijskoj pretpostavci Mander i ostali [4], s bazom efektivno utegnuto jezgra prikazanog na Preseku B-B (slika 1) i podužnom promenom u svemu prema Preseku A-A. Ovakav model prikazan je na slici 4b. Odnosom zapremina modela sa slike 4b i 4a dobijamo teorijski

where  $b_c$  and  $h_c$  are dimensions of the rectangular concrete cross-section,  $D_c$  is diameter of the circular cross-section and  $d_{bh}$  is diameter of the confinement rebar – hoops or ties.

By reducing the area surrounded by external stirrup, according to the Eurocode 8 regulations, we have determined the confinement effectiveness factor, i.e. the effectively confined area (Figure 3). When the interpretations shown on Figure 1 and 3 are compared according to the theoretical assumption and equations of Eurocode 8, it can be concluded that it is very difficult to determine the real meaning of the equations. The question that should be answered is how recommendations of Eurocode 8 interpret the effective area by the height of the element, i.e. which part of the column is considered effective.

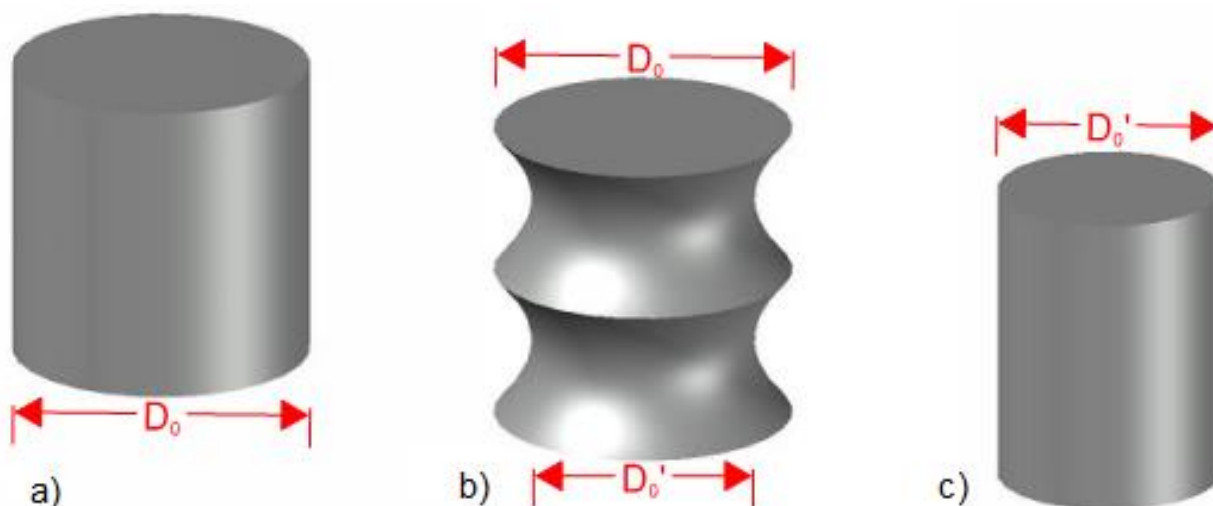
#### 4 ANALYSIS OF THE ACHIEVED CONFINEMENT EFFECTIVENESS FACTOR

In order to understand the shape of an effectively confined element along the height of the column according to the equations (1)-(4), and taking into account that the confinement effectiveness factor is the ratio of the effective confined area (Figure 3c) and confined area (Figure 3a), it is assumed that this can also be the ratio of the effectively confined and confined volume of the element. It is assumed that the equations of the Eurocode 8 interpret the effective volume as a "prism" with the base shown on Figure 3c, i.e. that there are no changes in the effective volume along the height of element.

The analysis starts with a simpler form of a column, i.e. a circular cross-section. The diameter of the cross-section is  $D_0=40$  cm and stirrup spacing  $s=20$  cm. The first parameter for the analysis is the confinement effectiveness factor according to the assumptions of the Eurocodes 8, i.e. equations (3) and (4), which is named  $\alpha[EC8]$ . Subsequently, three three-dimensional elements are designed, where the first is a column with diameter  $D_0$  (Figure 4a). The second element represents the effective volume according to the theoretical assumption of Mander et al. [4], with the base of the effectively confined core shown in Section B-B (Figure 1), and a vertical change of shape along the height of element according to Section A-A. This model is shown in Figure

koeficijent utezanja preseka i nazivamo ga  $\alpha$ [ACAD]. Prema rezultatima iz tabele 1, vidimo da je koeficijent utezanja prema izrazima manji i da nagoveštava da su propisi usvojili nešto jednostavniji, a sigurno konzervativniji oblik efektivno utegnuto elementa. Treći model predstavlja pretpostavljen „cilindar” (slika 4c). U slučaju kružnog stuba, kako je koeficijent  $\alpha_n=1$ , imamo da je prečnik baze „cilindra” jednak  $D_o' = D_o - 2 \cdot s/4 = 30$  cm, a koeficijent utezanja koji računamo kao odnos modela sa slike 4c i slike 4a, naziva se  $\alpha$ [EC8-ACAD]. Iz tabele 1 vidimo potpuno poklapanje rezultata za  $\alpha$ [EC8] i  $\alpha$ [EC8-ACAD], što znači da je pretpostavka ostvarena za kružni poprečni presek. Takođe, za kružni presek zaključujemo da je prečnik osnove trećeg modela ustvari jednak najmanjem prečniku teorijskog modela duž visine stuba, odnosno na sredini rastojanja između dve uzengije.

4b. With ratio of the model volume represented on Figures 4b and 4a the theoretical confinement effectiveness factor is obtained, which is named  $\alpha$ [ACAD]. According to the results from Table 1, it can be concluded that the confinement effectiveness factor by equations is smaller and suggests that the regulations of Eurocode 8 adopted a simpler, but certainly more conservative form of an effectively confined element. The third model is assumed to be a "cylinder" (Figure 4c). In the case of a circular column, as the coefficient  $\alpha_n=1$ , the diameter of the base cylinder is equal to  $D_o' = D_o - 2 \cdot s/4 = 30$  cm, and the confinement effectiveness factor is calculated as the ratio of the model from Figures 4c and 4a and named  $\alpha$ [EC8-ACAD]. From Table 1 it can be noticed that there is a complete match of the results for  $\alpha$ [EC8] and  $\alpha$ [EC8-ACAD], which means that the assumption made for a circular cross-section is fulfilled. In addition, for a circular cross-section, it can be concluded that the base diameter of the third model is actually equal to the smallest diameter of the theoretical model along the height of the column which is in the middle of the two stirrups.



Slika 4. Modeli stuba: a) Utegnut presek; b) Efektivno utegnuto jezgro elementa; c) Efektivno utegnuto element prema Evrokodu 8

Figure 4. Column models: a) Confined volume; b) Effectively confined volume; c) Effectively confined volume by Eurocode 8

Tabela 1. Koeficijenti utezanja kružnog stuba  
Table 1. Confinement effectiveness factor for circular column

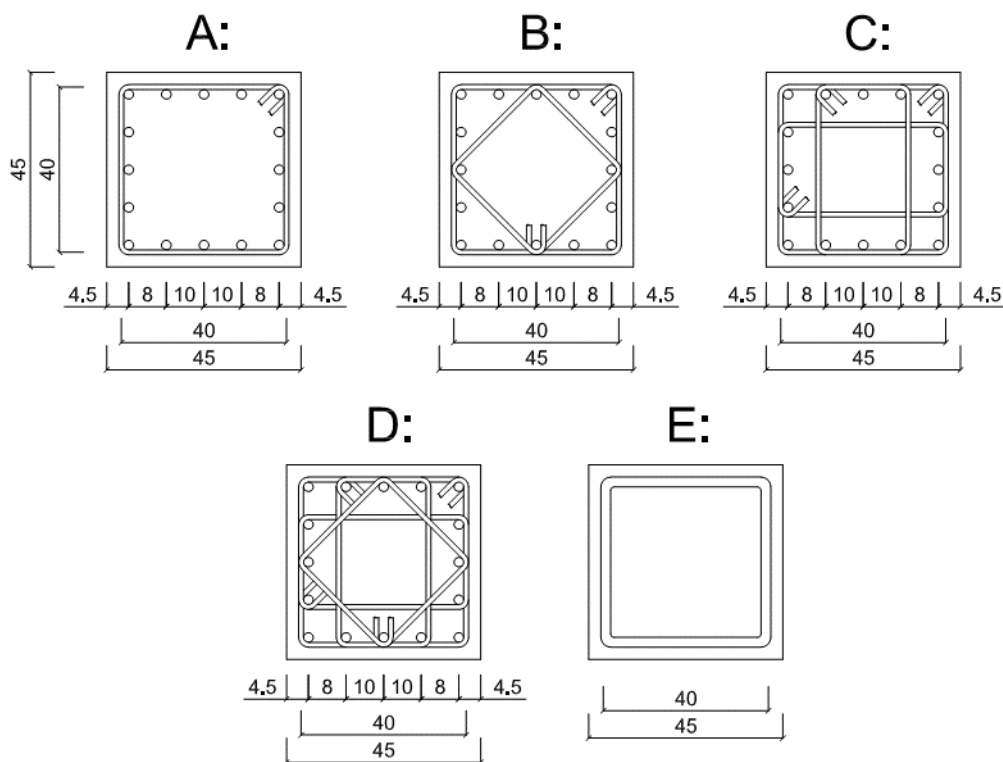
Oblik stuba Column shape	Prečnik Diameter [cm]	Razmak uzengija Stirrups spacing [cm]	$\alpha$ [EC8]	$\alpha$ [ACAD]	$\alpha$ [EC8-ACAD]
Kružni Circular	40	20	0,5625	0,6974	0,5625

Pošto smo s dovoljnom tačnošću zaključili šta predstavlja bazu „cilindra”, dalje analiziramo kvadratne stubove. Izabrano je nekoliko tipičnih načina armiranja (slika 5). Model A predstavlja presek s najmanjim mogućim stepenom armiranja, koji ne ispunjava minimalne uslove lokalne duktilnosti Evrokoda 8 u

Since it is concluded, with sufficient accuracy, what is the base of "cylinder", square columns are further analyzed. Several typical reinforcement forms have been selected (Figure 5). Model A represents the section with least possible reinforcement, which does not meet the minimum local ductility requirements by Eurocode 8, in

pogledu armiranja, ali je pogodan za modeliranje i suštinski bitan – kao početni reper u analizi. Modeli B, C i D česti su slučajevi armiranja u praksi, kod kojih sukcesivno smanjujemo neefektivnu zonu, dok je poslednji presek model E armiran tako da predstavlja teorijski najveći mogući efekat utezanja, koji bi trebalo da zameni kružnu uzengiju i postigne ekvivalentni efekat utezanja. Generalno, za pretpostavljene dimenzije stuba minimalno armiranje je predstavljeno modelom B (slika 5), kako bi se zadovoljio minimalan razmak podužnih pridržanih šipki armature od 20cm, s minimalnim prečnikom armature  $\varnothing 8$ . Prema Evrokodu 8, minimalni prečnik uzengije jeste  $\varnothing 6$  na rastojanju koje nije veće od  $b_0/2$ , 17,5 cm ili 8 minimalnih prečnika podužne (vertikalne) armature u stubu. Broj i prečnici poprečnih šipki mogu biti i veći, što zavisi od intenziteta uticaja u elementu kao i zadovoljenja izraza 5.15 datog u [2], koji treba da obezbedi minimalnu zahtevanu vrednost faktora duktilnosti krivine. Za potrebe analize, usvojene dimenzije utegnutog dela preseka su  $b_0=d_0=40$  cm s razmakom uzengija od  $s=20$  cm.

terms of reinforcement, but is suitable for modelling and essentially important as the starting point in the analysis. Models B, C and D are common types of reinforcement details in practice, in which the ineffective zone is reduced one after the other, while the last cross-section, model E, is detailed to represent the highest possible confinement, which should, theoretically, achieve the circular hoops effect of confinement. In general, for the assumed dimensions of the column, the minimal reinforcing provisions are represented by model B (Figure 5), which satisfies the minimum spacing of longitudinal reinforcement with 20 cm and minimum diameter  $\varnothing 8$ . According to Eurocode 8, minimum diameter of the stirrup is  $\varnothing 6$  at distance less than  $b_0/2$ , 17.5 cm or 8 thicknesses of the longitudinal reinforcement. Number and diameter of the rebar can be even higher, which depends on load level and satisfying the equation 5.15 given in [2]. When the second condition is met, the minimum ductile behaviour of the element is achieved. For the purpose of analysis, the dimensions of the cross-section  $b_0=d_0=40$  cm with stirrup spacing  $s = 20$  cm were adopted.



Slika 5. Usvojeni modeli za analizu  
Figure 5. Adopted models for analysis

Prilikom modeliranja kvadratnih stubova, nailazimo na nedostatak podataka regulisanih odredbama Evrokoda 8. Reč je o tome da ne znamo koliko maksimalno neefektivna zona ulazi u stub, po visini, između dva reda uzengija, pa su dva razmatrana modela prikazana na slici 6.

Na slici 6a usvojena je funkcija parabole sa žižom od  $s/4=5$  cm, dok je za drugi slučaj (slika 6b) usvojena raspodela konstruisanjem površine ograničene sa četiri parabole u programskom paketu AutoCAD, kod koje se

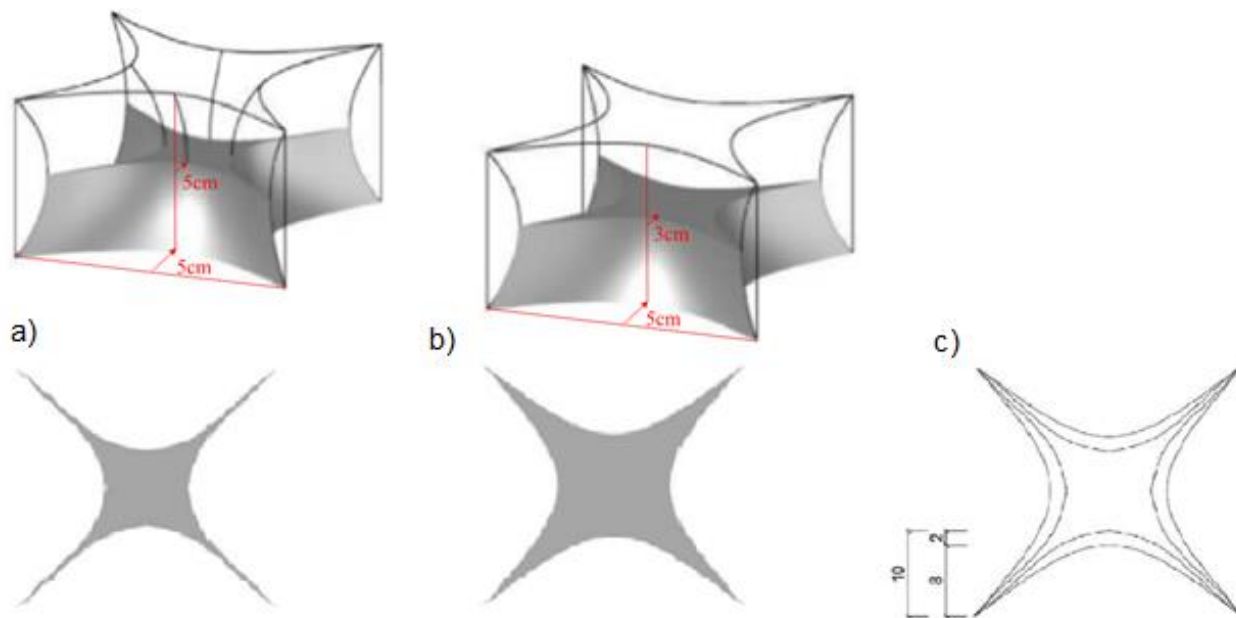
While modelling the square columns the lack of data, regulated by the provisions of Eurocode 8, is noticed. It is a matter of not knowing how the maximum ineffective zone enters the column between the two rows of the stirrups, along the height of the column, so the two models considered are shown in Figure 6.

In Figure 6a, the parabola function with apex  $s/4=5$  cm is adopted, while for the second case, Figure 6b, surface is designed with bounded four parabolas, using software package AutoCAD, in which the 3 cm apex is



dobija žiža u veličini od 3 cm. Na osnovu rezultata analize, prikazanih u tabeli 2, može se zaključiti da model sa slike 6a ima koeficijent utezanja  $\alpha$ [EC8-ACAD] mnogo manji u poređenju sa izrazima (1) i (2), tj.  $\alpha$ [EC8]. Kako smo pokazali na kružnom stubu da koeficijent  $\alpha$ [EC8-ACAD] zadovoljava vrednost koeficijenta utezanja iz propisa  $\alpha$ [EC8], to tačniju pretpostavku smatramo modelom sa slike 6b.

obtained. It can be noticed that the model on Figure 6a have confinement effectiveness factor  $\alpha$ [EC8-ACAD] much smaller compared to the equations (1) and (2), i.e.  $\alpha$ [EC8]. As shown on the circular column that the coefficient  $\alpha$ [EC8-ACAD] meets the value of the confinement effectiveness factor from the regulation  $\alpha$ [EC8], the model shown on Figure 6b is considered more accurate.



Slika 6. Razlika između dva pretpostavljena modela u prostoru  
Figure 6. The difference between two presumed models

Tabela 2. Dve pretpostavke utezanja modela A  
Table 2. Two confinement assumptions of model A

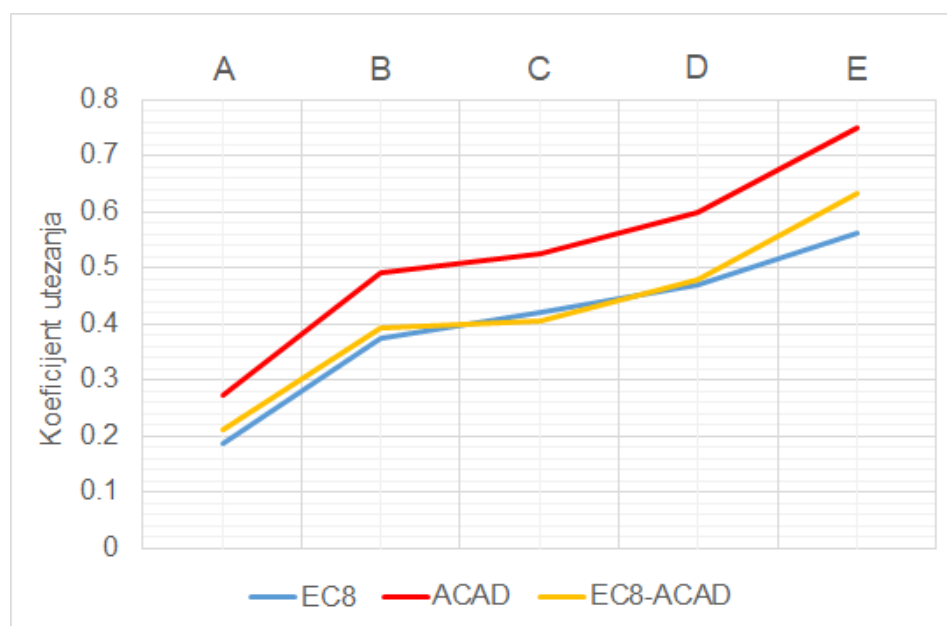
Model Model	Dimenzije Dimensions [cm]	Razmak uzengija Stirrups spacing [cm]	$\alpha$ [EC8]	$\alpha$ [ACAD]	$\alpha$ [EC8-ACAD]
A (Slika 6a) A (Figure 6a)	40x40	20	0,1875	0,1997	0,1147
A (Slika 6b) A (Figure 6b)	40x40	20	0,1875	0,2726	0,2108

Deo tabele 3, koji je označen kao Teorijski, predstavlja koeficijente utezanja kvadratnog stuba teorijskom pretpostavkom efektivne zone Mander i ostali [4] –  $\alpha$ [ACAD] i poređenje dobijenih rezultata s koeficijentima uzezanja dobijenih iz izraza (1) i (2) –  $\alpha$ [EC8]. Drugi deo tabele 3 (Prema EC8) predstavlja odnos „prizmatične” pretpostavke efektivno utegnute zone betonskog elementa –  $\alpha$ [EC8-ACAD] i izraza (1) i (2) –  $\alpha$ [EC8]. Zaključujemo, prema rezultatima tabele 3, da propisi pojednostavljuju oblik efektivno utegnute zone stuba i da je koeficijent utezanja konzervativan. To se uočava u jako maloj razlici ( $\Delta$ ) pretpostavljenog modela i izraza (1) i (2) iz Evrokoda 8, koja su oko 0,02 za klasične slučajeve armiranja.

Part of Table 3, which is named Theoretical, is the square-column confinement effectiveness factor for theoretical assumption of effective zone by Mander et al. [4] -  $\alpha$ [ACAD] and a comparison with obtained results for coefficients calculated from equations (1) and (2) -  $\alpha$ [EC8]. The second part of Table 3 (According to EC8) is the relation between the "prismatic" assumption of the concrete element effective confinement zone -  $\alpha$ [EC8-ACAD] and the equations (1) and (2) -  $\alpha$ [EC8]. According to the results shown in Table 3, it is concluded that the regulations simplify the shape of the effectively confined zone of the column and that the confinement effectiveness factor is conservative. This is noticeable in the very small difference ( $\Delta$ ) between the assumed model and equation (1) and (2) from Eurocode 8, which are about 0.02 for usual reinforcement details.

Tabela 3. Koeficijenti utezanja modela  
Table 3. Confinement effectiveness factors

Model / Model		A	B	C	D	E
Teorijski Theoretical	$\alpha$ [EC8]	0,1875	0,3750	0,4219	0,4688	0,5625
	$\alpha$ [ACAD]	0,2726	0,4922	0,5245	0,5989	0,7512
	$\Delta$	0,0851	0,1172	0,1026	0,1301	0,1887
Prema EC8 According to EC8	$\alpha$ [EC8]	0,1875	0,3750	0,4219	0,4688	0,5625
	$\alpha$ [EC8-ACAD]	0,2105	0,3929	0,4044	0,4787	0,6331
	$\Delta$	0,0233	0,0179	-0,0175	0,0099	0,0706



Slika 7. Poređenje koeficijenata utezanja razmatranih modela (napomena: veza između modela A-E nije linearna)  
Figure 7. Comparison of the confinement effectiveness factors for considered models (note: the relation between models A-E is not linear)

Kod stubova kružnog poprečnog preseka, sila utezanja ravnomerno deluje duž kružne uzengije i nema neefektivnih delova utegnutog poprečnog preseka. Shodno tome, greške pri modeliranju efektivno utegnutog elementa, sa osnovom utegnutog elementa koja je skalirana izrazima (3) i (4), nije bilo i videli smo poklapanja rezultata prema tabeli 1. To nije slučaj i kod kvadratnih preseka, gde postoji komplikovanija geometrija i kod koje se zbog greške modela javljaju određene razlike. Greška se uvećava, takođe, zbog usvajanja površina koje generiše sam program, sa određenom gustinom mreže.

Čest slučaj u praksi jeste da se stubovi dodatno utežu na određenim mestima duž visine stuba (npr. u zoni spoja grede i stuba) postavljanjem spoljašnje uzengije na duplo manjem rastojanju. Prema odredbama Evrokoda 8, utezanje preseka radi se uniformno po celoj visini disipativne zone, postavljanjem svih uzengija preseka na istom rastojanju, pa se postavlja pitanje efikasnosti utezanja preseka progušćenjem samo spoljne uzengije. Pomenuti slučaj iz prakse analizira se dodatnim utezanjem elementa, postavljanjem barem jedne osnovne uzengije na polovini prethodno usvojenog

In the case of circular cross-section the confining force acts equally along the circular hoop and there are no ineffective parts of confined cross-section. Consequently, there were no errors in the modelling an effectively confined element, with the basis scaled by the factors calculated from equations (3) and (4), and we noticed the matching of the results in Table 1. This was not the case while designing the square cross-section columns with more complicated geometry and where certain differences occur, due to model errors. The error is also increased by adopting surfaces generated by the software itself, with a certain density of the mesh.

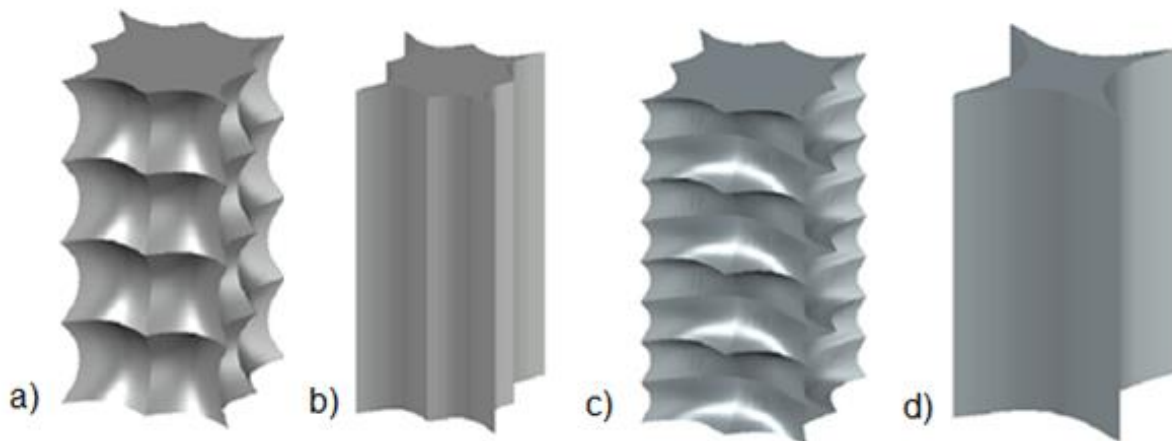
In most cases, in practice, the columns are additionally confined at certain levels along the height of the column (for example, in the zone of beam and column joints) by adding an external stirrup between existing ones. According to the regulations of Eurocode 8, the cross-section confinement is uniform over the entire height of the dissipative zone by placing all stirrups at the same distance, so the question of any extra efficiency on confined element with that external stirrup is to be answered. The mentioned case from the practice is analyzed by additional confinement of the

razmaka ( $s$ ). Osnovnom uzengijom smatra se ona koja pridržava krajnje šipke longitudinalne armature.

Modele s dodatnom osnovnom uzengijom na sredini razmaka ( $s$ ) nazivamo, respektivno, BA, CA, DA, EA (slika 8). Pri proračunu koeficijenta utezanja ovih modela, korišćenjem izraza Evrokoda 8, sračunata je ista vrednost, jer je u poprečnom preseku na rastojanju  $s$  isti način armiranja. Ovo znači da Evrokod 8 ne prepoznaje ovakav princip kao dodatno utezanje, što ga čini konzervativnim, tj. na strani sigurnosti, ali ostaje pitanje da li je dodatno utezanje suštinski ostvareno.

element, adding at least one basic stirrup at half of the previously adopted spacing ( $s$ ). The basic stirrup is the one that wraps edge bars of the longitudinal reinforcement.

Models with additional basic stirrup at the centre of the distance ( $s$ ) are named, respectively, BA, CA, DA, EA (Figure 8). When calculating the confinement effectiveness factor of these models, by using equations given in Eurocode 8, the same value of effectiveness factor is calculated, since the cross-section at distance  $s$  have the same reinforcement form. This means that the Eurocode 8 fails to recognize this principle as an additional confinement, which makes it conservative, i.e. on the safe side, but the question whether additional confining has been substantially achieved still remains.



Slika 8. Modeli: a) B – teorijski; b) B – prema EC8; c) BA – teorijski; d) BA – prema EC8  
Figure 8. Models: a) B - theoretical; b) B - according to EC8; c) BA - theoretical; d) BA - according to EC8

Prema rezultatima iz tabele 3 i tabele 4, za teorijski koeficijent utezanja, zapažamo da s progušćenjem uzengija smanjujemo koeficijent, što nije očekivano i da dobijeni rezultati odstupaju od razmišljanja u praksi, gde se progušćene uzengije smatraju vidom dodatnog utezanja. Greška koja se pravi usvajanjem teorijskog modela jeste ta da parabolu na mestu dodatne uzengije mi teorijski usvajamo. Ona ima dužinu  $d_0$  i žihu  $s/4$ .

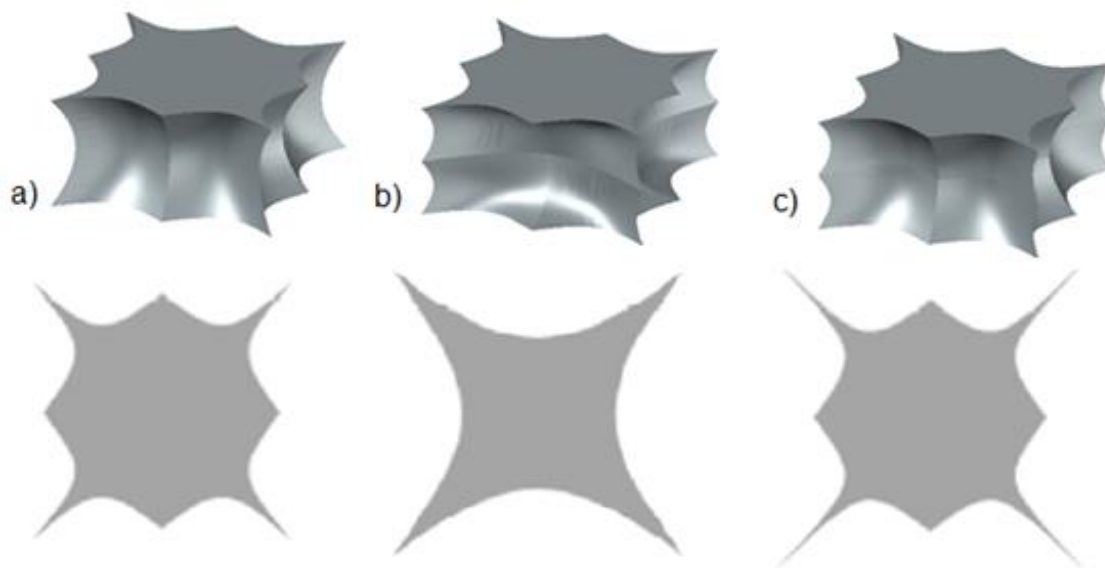
According to the results from Table 3 and Table 4, for the theoretical confinement effectiveness factor, it can be noticed that with additional basic stirrup the coefficient is reduced, which is unexpected and that the obtained results deviate from practice where the additional stirrup is considered as enhanced confinement. The mistake in designing the theoretical model was made because we adopted the parabola at the place of additional stirrup by theory. Parabola have length  $d_0$  and apex  $s/4$ .

Tabela 4. Koeficijenti utezanja modela s dodatnim utezanjem  
Table 4. Confinement effectiveness factors with additional confinement

Model / Model		A	B	C	D	E
Teorijski Theoretical	$\alpha$ [EC8]	/	0,3750	0,4219	0,4688	0,5625
	$\alpha$ [ACAD]	/	0,4128	0,4210	0,440	0,5243
	$\Delta$	/	0,0378	-0,0009	-0,0288	0,0382
Teorijski korigovan Corrected theoretical	$\alpha$ [EC8]	/	0,3750	0,4219	0,4688	0,5625
	$\alpha$ [ACAD]	/	0,4901	0,5245	0,5989	0,7420
	$\Delta$	/	0,1151	0,1026	0,1302	0,1795
Prema EC8 According to EC8	$\alpha$ [EC8]	/	0,3750	0,4219	0,4688	0,5625
	$\alpha$ [EC8-ACAD]	/	0,4007	0,4042	0,4795	0,6441
	$\Delta$	/	0,0251	-0,0177	0,0107	0,0816

Na modelu kod kog nema proglašavanja uzengija, a na sredini razmaka  $s$ , imamo realno mnogo veću efektivnu površinu (slika 9a) u poređenju sa utegnutim modelom (slika 9b) na čijem je mestu postavljena dodatna uzengija. Drugim rečima, dodatnim utezanjem fiktivno smanjujemo efektivan presek kako bismo usvojili pretpostavljenu raspodelu efektivne zone prema preporukama Evrokoda 8. Ovu grešku ispravljamo modeliranjem efektivnog preseka na  $s/2$  sa slike 9a, koji bi se maksimalno mogao pojaviti, tj. kao na modelu B. S tog modela usvajamo istu zavisnost u horizontalnom preseku na visini  $s/2$ , samo što je dodatno produžavamo do podužnih šipki armature, jer je na tom mestu armatura pridržana (slika 9c).

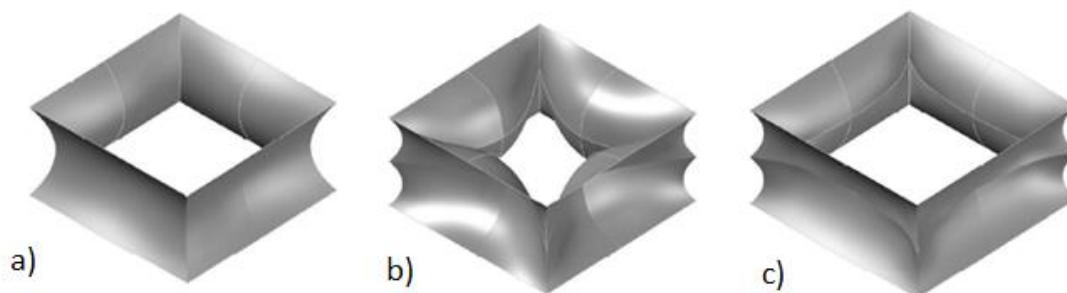
On the model with no additional stirrups, in the middle of the length  $s$ , there is a much larger effective zone (Figure 9a) than the model in which the additional stirrup is placed (Figure 9b). In other words, by adding basic stirrups, the effective cross-section is fictively reduced to adopt the assumed distribution of the effective zone according to the recommendations of Eurocode 8. This error is corrected by modelling the effective cross-section located at  $s/2$  from Figure 9a which could maximally appear, i.e. as on the model B. From this model, the same curve is adopted in the horizontal cross-section at the height  $s/2$ , but with extending the curve to the edge longitudinal bars, as the reinforcement is retained at those points (Figure 9c).



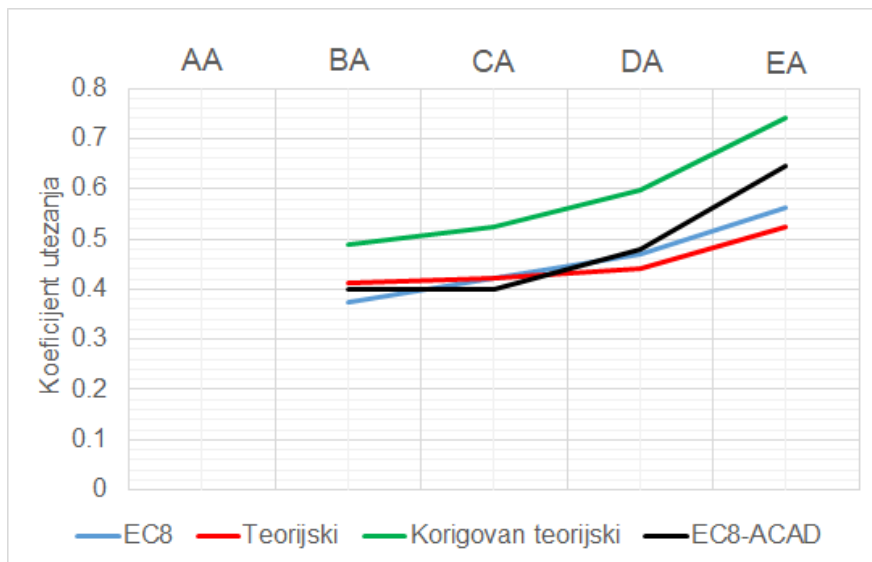
Slika 9. Prikaz razlike modela: a) B; b) BA; c) BA korigovanog;  $s$  poprečnim presecima na sredini visine  
Figure 9. Model differences: a) B; b) BA; c) BA corrected; with cross-sections in the middle of the height

Na slici 10 prikazan je model sa unutrašnje strane, gde se jasno može uočiti da – zbog ispunjenja preporuka Evrokoda 8 o neefektivnoj zoni između pridržanih šipki podužne armature – činimo grešku koju nadomešćujemo ograničavanjem neefektivne zone u tom preseku.

Figure 10 shows the model from the inside, where it can be clearly noticed that in order to fulfil the recommendations of Eurocode 8 on the ineffective zone between the retained longitudinal reinforcement, an error was made which is corrected by limiting the ineffective zone in that cross-section.



Slika 10. Minimalni poprečni presek po visini stuba modela: a) E; b) EA; c) EA korigovanog  
Figure 10. Minimal cross-section along the height of the models: a) E; b) EA; c) EA corrected

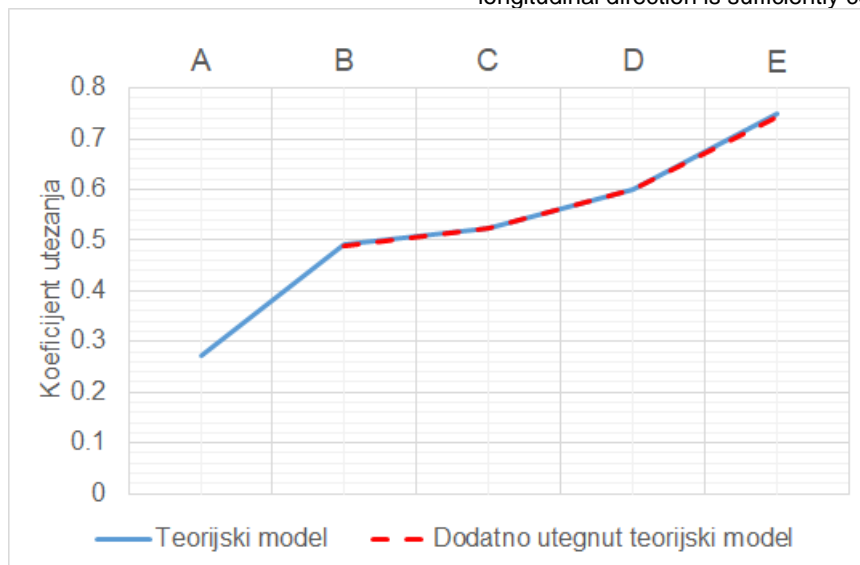


Slika 11. Poređenje koeficijenata utezanja za model s dodatnim proguščenjem armature za utezanje iz tabele 4 (napomena: veza između modela A-E nije linearna)

Figure 11. Comparison of confinement effectiveness factors for models with additional basic stirrups from Table 4 (note: the relation between models A-E is not linear)

S dovoljnom tačnošću možemo zaključiti da teorijski pretpostavljen, efektivno utegnut, element, kako su ga dali Mander i ostali [4] ( $\alpha$ [ACAD]), daje veće koeficijente utezanja od pretpostavke koju definišu izrazi prema odredbama Evrokoda 8 ( $\alpha$ [EC8]). Na slici 11 prikazana je razlika između ovih koeficijenata, s napomenom da veza između modela A do E nije linearna. Prema sumiranim rezultatima, na slici 11, zapažamo veoma mala odstupanja od koeficijenata utezanja prema izrazima (1) i (2) ( $\alpha$ [EC8]) u odnosu na pretpostavljenu „prizmu” ( $\alpha$ [EC8-ACAD]), pa shodno tome smatramo da je pretpostavka o obliku efektivno utegnuto elementa, u podužnom pravcu, dovoljno tačna.

With sufficient accuracy, it can be concluded that the theoretically assumed, effectively confined, element by Mander et al. [4] ( $\alpha$ [ACAD]) gives a higher confinement effectiveness factor than the recommendations defined by the equations in Eurocode 8 ( $\alpha$ [EC8]). Figure 11 shows the difference of these coefficients, with the note that the relation between the A-E model is not linear. According to the summarized results, in Figure 11, we notice very small deviations from the confinement effectiveness factor by equations (1) and (2) ( $\alpha$ [EC8]) in relation to the assumed "prism" ( $\alpha$ [EC8-ACAD]), and consequently it is considered that the assumption about the shape of an effectively confined element in the longitudinal direction is sufficiently correct.



Slika 12. Poređenje teorijskog i dodatno utegnuto teorijskog modela – tabele 3 i 4 (napomena: veza između modela A-E nije linearna)

Figure 12. Comparison of the theoretical and additionally confined theoretical model - Table 3 and 4 (note: the relation between models A-E is not linear)

## 5 ZAKLJUČAK

U radu je predstavljena analiza faktora efikasnosti utezanja armiranobetonskih preseka poprečnom armaturom, kao jednog od ključnih parametara koji utiču na obezbeđivanje zahtevanog faktora efikasnosti krivine preseka, prema Evrokodu 8 [2]. Objašnjeno je fizičko značenje faktora efikasnosti na osnovu grafičkog prikaza utegnutog betona elementa kvadratnog, odnosno kružnog poprečnog preseka. Dokazano je da su izrazi za sračunavanje koeficijenta utezanja prema Evrokodu 8 [2] definisani odnosom: (1) zapremine tela prizmatičnog oblika čija je osnova jednaka najmanjem poprečnom preseku efektivno utegnutog jezgra koji se može javiti duž elementa; (2) zapremine tela prizmatičnog oblika čija je osnova definisana oblikom spoljašnje uzengije. Ovakva definicija daje konzervativne rezultate u odnosu na „realni” faktor efikasnosti utezanja, definisan prema ukupnoj zapremini efikasno utegnutog betona. Takođe, dokazano je da dodatno progušćavanje spoljašnje konturne uzengije na duplo manjem rastojanju ne uvećava bitno vrednost koeficijenta utezanja. Ovaj zaključak odnosi se isključivo na koeficijent utezanja, što ne znači da betonski element, povećanjem poprečne armature, nema povećanje kapaciteta duktilosti.

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## 5 CONCLUSION

The paper presents the analysis of the confinement effectiveness factor for the reinforced concrete cross-sections with stirrups, as one of the key parameters that influence the achievement of the required cross-section curvature ductility factor, according to Eurocode 8 [2]. The physical meaning of the confinement effectiveness factor is graphically explained for confined concrete elements of square and circular cross-sections. Equations for calculating the confinement effectiveness factor according to Eurocode 8 [2] have been shown and defined by the relation: (1) the volume of a prismatic element with basis equal to the smallest cross-section of the effectively confined core that may occur along the element, and (2) the volume of the element of prismatic form with basis defined by the form of external stirrup. This definition gives conservative results with respect to the "real" confinement effectiveness factor, defined by the total volume of effectively confined concrete. In addition, it has been shown that the added external stirrup between existing ones insignificantly increases the value of the confinement effectiveness factor. This conclusion applies only to the confinement effectiveness factor, which does not mean that the concrete element will not increase the ductility capacity with increased transverse reinforcement.

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## REZIME

### OBEZBEĐENJE LOKALNE DUKTILNOSTI ARMIRANOBETONSKIH ELEMENATA PREMA EVROKODU 8 – KOEFICIJENT UTEZANJA

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Fokus ovog rada usmeren je na efekte utezanja armiranobetonskih preseka, odnosno na način na koji poprečna armatura utiče na poboljšanje karakteristika – kako materijala, tako i utegnute zone elementa. Pojašnjeno je praktično značenje koeficijenta utezanja iz izraza Evrokoda 8. Izvršena je procena veličine dela elementa koji je efektivno utegnut uzengijama na primerima različito armiranih kružnih i kvadratnih preseka stubova i analizom trodimenzionalnog prikaza efektivno utegnutog betona. Uspostavljena je relacija između koeficijenta utezanja prema izrazima Evrokoda 8 i efektivno utegnutog dela betonskog elementa.

**Ključne reči:** Evrokod 8, lokalna duktilnost, koeficijent utezanja

## SUMMARY

### THE DESIGN OF LOCAL DUCTILITY FOR REINFORCED CONCRETE ELEMENTS BY EUROCODE 8 - CONFINEMENT EFFECTIVENESS FACTOR

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This paper is focused on the effects of confinement of the reinforcement reinforced concrete sections, i.e. in the way that the transverse reinforcement affects the improvement of the characteristics of both the material and the affected zone of the element. The practical meaning of the confinement effectiveness factor from the expression of Eurocode 8 was explained. Size of the part of element that is effectively confined by the stirrups is estimated on examples of differently reinforced circular and square sections of the column by analysis of the three-dimensional presentation of effectively confined concrete sections. The connection between confinement effectiveness factor by Eurocode 8 and real effective concrete core is established.

**Key words:** Eurocode 8, ductility, confinement effectiveness factor