

# OCENA UTICAJA KOLIČINE VAZDUHA NA ČVRSTOĆU BETONA KLASIČNIM PRISTUPOM I NEURONSKIM MREŽAMA

## EVALUATION OF AIR CONTENT ON CONCRETE COMPRESSIVE STRENGTH WITH CLASSICAL APPROACH AND NEURAL NETWORKS

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### 1 UVOD

Od kada je uvlačenje vazduha u beton prvi put otkriveno, sredinom tridesetih godina prošlog veka, koncept aeriranog betona postao je pravilo, a ne izuzetak za beton u hladnim klimatskim područjima. Uvlačenje je otkriveno sasvim slučajno, kada je u proizvodnji cementa korišćen intenzifikator mlevenja da bi se poboljšala finoća mliva. Hemijski uvučen vazduh u beton unapredio je otpornost betona na dejstvo mraza, a aditivi aeranti pokazali su se u dužem periodu veoma uspešnim u unapređivanju otpornosti betona na zamrzavanje i odmrzavanje, kako njegove unutrašnje strukture, tako i njegove površine. Ipak, ovaj uspeh nije došao bez osporavanja, a i današnji proizvođači betona se bore s kontrolom količine vazduha u betonu i mnogim faktorima koji utiču na vazduh u betonu. Za celovito razumevanje složenosti uvlačenja vazduha u beton i za primenu u praksi, potrebno je u potpunosti shvatiti njegov mehanizam.

Zamrzavanje i odmrzavanje indukuje ciklične promene u zapremini betona, koje izazivaju njegovo cepanje, ljuštenje i pucanje. Uvučeni vazduh može unaprediti trajnost betona. Njegov najveći doprinos jeste u povećanju zaštite protiv zamrzavanja i odmrzavanja u prisustvu soli za odmrzavanje. Vazduh u betonu postoji

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### 1 INTRODUCTION

Ever since air entrainment was first discovered (by accident) in the mid-1930s, the concept of air-entrained concrete has become a rule, and not the exception in cold climate concreting. Discovered by chance when a grinding aid used to enhance cement grinding ended up chemically entraining air in concrete and improving frost resistance in the field, air-entraining agents have had years of success in improving resistance to freezing and thawing damage (due to both internal distress and salt scaling). However, this success has not come without some turmoil as even today concrete producers wrestle with controlling air content in concrete, and the list of factors affecting air entrainment. To fully understand the complexities of air entrainment, and more importantly, to apply this in practice, the mechanisms of air entrainment must first be understood.

Freeze-thaw action induces cyclic changes in concrete volume resulting in spalling, scaling, and cracking. Air entrainment can enhance the durability of concrete. It results in increased protection against frost action and deicing salt deterioration. Air exists in concrete in various different forms: aggregate pores, capillary voids, entrained air bubbles, entrapped air voids, and fractures. Aggregate pores are of submicroscopical

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u mnogo različitih formi: pore u agregatu, kapilarne probe, uvučeni vazdušni mehuri, zarobljeni vazduh i pukotine u unutrašnjoj strukturi. Pore u agregatu veoma su sitne i postoje u svakom agregatu. Te pore ne utiču na trajnost betona. Kapilarne pore predstavljaju prostore koji nisu ispunjeni čvrstim komponentama hidratirane cementne paste. U dosta hidratisanom cementu s niskim w/c odnosom, kapilarne pore su veličine od 10 do 50 nm; kada su u pitanju veći w/c odnosi u ranim starostima kapilarne pore mogu biti veličine od 3 do 5 µm. Mehurići uvučenog vazduha od 0.05 do 1 mm u prečniku mogu se proizvesti u betonu dodavanjem male količine aditiva aeranata. Ti sferični mehurovi se dobro raspoređuju u hidratiranoj cementnoj pasti, povećavajući otpornost na zamrzavanje i odmrzavanje. Da bi se osigurala adekvatna otpornost na zamrzavanje i odmrzavanje, faktor razmaka ne bi trebalo da prelazi vrednost od 0.2 [4]. Faktor razmaka pora definisan je kao srednja vrednost maksimalnog razmaka od hidratirane paste do ivice pore. Što je manji faktor razmaka pora, to je beton trajniji. Veći mehurovi zarobljenog vazduha, veličine od 1 do 4 mm, mogu se formirati za vreme ugradnje i zbijanja betona. Mikroprslina i prslina mogu nastati u betonu od opterećivanja betona ili od skupljanja prilikom sušenja.

Postoji više standardnih metoda za određivanje količine uvučenog vazduha u svežem i očvrslom betonu. Gravimetrijska (ASTM-C138), volumetrijska (ASTM-C173) i metoda putem pritiska (ASTM-C231) mogu se koristiti za određivanje srednje količine vazduha u svežem betonu. Ipak, sve tri metode ne mogu nam obezbediti informacije o veličini i distribuciji pora. Mikroskopske analize se mogu koristiti za merenje dimenzija specifične površine, faktora razmaka i odnosa vazduh/pasta u očvrslom betonu.

## 2 UTICAJ UVUČENOG VAZDUHA NA ČVRSTOĆU PRI PRITISKU

Prateći veoma dugu listu istraživača na ovom polju, Hughes je 1960-tih razmatrao, kao veoma važan, uticaj vazduha u betonu na čvrstoću pri pritisku [1].

U ranim pokušajima da se uključi uticaj vazduha na čvrstoću betona, istraživači nisu razlikovali vazdušne pore i pore od vode i – što je mnogo značajnije – nisu uzimali u račun redukciju pora od vode sa starošću betona koja nastaje usled procesa hidratacije. Popovic [5] jeste razmatrao taj problem i razdvojio je ove efekte uvođenjem modifikacija u istorijsku zavisnost čvrstoće i w/c odnosa:

$$f = \frac{A_0}{B_0^{w/c}} \times 10^{g \times a} \quad (1)$$

gde je **f** čvrstoća betona, **A<sub>0</sub>** je faktor u vezi sa cementom, **B<sub>0</sub>** je kompozitni faktor starosti betona i agregata i **a** je količina vazduha u betonu u %.

Podatke koje je izneo Popovic [6], ponovo je analizirao mađarski istraživač Ujhelyi i utvrdio da su koeficijenti za **A<sub>0</sub>** od 180 i **B<sub>0</sub>** od 20 potvrdili koeficijent od 0.038.

Na osnovu tih analiza, dat je teorijski izraz za smanjenje čvrstoće betona.

$$\text{smanjenjecvrstoce\%} = 100 \times (1 - 10^{(0.038 \times a)}) \quad (2)$$

dimensions and exist within particles of aggregate. These voids do not contribute to the durability of concrete. Capillary voids represent the space not filled by the solid components of the hydrated cement paste. In well-hydrated, low water/cement ratio pastes, the capillary voids may range from 10 to 50 nm; in high water/cement ratio pastes, at early ages of hydration, the capillary voids may be as large as 3 to 5 µm. Entrained air bubbles of 0.05 to 1 mm in diameter can be introduced in concrete by adding small amounts of air entraining agents. These spherical bubbles are well spaced in the hydrated cement paste to resist damage due to frost action. To ensure adequate frost protection, the spacing factor should not exceed 0.2 mm [4]. The spacing factor is defined as the average maximum distance from any point in the paste to the edge of a void. The smaller the spacing factor, the more durable the concrete is. Large entrapped air voids from 1 to 4 mm can be formed during compaction and casting. Microcracks and fractures can be induced when the concrete is subjected to loading or drying.

There are several standard methods for determination of air void content in freshly mixed and hardened concrete specimens. Gravimetric (ASTM-C138), volumetric (ASTM-C173), and pressure (ASTM-C231) methods can be used to determine the average air content of freshly mixed concrete. However, these three methods do not provide information on the air void size and spatial distributions. The microscopical determination method SRPS U.M1.056 can be used to measure dimensions, specific surface, spacing factor, and air/paste ratio of the air-void system in hardened concrete.

## 2 EFFECT OF AIR ON COMPRESSIVE STRENGTH

Following a long line of researchers, Hughes in the 1960s considered it important to include the effects of air voids when considering strength [1].

Early attempts to allow for the effects of air voids on strength did not distinguish air voids from water voids and more particularly did not take into account that the quantity of water voids reduced with age due to hydration whereas air voids were less affected. Popovics [5] has discussed this in considerable detail and has separated the effects by the following modification to the historical formula relating strength to water/cement ratio:

where **f** is strength, **A<sub>0</sub>** is a factor for the cement, **B<sub>0</sub>** is a composite factor for age at test and for aggregate, **γ** is 0.038 and **a** is the air content %.

Re-analysis of the data quoted by Popovics [6], from a Hungarian paper by Ujhelyi, yielded values of 180 for **A<sub>0</sub>**, 20 for **B<sub>0</sub>** and confirmed the value of 0.038 for **γ**.

The theoretical curves have the following equation:

Razmatrajući podatke koje je dao Klieger, Popovic je zaključio da je formula primenljiva i za uvučeni i za zarobljeni vazduh u betonu [6].

Ipak, Wright je objavio da za konstantni w/c odnos, smanjenje od 5.5% u čvrstoći za svaki % povećanja količine uvučenog vazduha do 8%, u poređenju sa 7-8% smanjenja čvrstoće za svaki % zarobljenog vazduha prema prethodnim istraživanjima.

Teychenne *et al.* je usvojio vrednost od 5.5% redukcije čvrstoće za svaki procenat vazduha za projektovanje aeriranih betona. Vrednost konstante u formuli za smanjenje čvrstoće treba da bude modifikovana od 0.038 do 0.025, da bi se dobio manji nivo smanjenja čvrstoće.

Na osnovu svega, predložena je generalizovana formula za redukciju čvrstoće.

$$\text{ smanjenjecvrstocel\%} = 100 \times (1 - 10^{(k_1 \times a_1 + k_2 \times a_2)}) \quad (3)$$

gde  $k_1$  je  $-0.038$  za zarobljen vazduh,  $a_1$  je sadržaj zarobljenog vazduha (%),  $k_2$  je  $-0.015$  do  $-0.038$  za uvučen vazduh, veća vrednost se može primeniti za veći procenat vazduha i u slučaju sumnje i  $a_2$  je sadržaj uvučenog vazduha (%).

To je dovelo do mnogo uopštenije formule za čvrstoću pri pritisku:

$$f = \frac{A_0}{B_0^{w/c}} \times 10^{(k_1 \times a_1 + k_2 \times a_2)} \quad (4)$$

Navedena formula razdvaja uticaje zarobljenog i uvučenog vazduha na beton.

### 3 NEURAL NETWORKS

Neuron je element s više ulaza i jednim izlazom. Veštačke neuronske mreže formiraju se od velikog broja neurona, povezivanjem izlaza i ulaza svih neurona. Neki od neurona u direktnoj su vezi sa okruženjem. Ulazni nivo neuronske mreže prima informacije iz okruženja, dok izlazni neuroni generišu signal za pojedine akcije. Ostali neuroni, koji nisu u direktnoj vezi sa okruženjem, zovu se skriveni i služe za unutrašnju prezentaciju informacija. Najpoznatija arhitektura neuronske mreže jeste svakako slojevita. Neuroni su organizovani u nivoe, a izlaz iz jednog neurona vodi do ulaza svih neurona u sledećem nivou. Neuroni mogu biti statički i dinamički, zavisno od procesa za koji se neuronska mreža koristi [2].

Svaki model neurona je karakterizovan s dve funkcije: a) prva daje zavisnost aktivacionog signala od ulaznih signala – takozvana funkcija interakcije ulaza; b) druga koja definiše uticaj aktivacionog signala na izlaz neurona – aktivaciona funkcija. Šema statičkog neurona prikazana je na slici 1.

Najčešće korišćena jeste linearna funkcija interakcije ulaza, koja aktivacioni signal izražava kao linearnu kombinaciju ulaznih signala prema izrazu (5); takođe, njena forma može biti nelinearna ili plinomnska, kako bi se povećala procesna moć neurona.

In the view of Popovics (1985), based on assessment of data from Klieger, the formula is valid for entrained air as well as for entrapped air.

However, Wright reported that, at constant w/c, 5.5% reduction in air was obtained for each 1% increase in entrained air content up to 8%, compared with a reduction for entrapped air commencing at 7 to 8% reduction for each 1% air.

Teychenne *et al.* adopted a value of 5.5% reduction per 1% air for the design of air entrained concrete. The value of the constant in the formula would need to be modified from  $-0.038$  to  $-0.025$  to accommodate this lower rate of strength reduction.

Thus, a more general formula is proposed for strength reduction as:

where  $k_1$  is  $-0.038$  for entrapped air,  $a_1$  is the entrapped air content (%),  $k_2$  is  $-0.015$  to  $-0.038$  for entrained air, high values may apply to high percentages of air and in case of doubt and  $a_2$  is the entrained air content (%).

Thus leads to more general formula for compressive strength:

which allows for both entrapped and entrained air.

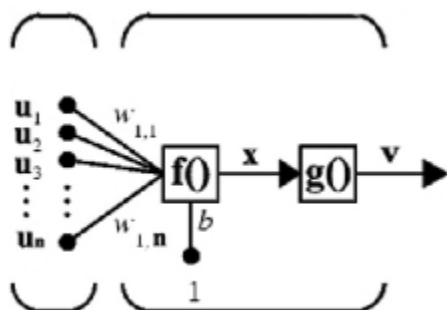
### 3 NEURAL NETWORKS

Neuron is an element with multiple inputs and one output. Artificial neural network are forming of larger number of neurons connecting the outputs and inputs with each other. A number of neurons is in connection of network with the working environment. Input layer of neurons accept information from the environment, while the output neurons generate the signals for certain actions. Other neurons that are not directly related to the environment, are called hidden and used for internal representation of information about the operating environment. The most famous architecture of neural networks is certainly layered. Neurons are organized to form layers, and the input of one neuron are lead to all of neurons from the previous layer. Neurons can be static or dynamic depending on whether the process and time-varying signals [2].

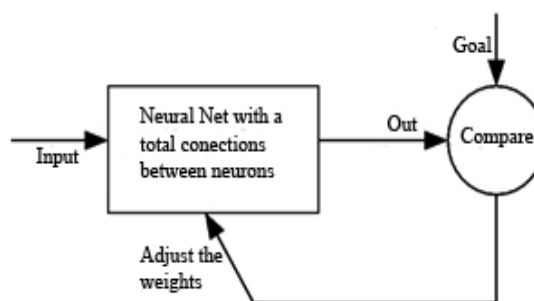
Each model of neurons are characterized by two functions: a) first gives the dependence of the activation signal from the input signal a function of interaction inputs b) other which define the influence of the activation signal to the output of neurons - activation function. Scheme of a static neuron is shown in Figure 1.

Most often used the linear function of the interaction of input with activation signal expressed simply as a linear combination of excitation signals according to expression (5), although their form may be nonlinear or polynomial in order to increase the processing power of neurons.

$$f(u) = \sum_{i=1}^n w_i u_i \quad (5)$$



Slika 1 Shema statičkog neurona  
Figure 1. Sheme of static neuron



Slika 2 Ponašanje neuronske mreže  
Figure 2. Behavior of neural networks

Pored brojnih različitih funkcija interakcije ulaza, u upotrebi su i različite aktivacione funkcije. Najjednostavnija je linearna aktivaciona funkcija u formi (6), dok je za rešavanje nelinearnih modela najbolje koristiti sigmoidalnu funkciju (7) [3].

$$g(x) = x - q \quad (6)$$

$$g(x) = \frac{1}{1 + e^{-(x-q)}} \quad (7)$$

Neuronske mreže podešavaju se tako da pojedine ulaze procesuiraju u željeni izlaz – ciljnu vrednost. Slika 2 prikazuje generalni pristup neuronskih mreža. Mreža je podešena da poredi izlaz i ciljnu vrednost dok izlazna vrednost iz neuronske mreže ne postigne željenu tačnost ciljne vrednosti. Da bi se postiglo slaganje, nekada je potrebno mnogo parova ulaz-cilj. Taj proces naziva se učenje neuronske mreže.

Model neurona u neuronskoj mreži određuje kako će se transformisati ulazne vrednosti u izlaz mreže. Ta transformacija može se opisati kao računanje.

Učenje neuronske mreže jeste modifikacija ponašanja zasnovana na iskustvu i interakciji sa okruženjem koje vodi ka različitim odgovorima na spoljašnje uticaje. Učenje neuronske mreže zavisi od arhitekture mreže, težinskih koeficijenata, funkcije interakcije ulaza i aktivacione funkcije u neuronima. Prema tome, kada je mreža uspostavljena, promene su veoma teške. Procedure učenja podeljene su u dve grupe: nadgledano i nenadgledano učenje.

Svaka procedura učenja zasnovana je na algoritmima u kojima se funkcija greške formira tako da predstavlja meru razlike između željenog i stvarnog odgovora neuronske mreže. Postoje dva pravila za formiranje funkcije greške: a) pravila zasnovana na korekciji greške; b) mehanizmi koji koriste gradijentna pravila.

#### 4 EKSPERIMENTALNI RAD

Za projektovanje betonskih mešavina korišćena je formula Skremtajeva. Na bazi te formule, usvojen je odgovarajući vodocementni odnos koji zavisi od

Besides many different functions of interaction inputs are in use and different activation functions. The simplest is a linear activation function of the form (6) while for solving nonlinear models for the best use is sigmoidal (7) [3].

Neural networks are generally set to particular input proceed to the certain output value - target. Figure 2 shows the general approach of neural networks. The network are set up to compare the output and target value until output data of neural networks do not coincides with the target value. In order to this data matched in some cases a lot of pair input-target is need. This process is called network training.

Model of neuron in the neural network architecture determine how perform the transformation of input data in the output of the network. This transformation can be described as a kind of computation.

Learning of neural network is a modification of behavior based on experience, and in the interaction with the environment that leads to different responses to external impacts. Learning of neural network depends on network architecture, weights, interactions function and the activation functions in neurons. Therefore when the network is established changes are hardly possible. Procedures for learning are divided in two groups: supervised and unsupervised learning.

Each procedure of learning is based on algorithms for learning in which the error function forming which represents a measure of the difference of desired and real response of neural network. There exist two approaches to the formation of the error function the rules based on correcting errors and mechanisms that use gradient rules.

#### 4 EXPERIMENTAL WORK

For the mix design of concrete was used the formula of Skremtajeva. Based on this formula was adopted the

zahtevane čvrstoće pri pritisku betona, klase cementa i kvaliteta primenjenog agregata. Da bi se odredile količine materijala u mešavini betona, potrebno je usvojiti u prvom koraku količinu vode, a za taj korak usvojena je u praksi široko primenjivana formula Feret (8).

$$m_v = \frac{k_0}{\sqrt[5]{D}} \quad (8)$$

U pomenutoj formuli **D** je maksimalno zrno agregata u mešavini, a **k<sub>0</sub>** – parametar koji zavisi od agregata i planirane konzistencije i u granicama je od 330 do 370 za rečni agregat i plastičnu konzistenciju.

Posle projektovanja betonskih mešavina, pristupalo se laboratorijskim probama. Sve laboratorijske probe su urađene u mešalicama s vertikalnom osovinom i planetarnim sistemom mešanja u količini od 60 do 100 l svežeg betona.

Prethodno osušen agregat, cement i voda mereni su uvek na istoj vagi. Temperatura i vlažnost bili su u skladom propisanim granicama, a sve to zahvaljujući klimatizaciji prostorije u kojoj su se izvodile probe. Beton je u kalupima zbijan s vibroglom prečnika Ø20 mm, a korišćeni su kalupi za kocke ivice 15 cm. Posle ugradnje, uzorci bi odležali 24 sata u uslovima u kojima su izrađivani i nakon toga su vađeni iz kalupa i stavljeni u vodu na temperaturu od 18 do 22°C do momenta ispitivanja.

Posle predviđenog odležavanja, uzorci su ispitivani na hidrauličnim presama kapaciteta od 1000 do 3000 kN, zavisno od klase betona koja se očekuje.

Baza podataka formirana je na osnovu prethodnih laboratorijskih ispitivanja betona u Institutu IMS u periodu od 2009. do 2011. godine. Za to vreme, rađene su prethodne laboratorijske probe sa cementima triju proizvođača s teritorije Srbije. Korišćena su tri tipa cementa – CEM II A/S, CEM II A/M(S-L), CEM II B/M(S-L) klase čvrstoće 42.5. Masa cementa po m<sup>3</sup> bila je u granicama od 250 do 500 kg. Kao agregat korišćen je rečni agregat iz Srbije.

Na svakom formularu za prethodna ispitivanja beleženi su podaci o količini materijala za probu. Takođe, prikazani su mereni parametri za vreme izrade prethodnih proba, kao što su sleganje na Abramsomovom konusu, ukupna količina vazduha u betonu, zapreminska masa svežeg betona, temeperature betona i okoline. Ukupno je razmatrano 97 prethodnih proba.

Podaci su obrađivani u dva nivoa. U prvom, baza podataka obrađivana je klasičnim metodama, primenom formule (1) s vrednostima koeficijenta 180 za A<sub>0</sub>, 20 za B<sub>0</sub> i vrednost 0.038 je zadržana za eksponencijalnu vrednost. U drugom nivou, neuronskim mrežama razmatrana je ista baza, tako što su napravljeni modeli s jednim ili sa dva skrivena sloja. Neuronske mreže napravljene su tako da ulazni i izlazni slojevi imaju linearne aktivacione funkcije, dok je za skrivene neurone korišćen za aktivacionu funkciju tangens hiperbolički (zbog jednostavnih izvoda). U izlaznom sloju je jedan neuron u svim modelima neuronske mreže, jer je izlaz iz mreže čvrstoća pri pritisku u starosti od 28 dana.

Kao kvantitativni pokazatelji za ocenu pristupa korišćeni su: a) standardna devijacija greške – standardna devijacija razlika dobijenih rezultata i

appropriate water-cement ratio, which obtained on the basis of the required compressive strength of concrete, cement class and quality of aggregates. In order to determine the quantity of materials in the mixtures is necessary to adopt the amount of water and in this case has been adopted in accordance with the Feret formula (8).

where **D** – maximum grain size of aggregate, **k<sub>0</sub>** – parameter that depends of aggregate and planned consistency in the range from 330 to 370 for river aggregate and plastic consistency.

After mix design of concrete trial laboratory mix was done. All concretes were made in a mixer with the vertical axis and the planetary mixing concrete in a quantity from 60 to 100l of fresh concrete.

Pre-dried aggregate, cement and water were measured on the same scale. Temperature and humidity are always in the same limits as ensured with air-conditioners. The concrete compacted with vibrator Ø20 mm in the metal molds 15 cm cube. After compacting the molded samples settle for 24 hours under the conditions of mixing concrete and then removed from the mold and kept in water until the moment of testing at temperature from 18 to 22°C.

After the scheduled aging samples are tested on hydraulic presses from 1000 to 3000kN depend on the class of concrete that was expected.

The database was formed based on previous laboratory tests of concrete in the IMS Institute on the period 2009-2011 years. During this period conducted a laboratory trial mix of concrete with cements from 3 different producers from the territory of Serbia. There were 3 types of cement CEM II A/S, CEM II A/M(S-L), CEM II B/M(S-L) and all cements were strength class 42.5. Mass of cement per cubic m of concrete was in range of 250 to 500 kg. As the aggregate were used in all concretes river aggregate from Serbia.

On each form of trial mix are given the presumed amount of material per cubic meter volume of concrete. Also provide the parameters that are measured during the development of laboratory trial mix tests such as the slump of concrete on Abrams cone, total amount of air, the measured density of fresh concrete, the temperature of the room and the temperature of concrete. A total of 97 previous tests was taken to the processing.

Data processing was performed in two stages. In first stage, database was considered with classical approach with formula (1) and values of 180 for A<sub>0</sub>, 20 for B<sub>0</sub> and the value of 0.038 for γ. In neural network stage, the models with one and with two hidden layers were considered and formed. The common fact for all models is that in the input and output layer, the neurons with linear activation function were used, and in the hidden layers were used the neurons with activation function of hyperbolic tangent (because of very simple derivatives). In the output layer, there was one neuron in all models, because the network output is the compressive strength at the age of 28 days.

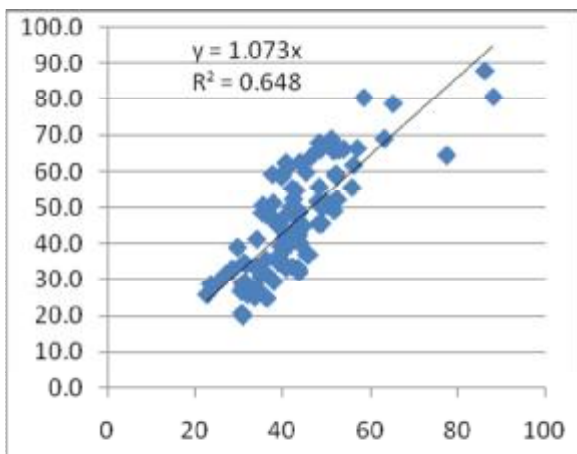
Quantitative indicators for determining which approach is better for actual use are (a) standard error deviation – standard deviation of difference between the

stvarnih rezultata čvrstoće pri pritisku; b) tačnost dobijenih rezultata pri pouzdanosti od 95.4% – koja je računata na bazi standardne devijacije greške. Ovi indikatori prikazani su u tabeli 1 za klasičan pristup i pristup koji koristi neuronske mreže. Na slikama 3 i 4 prikazan je odnos dobijenih i stvarnih rezultata čvrstoće pri pritisku. Na istim dijagramima date su najbolje linearne aproksimacije, kao i kvadrat korelacionog faktora.

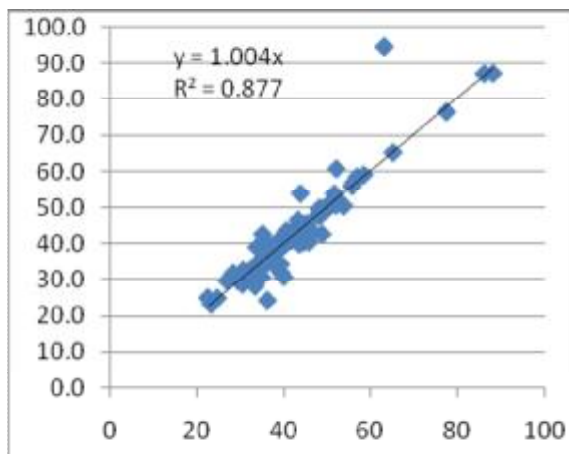
obtained results of compressive strength and real results of compressive strength ( $f_{c,28}$ ) and (b) accuracy of obtained results at reliability of 95.4% - which is calculated on the basis of standard error deviation. This indicators are presented in table 1 for classical approach and for neural network approach. In Figure 3 and 4 is provided the relationship of obtained and real results of compressive strength. On the same figures are given the best trend line functions and square correlation factor.

Table 1. Rezultati dobijeni različitim pristupima  
Table 1. Results obtained with different approach

	Standardna devijacija greške (Standard deviation of error) (N/mm <sup>2</sup> )	Tačnost pri pouzdanosti od 95.4% (Accuracy at reliability of 95.4%) (N/mm <sup>2</sup> )
Klasični pristup (Classical Approach)	8.8	17.6
Neuronske mreže (Neural Network Approach)	4.4	8.8



Slika 3. Klasični pristup  
Figure 3. Classical approach



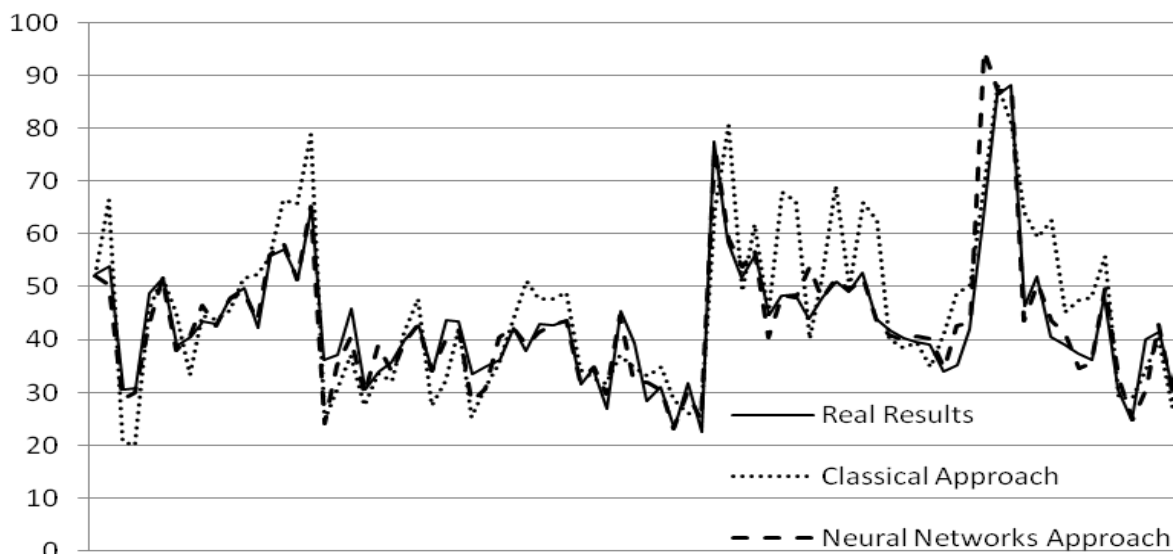
Slika 4. Pristup neuronskim mrežama  
Figure 4. Neural network approach

## 5 ANALIZA I ZAKLJUČCI

Da bi se napravila jasna slika dobijenih rezultata, formiran je dijagram na kome su paralelno prikazani rezultati dobijeni sa oba pristupa i stvarno dobijeni rezultati. Taj dijagram prikazan je na slici 5. Jasno se vidi da je pristup s neuronskim mrežama bliži stvarnim rezultatima od rezultata dobijenih klasičnim pristupom sa usvojenim koeficijentima u formuli. Jasne razlike između rezultata dobijenih klasičnim pristupom i stvarnih rezultata moguće je opravdati činjenicama da su u bazi podataka bili rezultati s tri tipa cementa i da su skoro u svim probama korišćeni super plastifikatori.

## 5 ANALYSIS AND CONCLUSIONS

To make a difference in the results obtained provide clearer set up a diagram of the results obtained with both approaches and real results for each test. This diagram is shown in Figure 5. It is clear that the neural network approach close to real output and the classical approach with adopted coefficients in many tests is very different. The cause of this deviation in the classical approach may be the inability to use summarization of different types of cements and the use of additives in concrete.



Slika 5 Paralelni prikaz svih rezultata  
Figure 5. Diagram of all results

Pristup s neuronskim mrežama može sa dobrim bazama podataka uzeti u obzir tip cemenata, kao i primenu aditiva u betonima. Takav pristup je dosta jednostavniji, ali s povećanjem uticajnih parametara, povećava se i broj neophodnih ispitivanja – potrebne su daleko veće baze podataka.

Approach with the neural networks can with a good database to take into account the type of cement and concrete additives in the application. This approach is much simpler, but with the expansion of the number of influential parameters are needed and much larger database.

## ZAHVALNOST

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## REZIME

### OCENA UTICAJA KOLIČINE VAZDUHA NA ČVRSTOĆU BETONA KLASIČNIM PRISTUPOM I NEURONSKIM MREŽAMA

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Mnogi parametri utiču na karakteristike svežeg i očvrstlog betona. Jedan od najvažnijih svakako jeste poroznost betona. Poroznost svežeg betona meri se količinom uvučenog vazduha. Uticaj uvučenog vazduha na beton i njegovu pritisnu čvrstoću istraživali su mnogi svetski istraživači. Na bazi tih istraživanja, izdvojene su dve, u praksi najviše korišćene, formule. Tehnike mekog programiranja, a posebno neuronske mreže, s formiranim bazama podataka laboratorijskih ispitivanja betona, otvaraju novi pristup u predviđanju uticaja količine uvučenog vazduha u svežem betonu na njegovu čvrstoću pri pritisku.

**Ključne reči:** neuronske mreže, uvučen vazduh, beton, čvrstoća pri pritisku.

## SUMMARY

### EVALUATION OF AIR CONTENT ON CONCRETE COMPRESSIVE STRENGTH WITH CLASSICAL APPROACH AND NEURAL NETWORKS

*Dragan BOJOVIC  
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Many parameters influence on the characteristics of fresh and hardened concrete. One of the most important characteristic of concrete is its porosity. Measure the porosity of fresh concrete is measured by the amount of entrained air. The effect of entrained air in concrete on compressive strength investigated by many authors. On the bases these works we have two formulas applicable in practice. Soft programming techniques especially neural networks and the formation of databases related to the testing in laboratories for concrete opened up new approaches in predicting the impact of the quantity of entrained air in concrete on compressive strength.

**Keywords:** Neural networks, entrapped air, concrete, compressive strength