

# ANALIZA VEZANE ENERGIJE I EMISIJE CO<sub>2</sub> PRI IZVOĐENJU MOSTOVSKJE KONSTRUKCIJE SA STANOVIŠTA ODRŽIVOSTI

## ANALYSIS OF THE EMBODIED ENERGY AND THE CO<sub>2</sub> EMISSION IN CONSTRUCTION PROCESS OF A BRIDGE STRUCTURE FROM THE ASPECT OF SUSTAINABILITY

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### 1 UVOD

U radu se razmatra uticaj različitih konstruktivnih rešenja mostovskih konstrukcija na potrebnu primarnu energiju za proizvodnju materijala i elemenata konstrukcije i pri izvođenju konstrukcije. Takođe, analizira se uticaj ovih procesa na životnu sredinu određivanjem odgovarajuće emisije CO<sub>2</sub>.

*Kao ključni strukturni element u saobraćajnoj mreži, mostovska infrastruktura ne koristi samo brojne prirodne resurse i energiju, već ima i dug životni vek, odnosno upotrebnii ciklus, što rezultuje i velikom zabrinutošću povodom uticaja konstrukcije na životnu sredinu. Međutim, aktuelni proces donošenja odluka i dalje se uglavnom bazira na tehničkom, sigurnosnom i ekonomskom aspektu, gde procena uticaja izgradnje i eksploatacije konstrukcije na životnu sredinu još nije integrisana u čitav proces. Iz perspektive zaštite životne sredine, odluke donesene danas mogu imati dugoročan efekat tokom kompletnog životnog veka mosta [1].*

U radu su prikazani rezultati proračuna vezane energije i emisije CO<sub>2</sub> za tri rešenja mosta na istoj lokaciji, različitih konstruktivnih sistema. Na osnovu lokacije

### 1 INTRODUCTION

This paper considers the influence of different structural solutions of bridge constructions on the amount of primary energy as part of the production process of construction materials and structural elements, as well as part of construction building process. It also analyzes the impact of these processes on the environment in the form of CO<sub>2</sub> emission.

*“As the fundamental structures in the transportation network, the bridge infrastructure not only consumes numerous natural resources and energy, but also have long-term life span, which results into significant concerns of the environmental impact. However, the current decision making process is still mainly focused on the technique, safety and economic perspectives, that the environmental assessment is not yet integrated. From the environmental perspective, the decisions made today may have a long-term effect for the whole life cycle of bridge” [1].*

The calculation results of the amount of embodied energy and CO<sub>2</sub> emission for three different structural solutions of bridge construction are presented in the

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mosta, karakteristika terena i projektnih zahteva, odabrana su tri sledeća konstruktivna rešenja glavnog nosećeg sistema:

- 1) **Niz prostih greda;**
- 2) **Kontinualna greda;**
- 3) **Ramovski sistem.**

Kolings (Collings [2006]) izvršio je poređenje formi mostovskih konstrukcija iz ugla uticaja na životnu sredinu, na osnovu kojih su dobijeni neki pokazatelji o vezanoj energiji i emisiji CO<sub>2</sub> kod mostova, pod pretpostavkom da su ovo racionalni pokazatelji uticaja konstrukcije na životnu sredinu. Glavni rezultati iz ovog poređenja navode nas na sledeće zaključke:

– Teret uticaja na životnu sredinu tokom izgradnje mosta je približno proporcionalan ceni konstrukcije, što je uglavnom jednako količini materijala utrošenog za izgradnju mostovske konstrukcije. Što je veći raspon konstrukcije, potrebno je utrošiti i više materijala, i na taj način se povećava teret uticaja na životnu sredinu. Upotreba materijala s manjom količinom vezane energije i ugljen-dioksida veoma je korisna. U poređenju s većinom mostovskih konstruktivnih tipova, betonski mostovi imaju manju količinu vezane energije i emisije CO<sub>2</sub>. Iako betonski mostovi sadrže cement, koji ima visoku količinu vezane energije, to se može ublažiti zamenom dela cementa suplementima.

– U toku eksploatacije konstrukcije, postoji konstantan uticaj na životnu sredinu tokom održavanja konstrukcije. Ovaj efekat povećava se kada se u obzir uzme i preusmeravanje saobraćaja.

– Za mostove srednjih raspona, količina emisije CO<sub>2</sub> tokom životnog veka konstrukcije od popravki i održavanja može biti slična onim u fazi izgradnje.

Dobijeni rezultati ukazuju na to da bi održive mostovske konstrukcije trebalo da imaju za cilj da očuvaju prirodne resurse i minimiziraju količinu otpada, odnosno štetnog uticaja (potreban je efikasan, minimalistički dizajn, koji izbegava ekstravagantne arhitektonske poduhvate), da svedu na minimum „vezanu” energiju u konstrukciji (odgovarajućim odabirom materijala i izvora materijala za funkcionalne potrebe mosta) i da ostvare dug period eksploatacije, s minimalnim ulaganjima u održavanje konstrukcije (dug životni vek i upotreba kvalitetnih, izdržljivih materijala)[2].

Radom je obuhvaćena analiza uslovljenosti energetskog utroška i emisije CO<sub>2</sub> projektnim rešenjima i načinima izvođenja konstrukcije, za tri prethodno napregnuta armiranobetonska drumska mosta.

Dobijeni rezultati treba da pokažu mogućnost da se usvajanjem određenog rešenja konstrukcije može direktno uticati na količinu utrošenog materijala i vezane energije konstrukcije, pa samim tim – i na emisiju CO<sub>2</sub>.

## 2 OPIS PROJEKTNIH REŠENJA

Profil terena korišćen za projektovanje konstrukcije i načina izvođenja svakog od tri mosta predstavljen je na *Slici 1*. Potrebno je premostiti rečno korito, saobraćajnicu i obostrani pad terena, sa zadatom kotom nivelete na visini od 14,00 m. Projektni maksimalni nivo vode iznosi 2,90 m. Takođe, predviđena je i saobraćajnica s profilom širine 10,00 i visine 5,00 m. Lokacija je u okolini

paper. The constructions are located on the same site. Based on the location, terrain characteristics and project requirements, the following three design solutions have been chosen for the main support system:

- 1) **Series of simple beams;**
- 2) **Continuous beam;**
- 3) **Frame.**

“Collings (2006) has performed an environmental comparison of bridge forms that provides some indication of embodied energy and CO<sub>2</sub> emissions in bridges, assuming these are a reasonable measure of the environmental burden of the structure. The major findings from that comparison suggest:

– The environmental burden during the construction of a bridge is approximately proportional to its cost, which in turn generally equates to the volume of materials consumed by the bridge. Larger spans use more material and have a higher burden. The use of materials with lower embodied energy and CO<sub>2</sub> are beneficial. For most bridge forms the concrete bridge has the lower embodied energy and CO<sub>2</sub> emission values. Whilst concrete bridges use cement that has a high embodied energy, this can be mitigated by the use of supplementary cementitious materials as partial cement replacement.

– There is an ongoing environmental burden during the maintenance of paintwork, bearings, joints etc., and a particular spike in that burden when resurfacing is undertaken. This is increased when traffic diversions are undertaken for.

– The CO<sub>2</sub> emissions during the life of the bridge from repair and maintenance can be similar to those of the construction phase, for bridges of moderate spans.

These findings suggest sustainable bridge construction should aim to conserve natural resources and minimize waste (be an efficient, minimalist design, avoiding extravagant architectural statements), minimize the embodied energy in the structure (appropriate selection of materials and material sources for the functional demands of the bridge), and have a long life with minimal maintenance input (long service life and durable materials)” [2].

The study includes the analysis of conditionality of embodied energy and CO<sub>2</sub> emission with design solutions and construction methods of three prestressed concrete road bridges.

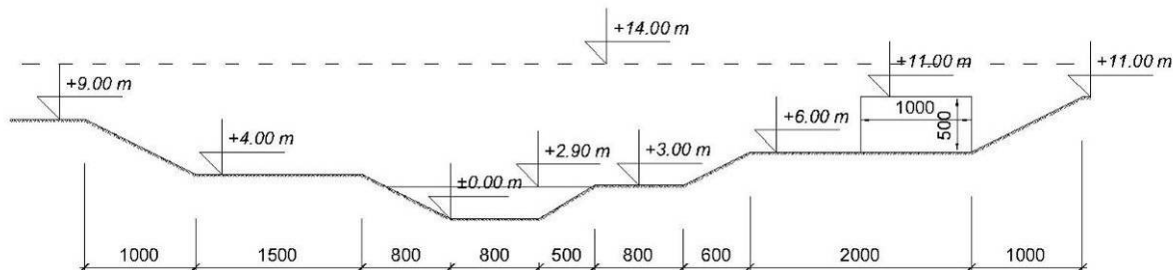
The obtained results show that, with the selection of a specific structural design, the quantity of used construction material, energy and CO<sub>2</sub> emission can be directly affected.

## 2 DESCRIPTION OF THE DESIGN SOLUTIONS

The terrain profile, on which the three bridge constructions should be located, is presented in *Figure 1*. The project demands bridging the river bed, road and double-sided slope of the terrain, with a given bridge grade at a height of 14.00 m. The projected water level maximum is 2.90 m, and the road profile with a width of

Beograda, a predviđeni vek trajanja konstrukcije 100 godina.

10.00 m and a height of 5.00 m. The location is in the vicinity of Belgrade, and the projected life cycle of the construction is 100 years.



Slika 1. Profil terena na lokaciji mosta  
Figure 1. Terrain profile on the location of the bridge

#### Parametri zajednički za sva tri rešenja konstrukcije:

- Projekti su urađeni u skladu sa srpskim propisima i podacima dobijenim od Instituta IMS u Beogradu, [3], [4];
- Tip saobraćaja – drumski; II kategorija puta; dve trake širine po 3,50 m, dve pešačke staze širine 1,5 m;
- Objekti se izvode na tlu nosivosti –  $\sigma_{Tla} = 300 \text{ kN/m}^2$ ;
- Konstrukcije su projektovane od marke betona MB40, sa upotrebom rebraste armature RA400/500;
- Kablovi za prethodno naprezanje su od užadi  $\varnothing 15.2$ , zatezne čvrstoće  $f_{pk} = 1670 \text{ N/mm}^2$  i modula elastičnosti  $E = 195 \text{ kN/mm}^2$
- Kolovoz je odvojen od pešačke staze betonskim ivičnjacima, dok se na krajevima pešačkih staza nalazi zaštitna ograda visine 1,40 m.

#### Specifičnosti pojedinačnih rešenja konstrukcije:

##### 1) Niz prostih greda

Glavni nosač je prethodno napregnuta armirano-betonska konstrukcija, koja se sastoji od niza prostih greda jednakih raspona 21,2 m, s razmakom stubova od 22,0 m i ukupnom dužinom od 88,0 m (Slika 2).

Glavne elemente konstrukcije čini pet armirano-betonskih stubova sa svojim temeljima, prethodno napregnuti montažni glavni nosači, poprečni nosači, kolovozna ploča i montažni delovi pešačkih staza (Slika 3). Glavni nosači i delovi pešačkih staza su montažni, dok se ostali elementi liju na licu mesta.

#### Parameters common for all three structure solutions:

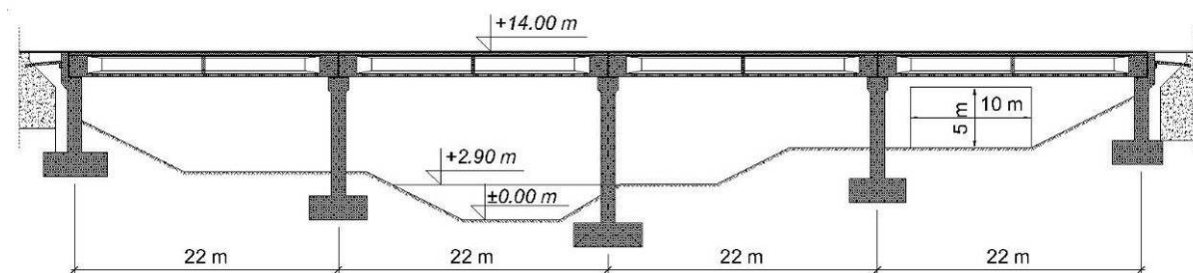
- The projects were developed in accordance with Serbian regulations and the data obtained from the IMS Institute in Belgrade, [3], [4];
- Traffic type – road traffic; II category; 2 lanes with 3.50 m width, 2 pedestrian paths with 1.5 m width;
- The objects are constructed on a soil with bearing capacity of  $\sigma_{soil} = 300 \text{ kN / m}^2$
- The structures are constructed with the MB40 type of concrete, and with ribbed steel reinforcement bars type RA400/500;
- Prestressing cables are composed from  $\varnothing 15.2$  type strands, with tensile strength  $f_{pk} = 1670 \text{ N/mm}^2$  and elasticity modulus  $E = 195 \text{ kN/mm}^2$
- Concrete curbs separate the road- and the pedestrian walkways; a protective fence with a height of 1.40 m is set at the end of the footpaths;

#### The specifics of the individual structural design solutions:

##### 1) Series of simple beams

The main girder is a prestressed reinforced concrete structure, which consists of a series of simple beams of equal range of 21.2 m, with distance between the pillars of 22.0 m and an overall length of 88.0 m, Figure 2.

The main elements of the construction consist of five reinforced concrete pillars and their foundations, prestressed precast main girders, cross beams, road deck and prefabricated parts of pedestrian walkways, Figure 3.

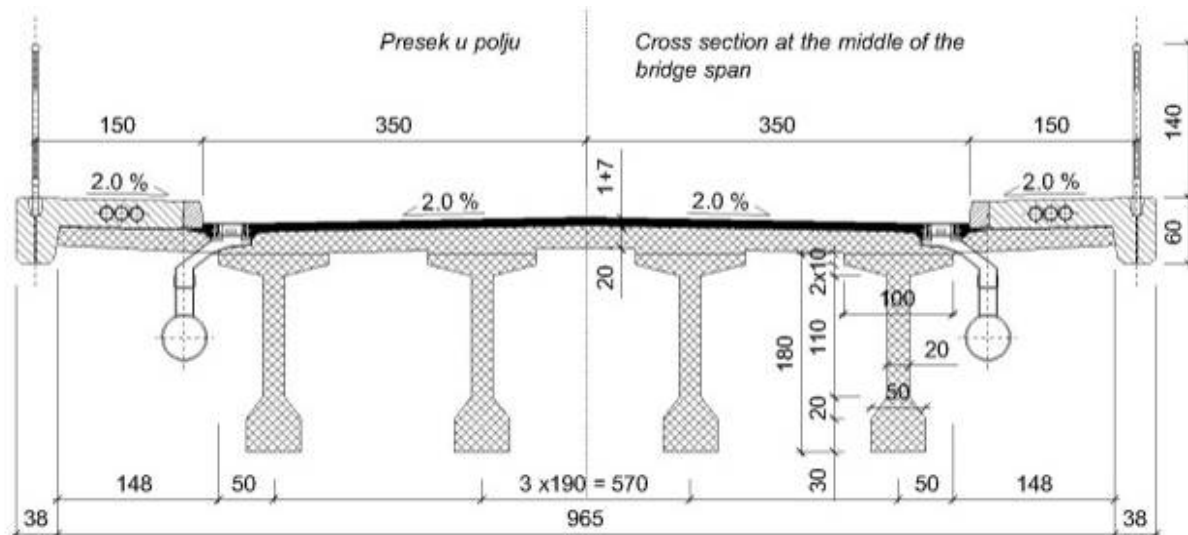


Slika 2. Poprečni presek mostovske konstrukcije – glavni nosač je niz prostih greda, (1)  
Figure 2. Cross section of the bridge - main deck as a series of simple beams, (1)

Glavni nosač mosta u jednom rasponu čine četiri prethodno napregnuta montažna betonska nosača sistema proste grede, „I” poprečnog preseka i konstantne visine (Slika 3). Nosači su spregnuti kolovoznom pločom i poprečnim nosačima na krajevima i u sredini raspona.

The main girders and walkway parts are prefabricated, while the other elements are constructed in site.

The main bridge girder consists of 4 prestressed concrete girders in each span that are simple beam system girders, with "I" cross-section and constant height, Figure 3. The girders are joined with road deck and cross girders at the ends and in the middle of the spans.



Slika 3. Poprečni presek konstrukcije (niz prostih greda, [1])  
Figure 3. Cross section of the construction (series of simple beams, [1])

## 2) Kontinualni nosač

Glavni nosač je prethodno napregnuta kontinualna greda, s rasponima 24,0 + 40,0 + 24,0 metara i ukupnom dužinom od, ponovo, 88,0 m (Slika 4).

Glavne elemente konstrukcije čine četiri armiranobetonska stuba sa svojim temeljima i prethodno napregnuta greda sandučastog poprečnog preseka konstantne visine, sa dijafragmama nad stubovima i u rasponima (Slika 4). Konstrukcija se lije na licu mesta, s montažnim delovima pešačkih staza.

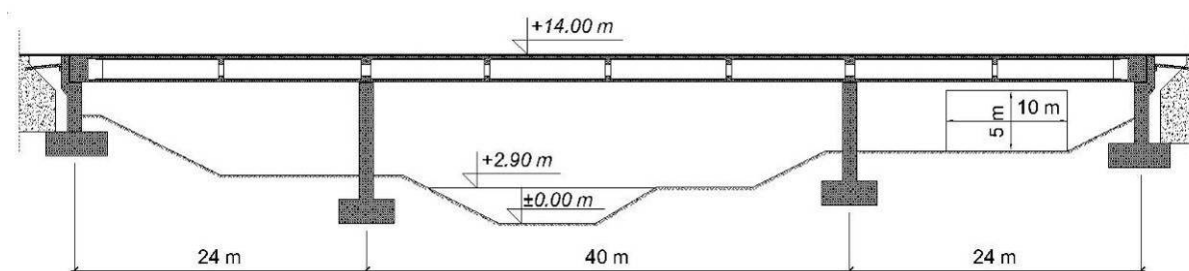
Glavni nosač je prethodno napregnut sa dvanaest kablova koji se pružaju celom dužinom nosača (Slika 10). Visina glavnog nosača je konstantna i iznosi 2,20 m.

## 2) Continuous beam

The main girder is a prestressed continuous beam with 24.0 + 40.0 + 24.0 m spans and a total length of, again, 88.0 m, Figure 4.

The main construction elements consist of 4 reinforced concrete pillars with their foundations and prestressed beam with box cross-section of constant height, and diaphragms over the pillars and at the middle of the spans, Figure 4. The construction is cast in situ, with mounting parts of walkways.

The main girder is prestressed with 12 cables which stretch throughout the entire girder, Figure 10. The height of the main girder is constant and it values 2.20 m.



Slika 4. Poprečni presek mostovske konstrukcije – glavni nosač je kontinualna greda (2)  
Figure 4. Cross section of the bridge - main deck as a continuous beam, (2)

### 3) Ramovski sistem

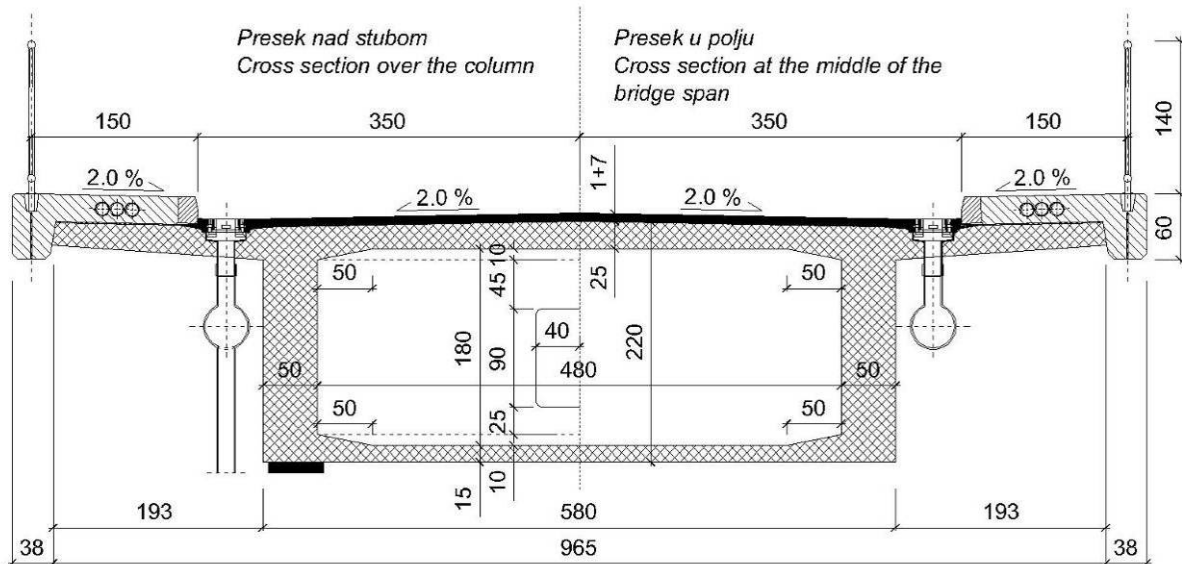
Glavni nosač je prethodno napregnuta greda kruto povezana sa srednjim stubovima, s rasponima 24,0+40,0 + 24,0 metara i ukupnom dužinom od 88,0 m (Slika 5).

Glavne elemente konstrukcije čine četiri armiranobetonoska stuba sa svojim temeljima i prethodno napregnuta greda sandučastog poprečnog preseka promenljive visine, sa dijafragmama nad stubovima i u rasponima (Slika 5). Konstrukcija se lije na licu mesta, s montažnim delovima pešačkih staza.

### 3) Frame

The main girder is a prestressed beam, rigidly connected with the middle pillars, with 24.0 + 40.0 + 24.0 m spans and a total length of 88.0 m, Figure 5.

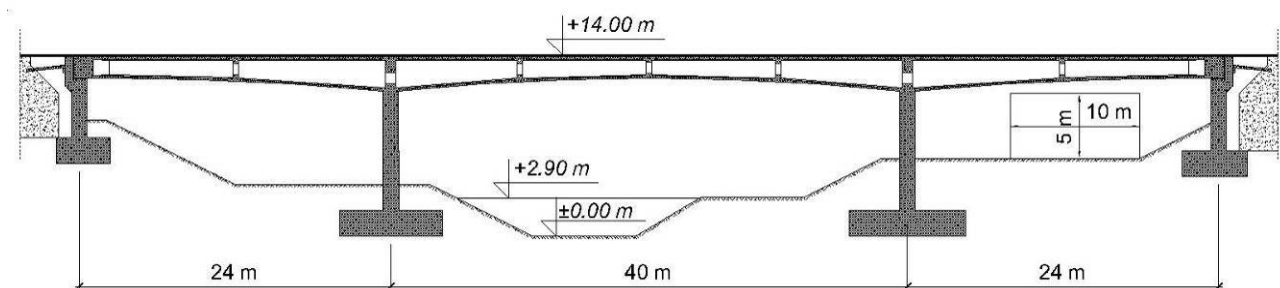
The main construction elements consist of 4 reinforced concrete pillars with their foundations and prestressed beam with box cross-section of varying height, and with diaphragms over the pillars and at the middle of the spans, Figure 5. The construction is cast in situ, with mounting parts of walkways.



Slika 5. Poprečni presek konstrukcije (kontinualna greda, [2])  
Figure 5. Cross section of the construction (continuous beam, [2])

Greda je prethodno napregnuta s dve grupe kablova. Osam kablova pruža se celom dužinom grede, dok su iznad središnjih stubova postavljena još po četiri kraća kabla (Slika 11).

The main girder is prestressed with two groups of cables. Eight cables are stretching throughout the whole length of the girder, and a couple of four shorter cables are placed above the central pillars, Figure 11.



Slika 6. Poprečni presek mostovske konstrukcije - konstrukcija je ramovskog sistema (3)  
Figure 6. Cross section of the bridge - main deck as a frame, (3)

Visina grede je promenljiva po paraboličnom zakonu i kreće se od 1,70 m u sredini srednjeg raspona i nad osloncima ivičnih stubova, do 2,70 m nad srednjim stubovima.

The height of the main girder varies according to parabolic law, ranging from 1.70 m in the middle of mid-span and over the edge abutments, up to 2.70 m above the central piers.



6" za proračun uticaja u elementima konstrukcija. Opterećenja za čije dejstvo je izvršena analiza:

- stalno opterećenje;
- saobraćajno opterećenje;
- seizmičko opterećenje;
- opterećenje vetrom;
- temperaturni uticaji.

Nakon proračuna sve tri konstrukcije, urađen je proračun količina materijala koji se ugrađuju u elemente konstrukcija.

*Optimalni izbor građevinskih mašina ima veliki značaj za uspeh investicionih projekata u građevinarstvu. Izabrane mašine moraju zadovoljavati sva tehnološka ograničenja na projektu. Cilj izbora građevinskih mašina jeste pronaći kombinaciju koja, uz sve zadate uslove ograničenja, ima optimalne ekonomske parametre [5].*

Mehanizacija se bira na osnovu predviđenog načina izvođenja svake od konstrukcija i u skladu s postizanjem optimalnih rezultata. Radovi na svakoj konstrukciji podeljeni su po pozicijama, u zavisnosti od operacije koja se izvodi:

- prethodni i pripremni radovi;
- zemljani radovi;
- betonski radovi;
- armirački radovi;
- prethodno naprezanje;
- završni radovi.

Na osnovu podataka dobijenih iz brošura proizvođača svake od mašina (tip motora, snaga mašine) i prema izračunatom broju radnih sati, pomoću pravilnika *Construction Equipment Ownership and Operating Expense Schedule* [6], izračunati su energetske troškovi svake od mašina za svaku od projektovanih konstrukcija.

made according to the principles of the First order theory (*linear theory of elasticity*) with the use of software package "Tower 6" for the calculation of load influences on the construction. Analyzed load cases are:

- permanent load,
- traffic load,
- seismic load,
- wind load,
- temperature influences.

After the needed structural calculations for three bridges, the amount of the required construction material was calculated.

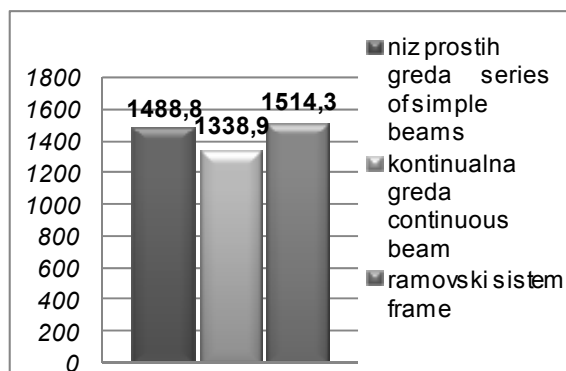
*"The optimal choice of the construction machinery has a great importance for the success of investment projects in the construction industry. Selected machines must comply with all the technological constraints on the project. The objective of construction machinery selection is to find a combination that, with all the given limiting conditions, has optimal economic parameters" [5].*

The selection of machinery is based on predicted method of construction of the each of structures, in accordance with achieving the optimal results. The works on each structure are divided per positions, depending on the type of operation:

- preliminary and preparatory works,
- terrain works,
- concrete works,
- steel reinforcement work,
- pre-stressing,
- finishing works.

Based on the data obtained from the manufacturer's brochure for each machine (engine type, engine power) and calculated number of working hours, the energy consumption of each machine during the work on each construction is calculated, according to the *"Construction Equipment Ownership and Operating Expense Schedule"* [6].

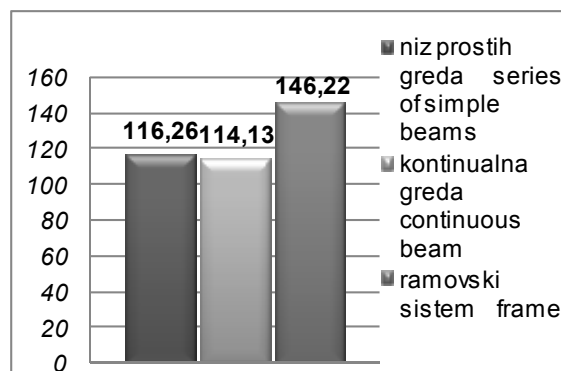
#### • Utrošak betona i armature



Grafik 1. Utrošak betona u zavisnosti od tipa konstrukcije

Chart 1. Quantity of concrete required, based on structure type

#### • Concrete and rebar requirement



Grafik 2. Utrošak armature u zavisnosti od tipa konstrukcije

Chart 2. Quantity of steel rebar required, based on structure type

Potrebne količine betona za svaku od tri konstrukcije slične su i razlikuju se za nekoliko procenata. Utrošak armature za prvu (1) i drugu (2) konstrukciju je sličan, dok je kod treće (3) dosta veći, što je posledica naprezanja usled temperaturnih uticaja.

The required amounts of concrete, for each of the three constructions, are very similar and differ by a few percent. Required amount of reinforcement bars for the first (1) and second (2) structure is similar, but a lot higher for the third (3), as a result of stress due to temperature effects.

• **Utrošak kablova za prethodno naprezanje**

• **Prestressing cables requirement**

Pregled kablova za prethodno naprezanje:

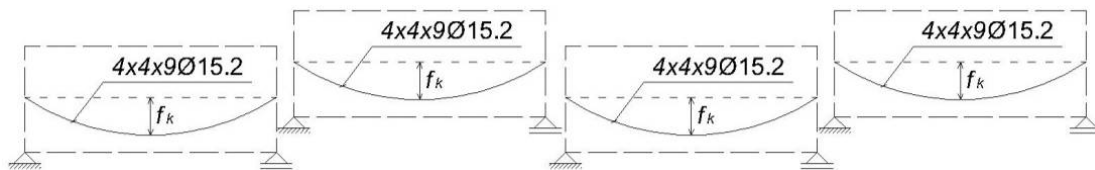
Overview of used prestressing cables:

Niz prostih greda:

Series of simple beams:

- Tip kablova: 9Ø15.2
- Broj kablova: 4 x 4 x 4 = 64
- Tip kotvi: S11/15
- Broj kotvi: 128

- Cables type: 9Ø15.2
- Number of cables: 4 x 4 x 4 = 64
- Anchors type: S11/15
- Number of anchors: 128



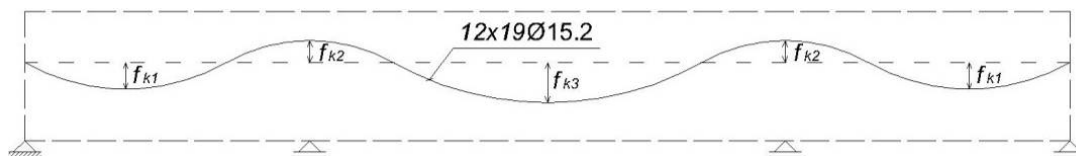
Slika 9. Trasa rezultatnih kablova, (1)  
Figure 9. Prestressing cables resultant route, (1)

Kontinualni nosač:

Continuous beam:

- Tip kablova: 19Ø15.2
- Broj kablova: 12
- Tip kotvi: S19/15
- Broj kotvi: 24

- Cables type: 19Ø15.2
- Number of cables: 12
- Anchors type: S19/15
- Number of anchors: 24



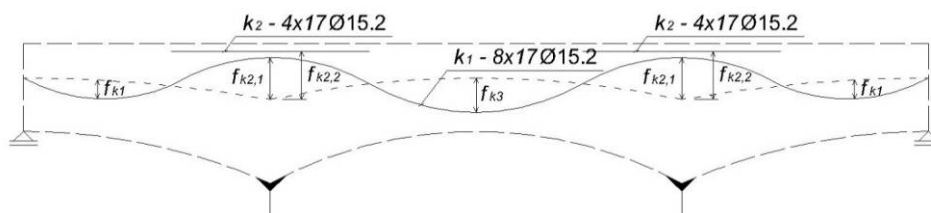
Slika 10. Trasa rezultatnih kablova, (2)  
Figure 10. Prestressing cables resultant route, (2)

Ramovski sistem:

Frame:

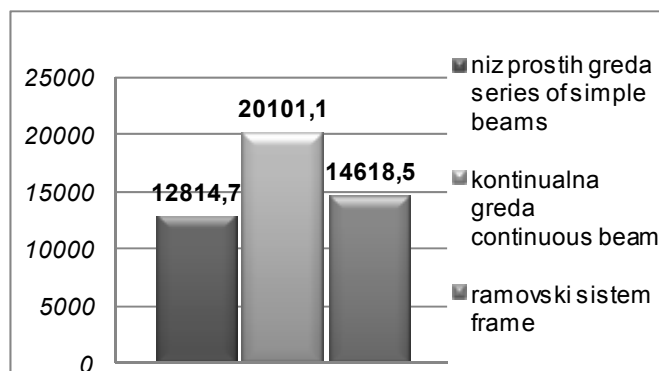
- Tip kablova: 17Ø15.2
- Broj kablova: 8 + 2 x 4 = 20
- Tip kotvi: S19/15
- Broj kotvi: 16 + 2 x 8 = 32

- Cables type: 17Ø15.2
- Number of cables: 8 + 2 x 4 = 20
- Anchors type: S19/15
- Number of anchors: 16 + 2 x 8 = 32



Slika 11. Trasa rezultatnih kablova, (3)  
Figure 11. Prestressing cables resultant route, (3)





Grafik 3. Ukupna dužina užadi za prethodno naprežanje  
Chart 3. Total length of prestressing strands

Najveća ukupna dužina užadi u kablovima glavnog nosača je u drugoj konstrukciji (2), a zatim slede treća (3) i prva (1) – Grafik 3.

The maximum total length of the strands of the prestressing cables of the main girder is in the second structure (2), followed by the third (3) and then the first (1), Chart 3.

• **Utrošak kotvi i ležišta**

• **Requirement of prestressing anchors and bridge bearings**

Tabela 1. Utrošak kotvi i ležišta u zavisnosti od tipa konstrukcije  
Table 1. Number and type of anchors and bearings depending on the type of construction

[ komada ] [ number of items ]	Niz prostih greda Series of simple beams	Kontinualni nosač Continuous beam	Ramovski sistem Frame
Kotve Prestressing anchors	128	24	32
Ležišta Bearings	32	8	4

U skladu sa usvojenim rešenjima triju konstrukcija, razlikuju se broj i tip potrebnih kotvi, kao i ležišta za glavne nosače (Tabela 1).

In accordance with adopted construction solutions for each structure, the quantity and type of anchors, as well as bearings for the main girders differ, Table 1.

**4 ODABIR MEHANIZACIJE, PRORAČUN UČINAKA I RADNOG VREMENA MAŠINA, PRORAČUN UTROŠKA ENERGIJE**

**4 SELECTION OF THE MACHINERY, CALCULATION OF THE EFFECTIVENESS, WORK TIME OF THE MACHINERY AND EMBODIED ENERGY CALCULATION**

• **Tip, model i operacija svake od mašina, koje učestvuju u izgradnji:**

• **Type, model, and the operation of each machine that participates in the construction:**

- dozer **CAT D6N** – skidanje humusa;
- utovarivač **CAT 953D** – utovar zemlje;
- vibro ploča **Wacker Neuson DPU4545He** – sabijanje tla;
- bager **CAT 329D L** –
- iskop, utovar i zatrpavanje;
- kiper **MERCEDES 2628** – transport;
- kamion **MAN TGS 41.480 8x4 BB** – transport;
- fabrika betona **LIEBHERR Mobilmix 2.25** – spravljanje betonske smese;
- auto mikser **LIEBHERR HTM 804** – transport betona;
- pumpa za beton **LIEBHERR 28 Z4 XT THP 125** – izlivanje betona;
- auto dizalica **LIEBHERR LTM 1040-2.1** – montaža glavnih nosača;

- dozer **CAT D6N** – removal of topsoil;
- loader **CAT 953D** – loading of soil;
- vibratory plate **Wacker Neuson DPU4545He** – soil compaction;
- hydraulic excavator **CAT 329D L** – excavation, loading and backfilling;
- dump truck **MERCEDES 2628** – transport;
- truck **MAN TGS 41.480 8x4 BB** – transport;
- mobile mixing plant **LIEBHERR Mobilmix 2.25** – preparation of concrete mixture;
- truck mixer **LIEBHERR HTM 804** – concrete transport;
- truck-mounted concrete pump **LIEBHERR 28 Z4 XT THP 125** – outpouring of concrete;
- mobile crane **LIEBHERR LTM 1040-2.1** –

- pervibrator **ENAR AX 48** – ugradnja betona;
- auto dizalica **MAEDA MC174 CRM** – držanje prese za prednaprezanje u zahtevanom položaju;
- presa i pumpa za prethodno naprezanje
  - **S - 180/PE - 180 S** – utezanje kablova;
  - presa i pumpa za prethodno naprezanje
    - **S - 310/PE - 300 S** – utezanje kablova;
- asfaltna baza **LINTEC CSD 2500** – spravljanje asfalta;
- finišer **CAT AP500E** – razastiranje asfalta;
- teški valjak **BOMAG BW 203 AD-4** – zbijanje asfalta;
- srednje teški valjak **BOMAG BW 161 AD-4** – zatvaranje gornje površine asfalta i
  - laki valjak **BOMAG BW 151 AD-5** – peglanje gornje površine asfalta.

Za sva tri slučaja – (1), (2), (3) – usvojena su ista rastojanja od gradilišta do objekata za dopremanje potrebnog materijala, na osnovu čega su računati učinci mašina, radno vreme i utrošak energije.

Proračun radnog vremena izveden je iz potrebnih količina materijala za izgradnju svake konstrukcije, izabranih mašina i njihovih učinaka. Za proračun utroška energenata korišćeni su američki standardi – *Construction Equipment Ownership and Operating Expense Schedule* [6].

#### • Proračun vezane energije:

Vezana energija predstavlja ukupnu količinu energije, utrošenu u nekom proizvodnom procesu, odnosno ukupnu količinu energije ugrađene u finalni proizvod.

Ono što se može zaključiti iz proračuna jeste da se razlike u potrošnji energije koju koristi mehanizacija, pre svega, primećuju kod kamiona i kiperu, kao i automiksera, odnosno transportnih mašina, čija je potrošnja energije direktno uslovljena tipom motora, rastojanjem gradilišta od objekata odakle se doprema materijal, kao i količinom materijala koji se prevozi. Kako su parametri koji se odnose na karakteristike motora mašina, kao i udaljenost gradilišta od objekata iz kojih se prevozi materijal isti za sva tri slučaja, razlika u potrošnji energije direktno je uslovljena količinom transportovanog materijala. Pretpostavljene transportne dužine pojedinih stavki date su u *Tabeli 2*.

Potrošnja primarne energije po proizvedenoj toni armature u elekrolučnoj peći prikazana je na *Grafiku 4*. Ovaj podatak preuzet je iz publikacije *CO2 emissions of the Swedish steel industry*. [7]

Vrednosti energije utrošene pri proizvodnji betona i asfalta preuzete su iz dva izveštaja kanadskog Instituta Atina (*Athena Sustainable Materials Institute*). Preuzeti su rezultati energetskog utroška za proizvodnju betona čije karakteristike najviše odgovaraju karakteristikama betona marke MB 40 po SRPS-u, [8], *Grafik 4*. Za asfalt je korišćena vrednost utroška primarne energije za mešavinu bez udela recikliranog materijala, [9] – *Grafik 4*.

- mounting of main girders;
  - concrete vibrator **ENAR AX 48** – compaction of concrete;
  - mini crane **MAEDA MC174 CRM** – holding the prestressing presses in the required position;
    - the press and prestressing pump **S - 180/PE - 180S** – prestressing of cables;
    - the press and prestressing pump **S - 310/PE - 300S** – prestressing of cables;
  - asphalt mixing plant **LINTEC CSD 2500** – asphalt mixing;
  - paver **CAT AP500E** – spreading of the asphalt;
  - heavy roller **BOMAG BW 203 AD-4** – compaction of asphalt;
  - medium roller **BOMAG BW 161 AD-4** – closing of the top surface of asphalt and
    - light roller **BOMAG BW 151 AD-5** – ironing of the top surface of asphalt.

In all three cases (1), (2), (3), the same distance from the construction site to the materials supplying facilities have been adopted. On that basis – the effectiveness of the machines, their operating time and the energy consumption were calculated.

The calculation of the working time of the machinery has been derived from the required quantities of construction materials for each construction, selected machinery characteristics and their effectiveness. For the calculation of consumed energy American standards "*Construction Equipment Ownership and Operating Expense Schedule*" [6], were used.

#### • Calculation of the embodied energy:

Embodied energy represents a total amount of energy consumed in a production process, i.e. a total amount of energy embedded in a final product.

According to the calculations it can be concluded that the differences in energy consumption used by the machinery, are primarily noticed at trucks and dump trucks, and mobile-mixer, i.e. transport machinery. Their energy consumption is directly conditioned by the type of their engines, the distance between the construction site and materials supplying facilities, and the quantity of the materials being transported. Since the parameters related to the machinery engine characteristics, as well as the distance between construction site and the supplying objects are the same in all three cases, the difference in energy consumption is directly conditioned by the amount of transported material. Presumed transport lengths of particular processes are provided in *Table 2*

Consumption of primary energy per tone produced rebar in the electric arc furnace is shown in *Chart 4*. This data was taken from the publication "*CO<sub>2</sub> emissions of the Swedish steel industry*." [7]

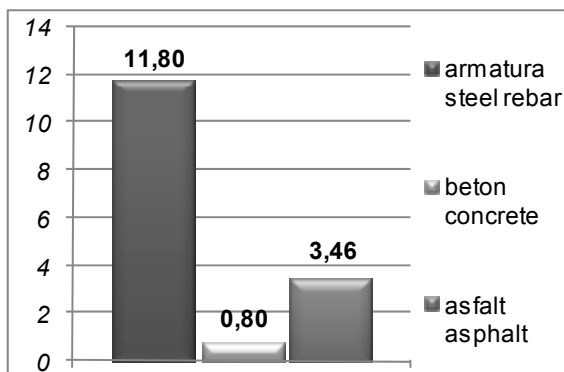
The values of the energy consumed for production of concrete and asphalt are taken from the two reports from the Canadian Athena Institute of (*Athena Sustainable Materials Institute*). Those values represent the energy, consumed in the production process of concrete whose characteristics correspond the most to the characteristics of concrete, MB 40 according to SRPS, [8] *Chart 4*. Also, a value of primary energy consumed for the production of asphalt mix without the share of recycled material was used, [9], *Chart 4*.

Tabela 2. Rastojanje između gradilišta i objekata za snabdevanje građevinskim materijalima i elementima konstrukcije  
 Table 2. The distance between construction site and objects for supplying building materials and construction elements

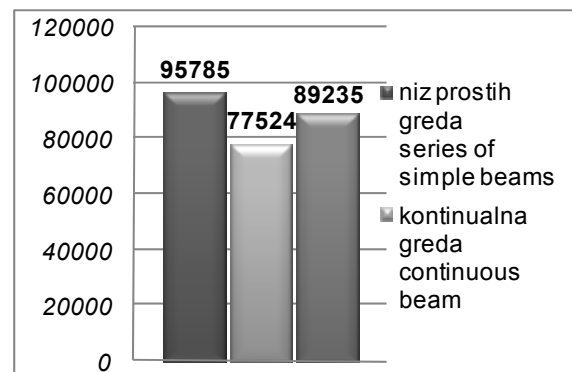
Lokacija objekta Lokation of object	Udaljenost od gradilišta Distance from the site [km]
Manevrisanje na gradilištu On site maneuvering	≈ 0.06
Armaturni pogon Rebar bending	10
Doprema kablova za prethodno naprezanje Prestressing cables shipping	25
Nabavka hidroizolacije Waterproofing delivery	7
Prefabrikacija betonskih ivičnjaka Prefabrication of concrete curbs	20
Nabavka bravarije Metalwork supply	17
Nabavka odvodnih cevi Drain pipes supply	12
Asfaltna baza Asphalt mixing plant	9

Tabela 3. Ukupan utrošak energenata za mehanizaciju  
 Table 3. Total energy consumption of mechanization

Potrošnja energenata Energy consumption	Niz prostih greda Series of simple beams	Kontinualni nosač Continuous beam	Ramovski sistem Frame
Električna energija Electric energy [ kWh ]	1.667,50	1.557,26	1.730,17
Benzin Gasoline [ l ]	28,43	12,44	11,85
Dizel Diesel [ l ]	15.123,20	12.226,51	14.081,01
Ukupno Total [ kWh ]	95.784,60	77.524,13	89.235,41



Grafik 4. Vezana energija ugrađenih materijala  
 Chart 4. Embodied energy of embedded materials, [GJ/t], [7], [8], [9]



Grafik 5. Ukupan energetska utrošak mehanizacije  
 Chart 5. Total energy consumption of the machinery [kWh]

Količina energetskog utroška po toni proizvedenog betona višestruko je manja od količine energije utrošene po toni proizvedenih armature i asfalta, što će se odraziti na dobijene rezultate.

The amount of energy consumption per tone of concrete is several times smaller than the amount of consumed energy per tone of steel rebar and asphalt, which will be reflected in the obtained results.

Zbog masenog udela ugrađenih materijala, najveća količina energije će biti utrošena pri proizvodnji betona, što se može i videti na *Graficima 6. i 7.* Na *Grafiku 5.* prikazan je energetska utrošak mehanizacije, koji je najmanji za drugu konstrukciju (2).

Međutim, energetska utrošak mehanizacije je prilično mali u poređenju sa energetska utroškom za beton, čelik i asfalt. Samim tim, količina vezane energije od mehanizacije dosta je mala u poređenju sa ukupnom vrednošću.

Na *Graficima 6. i 7.* vidi se uticaj količine betona ugrađenog u konstrukciju, na odnos svakog procesa u ukupnoj količini vezane energije.

Sve tri konstrukcije su prethodno napregnuti betonski mostovi, s dominantnim udelom betona u zapreminskom i masenom odnosu ugrađenih materijala. Samim tim, relevantna jedinica, po kojoj će biti izvršena analiza rezultata, biće kubni metar betona.

Due to the mass fraction of the incorporated materials, the largest amounts of energy consumption will be in the production of concrete, as can be seen at the *Charts 6. and 7.* *Chart 5.* shows the energy consumption of the machinery, which is the smallest for the second structure (2).

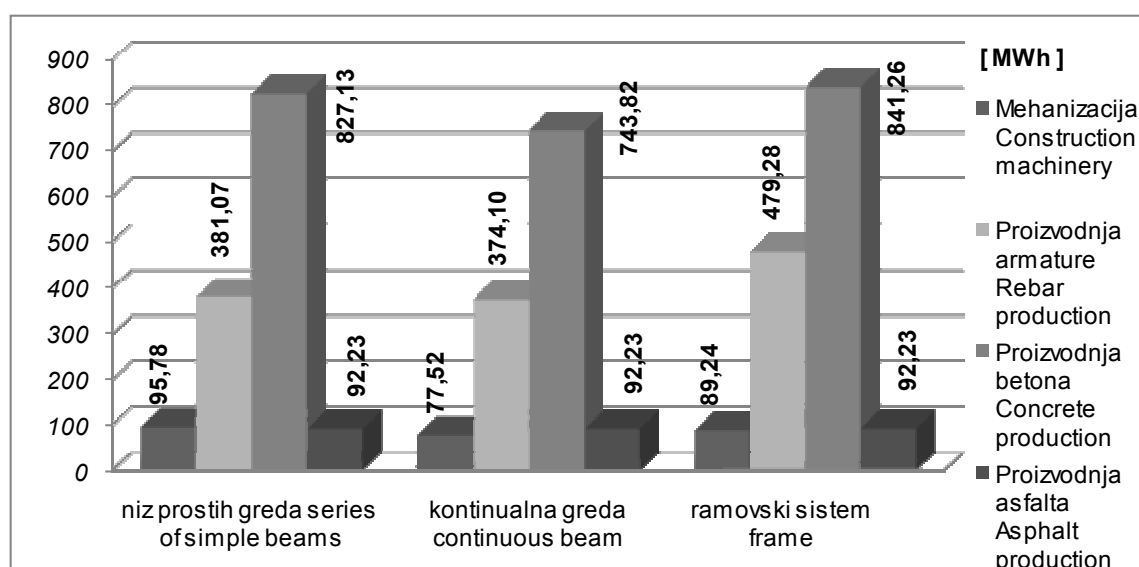
However, the energy consumption of the machinery is quite small, compared to the energy consumption for concrete, steel and asphalt production process. Therefore, the amount of embodied energy from the machinery will be quite small in comparison with the total value.

*Charts 6. and 7.* show the impact of quantity of concrete embedded in the structure, to each process ratio in the total amount of embodied energy.

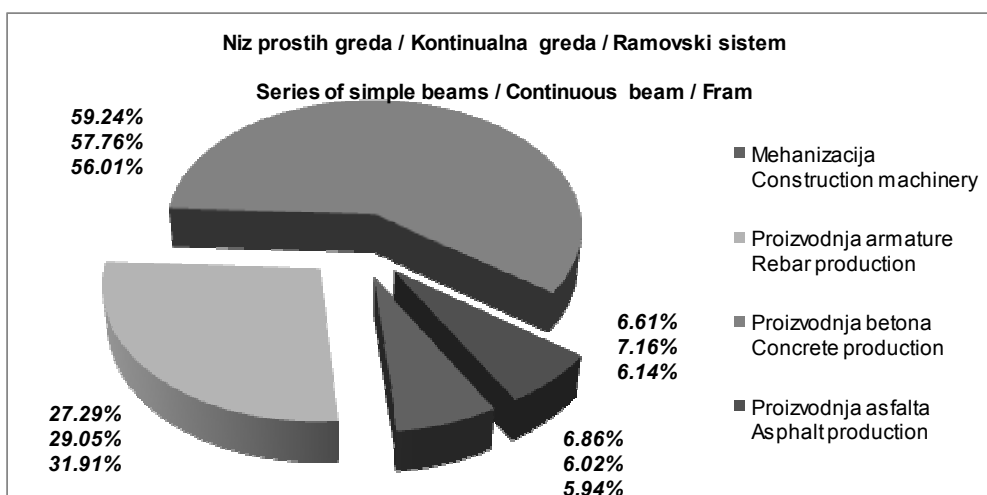
All three structures are prestressed concrete bridges, with a dominant percentage of concrete in the volume and mass ratio of all used materials. Therefore, the relevant unit, per which the analysis of the results will be done, is going to be a cubic meter of concrete.

*Tabela 4. Ukupna količina vezane energije*  
*Table 4. Total amount of embodied energy*

<i>Ukupna količina energije</i> <i>Total energy amount [ MWh ]</i>	<i>Niz prostih greda</i> <i>Series of simple beams</i>	<i>Kontinualni nosač</i> <i>Continuous beam</i>	<i>Ramovski sistem</i> <i>Frame</i>
<i>Mehanizacija</i> <i>Construction machinery</i>	95,78	77,52	89,24
<i>Proizvodnja armature</i> <i>Steel rebar production</i>	381,07	374,10	479,28
<i>Proizvodnja betona</i> <i>Concrete production</i>	827,13	743,82	841,26
<i>Proizvodnja asfalta</i> <i>Asphalt production</i>	92,23	92,23	92,23
<i>Ukupno</i> <i>Total</i>	1.396,21	1.287,67	1.502,00



*Grafik 6. Ukupna količina vezane energije po procesu*  
*Chart 6. Total amount of embodied energy per production process*



*Grafik 7. Udeo u količini vezane energije po procesu*  
*Chart 7. Proportional share in total embodied energy amount, per process*

*Grafik 8.* prikazuje odnos ukupne količine vezane energije sve tri konstrukcije, kao i vezanu energiju projektovanu na jedan kubni metar betona. Razlike u ukupnoj količini utrošene energije u poređenju s najpovoljnijim slučajem – što je drugo konstruktivno rešenje (2) – iznose približno 10% više u odnosu na prvo (1), odnosno 15% više energije u odnosu na treće rešenje (3).

Razlika u količini vezane energije, po kubnom metru betona ugrađenog u konstrukciju, u odnosu na drugu konstrukciju (2) iznosi približno 2,5% manje za prvo (1), odnosno približno 3% više za treće rešenje (3).

Pri približnom međusobnom odnosu betona, armature i asfalta u sva tri rešenja i pri upotrebi istog tipa mehanizacije, ukupna količina vezane energije najviše bi varirala u zavisnosti od količine betona i armature ugrađenih u konstrukciju.

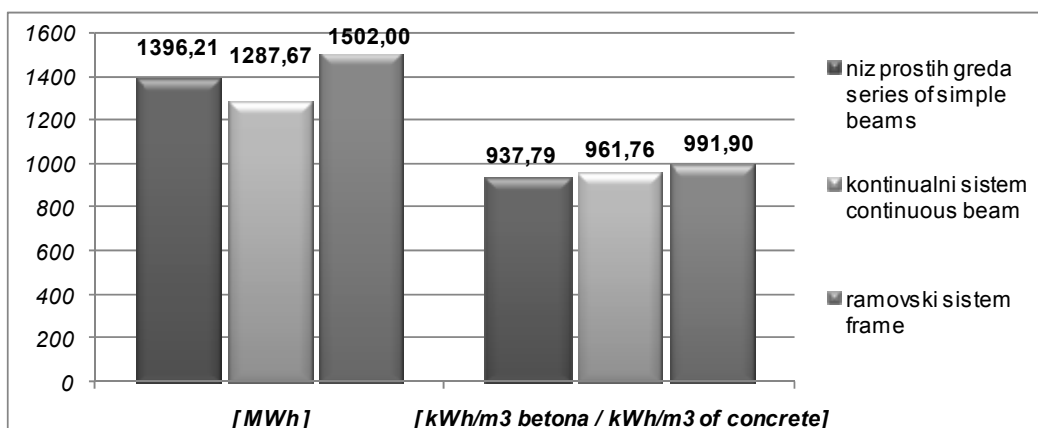
Najmanja količina vezane energije po  $m^3$  betona jeste u prvoj konstrukciji (1), ali to ne rezultuje i najmanjom ukupnom količinom vezane energije u prvoj konstrukciji (1), nego u drugoj (2), što je posledica različite količine utrošenog materijala, u zavisnosti od konstrukcije (*Grafik 8*).

*Chart 8.* displays the ratio of total amounts of embodied energy for all three constructions, as well as the total amounts of embodied energy per one cubic meter of concrete. The differences in the total amount of used energy, when compared with the most favourable case, which is the 2nd structural solution (2), are approximately 10% more for the first (1), and 15% more energy used for the third solution (3).

The difference in the amount embodied energy per cubic meter of concrete, embedded into structure, compared to other structure (2) is approximately 2.5% less for first (1), and approximately 3% more for third solution (3).

At an approximate mutual relation of concrete, rebar and asphalt in all three solutions and with the use of the same type of machinery, the total amount of embodied energy vary the most depending on the amount of concrete and steel rebar, embedded in the structure.

The smallest amount of embodied energy per  $m^3$  of concrete is in the first structure (1), but it does not result in the lowest total amount of embodied energy in first solution (1), but in second (2), which is the result of different material quantities used for each structure, *Chart 8*.



*Grafik 8. Ukupna količina vezane energije*  
*Chart 8. Total amount of embodied energy*

## 5 EMISIJA CO<sub>2</sub> KAO NUSPRODUKT ENERGETSKOG UTROŠKA

Za proračun emisije CO<sub>2</sub> od mehanizacije, korišćene su vrednosti koje prikazuju prosečnu emisiju CO<sub>2</sub> na teritoriji Srbije [10], u zavisnosti tipa energenta koji se koristi za rad mašine:

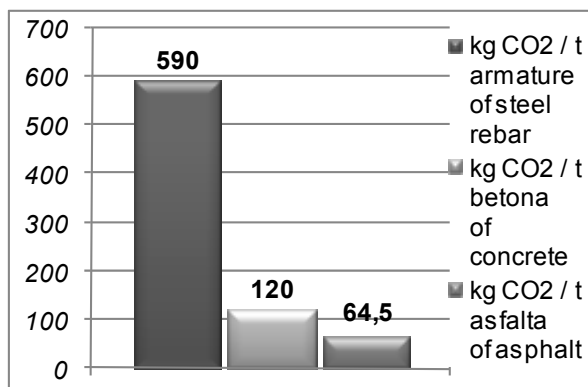
- električna energija:  $0,71779 \frac{\text{kg (CO}_2\text{)}}{\text{kWh}}$
- benzin:  $2,3035 \frac{\text{kg (CO}_2\text{)}}{\text{l}}$
- dizel:  $2,6256 \frac{\text{kg (CO}_2\text{)}}{\text{l}}$

Proizvodnja čelika zasniva se na korišćenju proizvoda na bazi uglja, a posledica toga jeste emisija velike količine CO<sub>2</sub>. Emisija CO<sub>2</sub> po proizvedenoj toni armature u elektrolučnoj peći, prikazana je na *Grafiku 9* [7].

Vrednosti emisije CO<sub>2</sub> pri proizvodnji betona i asfalta su preuzete iz dva izveštaja kanadskog Instituta Atina (*Athena Sustainable Materials Institute*). Preuzete su vrednosti emisije CO<sub>2</sub> pri proizvodnji betona, čije karakteristike najviše odgovaraju karakteristikama betona marke MB 40 po SRPS-u, [8], *Grafik 9*. Za asfalt je korišćena vrednost emisije CO<sub>2</sub> za mešavinu bez udela recikliranog materijala, [9] – *Grafik 9*.

Proračun emisije CO<sub>2</sub> od mehanizacije, na osnovu utrošene energije, učinjen je na osnovu podataka *Internacionalne Agencije za Energiju (IEA – International Energy Agency [11])*.

Na *Grafiku 10*. data je vrednost emisije ugljen-dioksida pri upotrebi mehanizacije. Vidi se da se zadržao približan odnos među konstrukcijskim rešenjima, kao i na *Grafiku 5*, kao i direktna uslovljenost emisije CO<sub>2</sub> količinom utrošene energije u slučaju upotrebe mehanizacije.



*Grafik 9. Emisija CO<sub>2</sub> po toni proizvedenog materijala*  
*Chart 9. CO<sub>2</sub> emission per tonne of construction material, [7], [8], [9]*

U *Tabeli 5.* i na *Graficima 11. i 12.*, primetno je da je – kao i u slučaju analize vezane energije – dominantna količina CO<sub>2</sub> emitovana u procesu proizvodnje betona, kao najzastupljenijeg materijala u sve tri konstrukcije.

## 5 CO<sub>2</sub> EMISSION AS A BYPRODUCT OF ENERGY CONSUMPTION

To calculate CO<sub>2</sub> emission from the machinery, the values that show the average CO<sub>2</sub> emissions on the territory of Republic of Serbia were used [10], depending on the type of energy used to operate the machine:

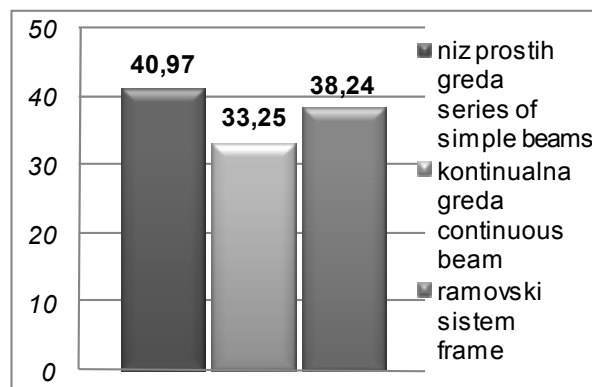
- electrical energy:  $0,71779 \frac{\text{kg (CO}_2\text{)}}{\text{kWh}}$
- gasoline:  $2,3035 \frac{\text{kg (CO}_2\text{)}}{\text{l}}$
- diesel:  $2,6256 \frac{\text{kg (CO}_2\text{)}}{\text{l}}$

Production of steel is based on the use of coal products, which results in the emission of large amounts of CO<sub>2</sub>. CO<sub>2</sub> emissions per tone of steel rebar produced in electric arc furnace are shown in *Chart 9* [7].

The data that represent CO<sub>2</sub> emissions from the production process of concrete and asphalt are taken from two reports of the Canadian *Athena Sustainable Materials Institute*. The values of CO<sub>2</sub> emissions in concrete production, whose characteristics correspond the most with the characteristics of concrete, MB 40 according to SRPS, are used, [8], *Chart 9*. CO<sub>2</sub> emission data from the asphalt production is taken for a mixture without the share of recycled material, [9], *Chart 9*.

Calculation of CO<sub>2</sub> emission of machinery, based on its energy consumption was made based on the data of the IEA (*International Energy Agency*) [11].

*Chart 10.* displays the value of carbon dioxide emission from the use of machinery. The ratio of CO<sub>2</sub> emission between the structural solutions remained similar, like on the *Chart 5.* and the direct conditionality between CO<sub>2</sub> emission and the amount of energy consumption by the machinery can be seen.

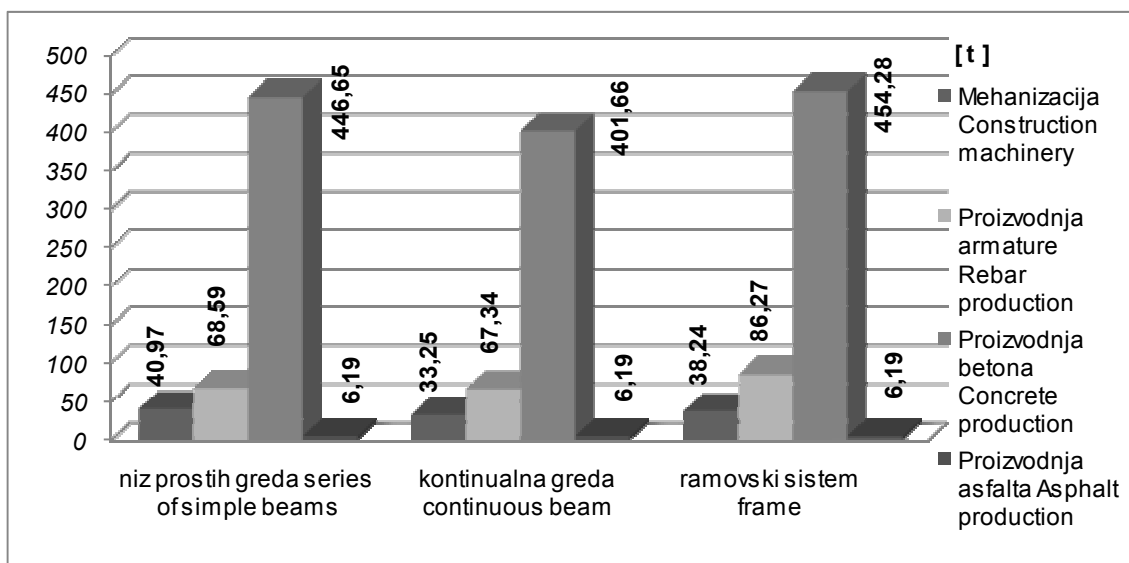


*Grafik 10. Ukupna emisija CO<sub>2</sub> od mehanizacije*  
*Chart 10. Total CO<sub>2</sub> emission of the machinery [ t ]*

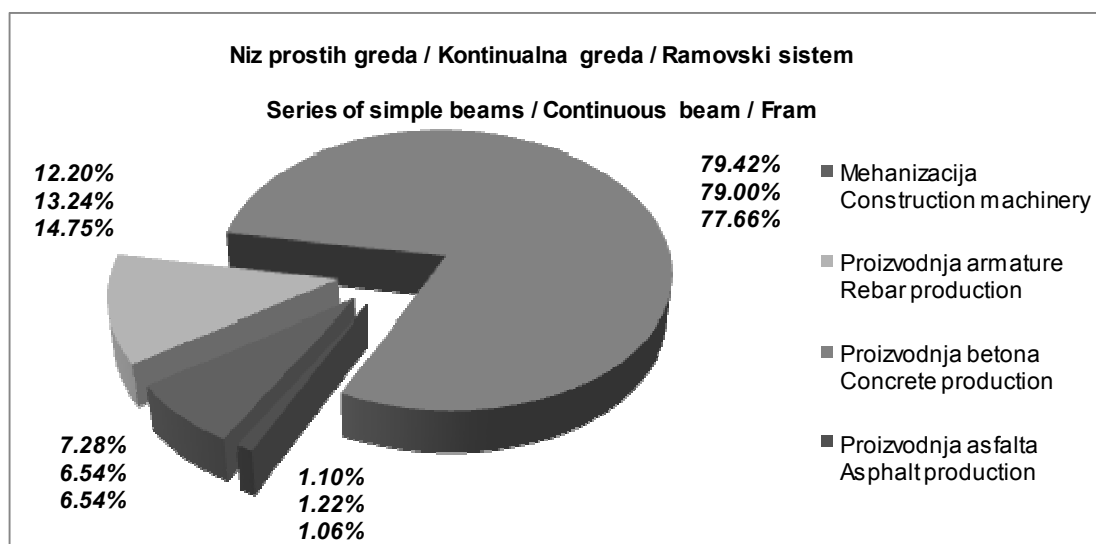
It is noticeable (*Table 5.* and *Charts 11. and 12.*) that, as in the case of embodied energy analysis, the dominant amount of CO<sub>2</sub> is emitted in the production process of concrete, as predominant material in all three constructions.

Tabela 5. Ukupna emisija CO<sub>2</sub>  
Table 5. Total CO<sub>2</sub> emission

Ukupna emisija CO <sub>2</sub> Total emission of CO <sub>2</sub> [ t ]	Niz prostih greda Series of simple beams	Kontinualni nosač Continuous beam	Ramovski sistem Frame
Mehanizacija Construction machinery	40.97	33.25	38.24
Proizvodnja armature Steel rebar production	68.59	67.34	86.27
Proizvodnja betona Concrete production	446.65	401.66	454.28
Proizvodnja asfalta Asphalt production	6.19	6.19	6.19
<b>Ukupno Total</b>	<b>562.40</b>	<b>508.44</b>	<b>584.98</b>



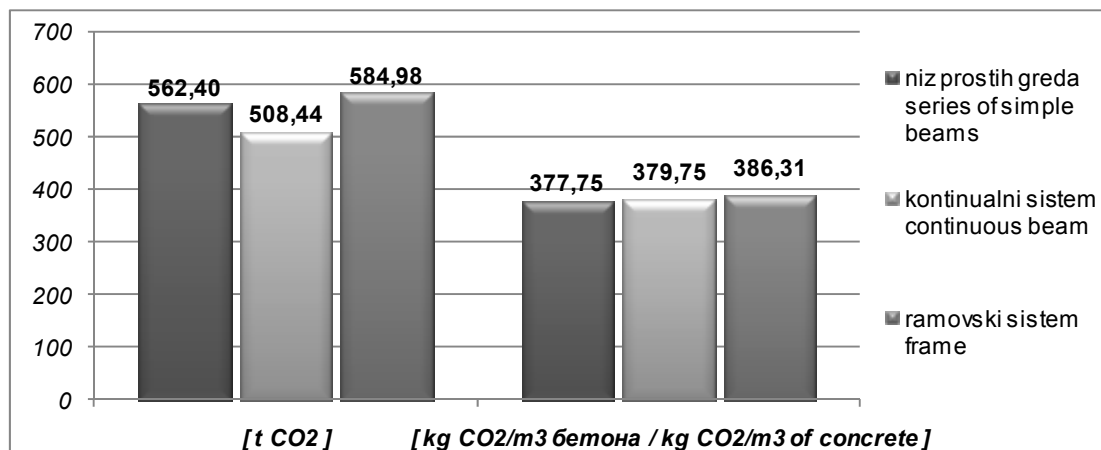
Grafik 11. Ukupna emisija CO<sub>2</sub> po procesu  
Chart 11. Total CO<sub>2</sub> emission per process



Grafik 12. Udeo u emisiji CO<sub>2</sub> po procesu  
Chart 12. Proportional share in total CO<sub>2</sub> emission, per process

Na *Graficima 11. i 12.* vidi se da u ovom slučaju još veći udeo emitovanog ugljen-dioksida u ukupnoj količini, dolazi od energetskog utroška pri proizvodnji betona. Emisija CO<sub>2</sub> od proizvodnje armature dosta je manja u poređenju sa udelom vezane energije pri istom procesu, a emisija CO<sub>2</sub> od asfalta je u granicama od svega 1–1.5%. Ovi rezultati su posledica emisije CO<sub>2</sub> po jedinici materijala (*kg CO<sub>2</sub>/t*), kao i njihovog zapreminskog udela u ukupnoj količini materijala u svakoj konstrukciji.

On the *Charts 11. and 12.* can be seen, that in the case of CO<sub>2</sub> emission analysis, an even greater proportion of CO<sub>2</sub> emission in the total amount comes from the energy used in concrete production. CO<sub>2</sub> emission from the production of steel rebar is a lot less, comparing to the energy consumed in the same process, and the CO<sub>2</sub> emission from the asphalt production process is in the range of 1 -1.5%. This is the result of CO<sub>2</sub> emission per unit of material (*kg CO<sub>2</sub>/ton*), as well as their share in the total amount of materials used in each structure.



*Grafik 13. Ukupna emisija CO<sub>2</sub>*  
*Chart 13. Total CO<sub>2</sub> emission*

*Grafik 13.* prikazuje odnos ukupne emisije CO<sub>2</sub> za sve tri konstrukcije, kao i emisiju CO<sub>2</sub> po jednom kubnom metru betona. Razlike u ukupnoj količini emisije CO<sub>2</sub> u poređenju s najpovoljnijim slučajem – drugim konstruktivnim rešenjem (2), iznose približno 10% više od prvog rešenja (1), odnosno 15% više energije u odnosu na treće rešenje (3).

Možemo primetiti da su procentualni odnosi skoro isti kao procentualni odnosi nastali pri analizi vezane energije po kubnom metru betona.

Razlika u emisiji CO<sub>2</sub>, po kubnom metru betona ugrađenog u konstrukciju, u odnosu na drugu konstrukciju (2) iznosi približno 0,5% manje za prvo (1), odnosno približno 1,75% više za treće rešenje (3). To je, takođe, posledica različite količine utrošenog materijala, u zavisnosti od konstrukcije, i male procentualne razlike u emisiji CO<sub>2</sub> po m<sup>3</sup> betona.

Najmanja emisija CO<sub>2</sub> po m<sup>3</sup> betona jeste za prvu konstrukciju (1), ali to ne rezultuje i najmanjom ukupnom emisijom CO<sub>2</sub> kod prve konstrukcije (1), nego kod druge (2), što je posledica različite količine utrošenog materijala, u zavisnosti od konstrukcije – *Grafik 13.*

Na *Grafiku 14.* prikazan je odnos ukupne količine vezane energije i emisije CO<sub>2</sub> za tri razmatrana konstrukcijska rešenja. Na osnovu svih prethodno sračunatih vrednosti, primetna je direktna uslovljenost na relaciji izbora konstruktivnog rešenja, količine i tipa utrošenog materijala, vezane energije i emisije CO<sub>2</sub>.

Pri analizi vezane energije i emisije ugljen-dioksida, detaljno su razmatrani učinci mašina koje učestvuju u navedenim procesima i njihova potrošnja energenata. Podaci koji su korišćeni za proračun vezane energije i

*Chart 13.* shows the total CO<sub>2</sub> emission ratio for all three structures, as well as the CO<sub>2</sub> emission per cubic meter of concrete. The differences in the total amount of CO<sub>2</sub> emission, compared to the most favourable case – 2nd structural solution (2), are approximately 10% more than in the first (1), or 15% more energy compared to the third solution (3).

We can notice that the percentage ratio is almost the same as the percentage ratio incurred in the analysis of the embodied energy per cubic meter of concrete.

The difference in CO<sub>2</sub> emission per cubic meter of concrete, embedded into structure, compared to the 2nd structure (2) totals approximately 0.5% less than the first (1) and 1.75% more amount for the third solution (3). This is also a result of different amounts of used construction materials, and small percentage differences in CO<sub>2</sub> emissions per m<sup>3</sup> of concrete.

The lowest CO<sub>2</sub> emission per m<sup>3</sup> of concrete is for the first structure (1), but it does not result in the lowest total CO<sub>2</sub> emissions for the first structure (1) but in the 2nd (2), which is a result of different amounts of used materials, built in structures, *Chart 13.*

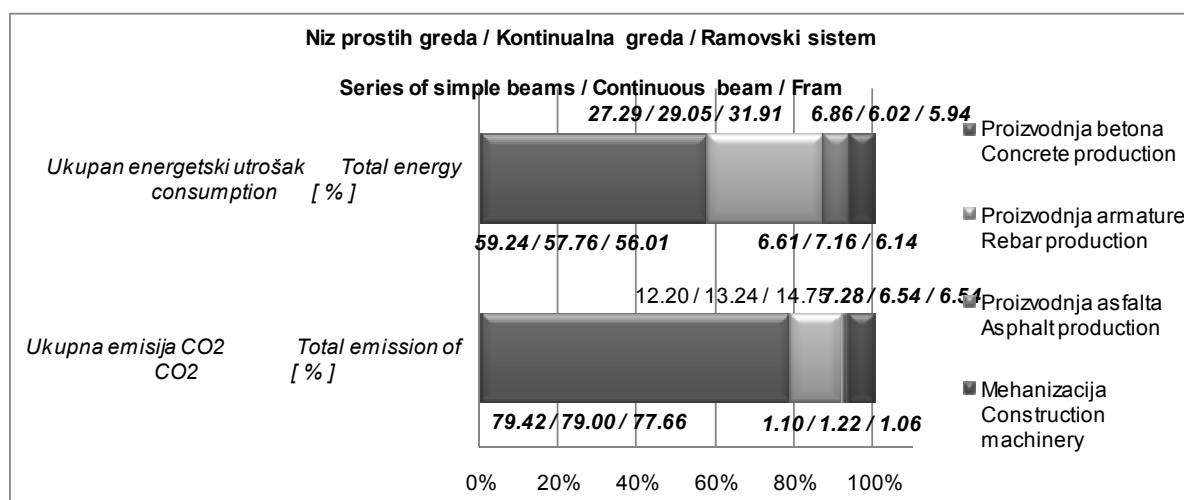
The *Chart 14.* shows the participation per process in the total amount of embodied energy and CO<sub>2</sub> emission for three structural solutions. Based on all of the previously calculated values, there is a noticeable direct causality between the choice of structural solution, the amount and type of used materials, and embodied energy and emission of CO<sub>2</sub>.

In the analysis of embodied energy and carbon dioxide emission, the effectiveness of machinery involved in construction processes and their consumption of



emisiju CO<sub>2</sub> u procesima proizvodnje konstruktivnih materijala, korišćeni su iz navedenih izvora [7], [8], [9], [10], [11].

energy were considered in detail. The data used for the calculation of embodied energy and CO<sub>2</sub> emissions in the production processes of construction materials, was retrieved from sources [7], [8], [9], [10], [11].



Grafik 14. Procentualni udeo vezane energije i emisije CO<sub>2</sub>, po procesu  
Chart 14. Participation of embodied energy and CO<sub>2</sub> emission, per process

## 6 ZAKLJUČCI

Analizom dobijenih rezultata, prikazana je direktna veza između konstruktivnog rešenja, načina izvođenja, količine utrošenog materijala i vezane energije, kao i emisije CO<sub>2</sub>, odnosno uticaja na životnu sredinu.

Svaki korak proračuna uslovljen je prethodno usvojenim rešenjima i ulaznim parametrima. Izbor statičkog sistema konstrukcije direktno se odražava na oblik, dimenzije i broj konstruktivnih elemenata i količine konstrukcionih materijala. Osim toga, trajanje radova i količina utrošene energije uslovljeni su odabirom i karakteristikama mehanizacije i planom izvođenja konstrukcije. Sve to se odražava na količinu vezane energije objekta (mosta), na osnovu prikazanih rezultata proračuna vezane energije i emisije CO<sub>2</sub>.

U ovom radu prikazan je jedan mogući način procene vezane energije i emisije CO<sub>2</sub> u procesu gradnje betonskih grednih mostova, koji je baziran na proračunu količina u svim glavnim koracima realizacije konstrukcije i obuhvata sve glavne generatore konačnog rezultata.

Razmatranje međusobne uslovljenosti glavnih koraka u projektovanju i izvođenju mostova daje uvid u to na koji se način ovi procesi odražavaju na energetski aspekt i emisiju štetnih elemenata na našu okolinu. Prikazani rezultati omogućavaju da se bolje sagleda uticaj pojedinih činilaca, ukoliko se kao dodatni kriterijum pri projektovanju uključi i ekološki aspekt.

Dati su kvantitativni rezultati vezane energije i emisije CO<sub>2</sub> za tri konstrukcije mosta različitih statičkih sistema i iste ukupne dužine mosta, svedeni na m<sup>3</sup> ugrađenog betona. Prikazano je i procentualno učešće pojedinih komponenti u ukupnom rezultatu kod svih razmatranih primera konstrukcija. Dobijene vrednosti vezane energije iznosile su oko 1000 kWh, a emisija ugljenika oko 400 kg CO<sub>2</sub>, po m<sup>3</sup> ugrađenog betona. Direktna veza

## 6 CONCLUSIONS

The analysis of the obtained results shows direct correlation between the structural design, construction methods, quantity of used materials and embodied energy, as well as CO<sub>2</sub> emission and its environmental impact.

Each step of calculation procedure is conditioned by the previously adopted solutions and input parameters. The choice of structural system directly affects the shape, dimensions and number of structural elements and the quantity of construction materials. In addition, the duration of construction works and the amount of embodied energy are conditioned by the selection and the characteristics of machinery and construction plan. Based on the presented results of calculation, the amount of embodied energy of the object (bridge) and CO<sub>2</sub> emission are consequently affected by selected solutions.

Paper presents a possible method for evaluation of embodied energy and CO<sub>2</sub> emission in the process of construction of concrete girder bridges. The method is based on calculation of the amounts in all main steps of the construction and it includes all main generators of the final result.

Correlation of the main steps in the design and construction process of a bridge affects the energy aspect and the emission of harmful elements. Presented results enable better recognition of the impact of certain factors, when the environmental aspect is an additional criterion in the design.

Quantitative results of the embodied energy and CO<sub>2</sub> emission, for three bridge structures of different structural system and equal total length of the bridge per m<sup>3</sup> of concrete are presented. The participation of individual components in the total result, in all considered examples of the structures is shown. The obtained values were approximately 1000 kWh of embodied energy and - ap-

konstruktivnog sistema i vezane energije i emisije CO<sub>2</sub> izražava se različitim količinama ukupnih materijala potrebnim za izgradnju mosta na određenoj lokaciji, kada se primenjuju različita konstrukcijska rešenja.

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## REZIME

### ANALIZA VEZANE ENERGIJE I EMISIJE CO<sub>2</sub> ZA IZVOĐENJE MOSTOVSKJE KONSTRUKCIJE SA STANOVIŠTA ODRŽIVOSTI

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U radu je prikazana uporedna analiza vezane energije i emisije CO<sub>2</sub> u procesu gradnje, za tri mostovske konstrukcije. Analizirane konstrukcije su prethodno napregnuti betonski mostovi, različitih statičkih sistema, ukupne dužine 88 metara.

Razmatrana je međusobna uslovljenost izbora konstruktivnih rešenja, načina izvođenja konstrukcije, količine utrošenog materijala, vezane energije i emisije CO<sub>2</sub>.

Dat je uvid u način na koji se glavni koraci u projektovanju i izvođenju mostova odražavaju na energetski utrošak i emisiju CO<sub>2</sub>, procentualno i u ukupnom iznosu.

Dobijeni rezultati bi trebalo da omoguće bolje sagledavanje uticaja pojedinih faktora u procesu izvođenja mostova i njihov uticaj na životnu sredinu.

**Ključne reči:** Vezana energija, Emisija CO<sub>2</sub>, Mostovske konstrukcije, Održivost, Ekološki aspekt

proximately 400 kg of CO<sub>2</sub> emission per m<sup>3</sup> of built in concrete. Direct correlation of structural system and embodied energy and CO<sub>2</sub> emission is expressed through different total quantities of the materials necessary for the construction of bridge at a particular location, when different structural solutions are applied.

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## SUMMARY

### ANALYSIS OF THE EMBODIED ENERGY AND THE CO<sub>2</sub> EMISSION IN CONSTRUCTION PROCESS OF A BRIDGE STRUCTURE FROM THE ASPECT OF SUSTAINABILITY

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This paper presents a comparative analysis of embodied energy and CO<sub>2</sub> emission, in the construction process of three bridge structures. Analyzed structures are prestressed concrete bridges with different structural systems and a total length of 88 meters.

The correlation of structural system, construction method, material quantities and embodied energy and CO<sub>2</sub> emission were considered.

Influence of the selected solutions in main steps of design and construction on the energy consumption and the emission of CO<sub>2</sub> is presented.

The results should provide a better understanding of the effects of certain factors, in the bridge construction process, and their impact on the environment.

**Key words:** Embodied energy, CO<sub>2</sub> emission, Bridge structures, Sustainability, Environmental aspect