EFFECTS OF SELECTION AND SCALING METHODS USED FOR GROUND MOTION DATA ON DETERMINATION OF SEISMIC RESPONSE OF RC BRIDGE

EFEKAT IZABORA METODE SKALIRANJA I ZAPISA ZEMLJOTRESA NA ODREĐIVANJE SEIZMIČKOG ODGOVORA MOSTA

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Summary: In this paper two different methods of selection and scaling ground motion data were investigated in order to examine their effect on accuracy predicting seismic response of RC bridge. First method used is one proposed in EN 1998-2 and second method is scaling of earthquakes based on calculated conditional mean spectrum (CSM) related known parameters of earthquake scenario for certain location. For both methods certain limitations upon scaling factor were implemented in order to examine its effect on accuracy. Totally 4 sets consisted of 7 records were selected, and average seismic response were obtained from nonlinear dynamic analysis. Responses were compared to calculated real response of bridge, so called point of comparison. Conclusions were made about investigated methods accuracy and effect on imposed limitation of scaling factor on realistic prediction of seismic bridge response.

Keywords: RC bridge, scaling and selection method, earthquake data, seismic response

Rezime: U ovom radu su istraživane dvije različite metode izbora i skaliranja zapisa zemljotresa sa ciljem određivanja efekta na tačnost proračuna seizmičkog odgovora konstrukcije AB mosta. Prva istražena metoda je ona predložena u EN 1998-2 dok se druga metoda bazira na skaliranju na osnovu CSM spectra. CSM spektar se konstruiše na osnovu poznatih parametra zemljotresnog scenarija na zadatoj lokaciji. Ukupno 4 seta zapisa, gdje se svaki sastoji od 7 zemljotresa, su generisani iz nelinearnih analiza sračunat je i srednji odgovor konstrukcije za svaki set. Odgovori po setovima i metodama su upoređivani sa sračunatim stvarnim odgovorom konstrukcije, takozvanom tačkom upoređenja. Formulisani zaključci odnose se na uticaj izbora metoda skaliranja zapisa, i nametnutih ograničenja u faktoru skaliranja na tačnost realnog predviđanja seizmičkog odgovora mosta.

Ključne reči: AB most, metode skaliranja i izbora, zemljotresni zapisi, seizmički odgovor

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1. INTRODUCTION

Selecting and scaling techniques for ground motion data to be used in seismic analysis of structures are very interesting topics that is getting attention in research and publications in past few years. This topic is equally interesting to researchers and engineers in practice, as non-linear dynamic analysis (NDA) is suggested in almost all regulations as a method of seismic analysis. In addition, it is clear that the methods of selecting and scaling earthquake records are very closely linked to the accuracy of the results obtained.

In current performance-based design and evaluation of structures it is common practice to scale record by their intensities rather than by their frequency content. Primary aim of scaling method is to provide scaling factor for small number, usually maximum 7 records, to be used in NDA. Median response from selected earthquakes data should give accurate prediction of structural response (EDP). One of the earliest approaches used, was scaling ground motions data to certain value of PGA. This approach was found to give inaccurate response prediction as well as great dispersions among results [1], [2]. Next improvement in selecting earthquakes was to scale records to target value of spectral acceleration at fundamental period of vibration. Even if this technique is proven to be effective for structures whose response is dominated by first mode [2], it is frequently used in practice. Approach developed to minimize the difference between its elastic response spectrum and the target spectrum has been proposed in literature [3], [4]. European regulations for bridge structures [5] require to select and scale record in such way that the average value of the SRSS 5%-damped elastic response spectra (obtained applying SRSS rule on two horizontal components of

1. UVOD

Izbor i skaliranje zapisa zemljotresa koji će se koristiti u seizmičkim analizama konstrukcija vrlo su interesantne teme koje u proteklih nekoliko godina istražuju i publikuju. Ova je tema jednako zanimljiva istraživačima i inženjerima u praksi, budući da se gotovo u svim propisima predlaže nelinearna dinamička analiza (NDA) kao metoda seizmičke analize. Osim toga, jasno je da su metode izbora i skaliranja zapisa zemljotresa vrlo tijesno povezane sa tačnošću dobijenih rezultata.

U aktuelnom projektovanju i ocjeni konstrukcija zasnovanih na performansama, uobičajena je praksa da se zapis skalira po intenzitetu, a ne po frekventnom sadržaju. Primarni cilj metode skaliranja je sračunati faktor skaliranja za mali broj, obično najviše 7 zapisa, koji će se koristiti u NDA. Medijana odgovora od odabranih zapisa trebalo bi da predstavlja pouzdani odgovor konstrukcije (EDP). Jedan od najranijih pristupa koji se koristio je skaliranje zapisa na određenu vrijednost PGA vršno ubrzanje). Međutim, rezultati su pokazali da ovaj pristup daje netačan odgovor konstrukcije kao i velike disperzije među rezultatima [1], [2]. Sljedeće poboljšanje pri izboru zapisa zemljotresa bilo je skaliranje zapisa na ciljnu vrijednost spektralnog ubrzanja u osnovnom periodu vibracija. Čak i ako je pokazano da je ova tehnika djelotvorna za konstrukcije koje dominantno vibriraju u osnovnom tonu [2], ipak često se koristi u praksi za širi dijapazon konstrukcija. Metod skaliranja koji je razvijen kako bi se smanjila razlika između elastičnog spektra odgovora i ciljnog spektra predložena je u literaturi [3], [4]. Evropski propisi za mostove [5] zahtijevaju izbor i skaliranje zapisa na takav način da je prosječna vrijednost 5% prigušenog SRSS elastičnog spektra odgovora (dobijena primjenom pravila SRSS na dvije horizontalne komponente pomjeranja motion) for a set of scaled motions is not less than the 1.3 times elastic response spectrum of design seismic action over the period range from 0.2 T_1 to 1.5 T_1. This method will be evaluated in this paper. Very similar code method is one proposed proposed in [6] were conditional mean spectrum (CSM) is used as target spectral shape. CSM is constructed based on earthquake scenario, and this method will be also investigated in this paper. Detailed overview of selection and scaling techniques were presented in [7].

In this paper, the influence of the earthquake data selection and scaling on the assessment of the response of RC bridge will be analyzed. Selection of records and scaling techniques will be done according to two different methods that are in common use in practice and research: method represented in EN 1998-2 and scaling according CMS as target spectrum instead of uniform hazard spectrum stated in regulations. Afterwards, these records will be used as input data for NDA. Analyses are conducted on RC bridge with two equal spans. Different predictions of bridge response will be compared with the "real" response of the structure. This "real" answer is in fact the assessment of the actual structural response due to all the uncertainties of the earthquake load.

2. DESCRIPTION OF EVALUATED SELECTION AND SCALING TECHNIQUES

Preliminary selection of records is done to match given earthquake scenario. Earthquake scenario id given by values of magnitude, distance and soil characteristics (see (1)). From the preliminary ground motion suit, using rules defined in investigated techniques, sets of 7 pairs of horizontal motion data were selected.

tla) za set skaliranih zemljotresa nije manja od 1,3 puta elastičnog spektra odgovora u opsegu perioda od 0,2 T_1 do 1,5 T_1. Ova metoda je istražena u ovom radu. Vrlo slična metoda skaliranja je predložena u [6], gdje je uslovljeni srednji spektar (CSM) korišten kao ciljni spektar. CSM je konstruisan na osnovu zemljotresnog scenarija. Ova tehnika skaliranja će takođe biti predmet ovog rada. Detaljni pregled tehnika izbora i skaliranja prikazan je u [7]. U ovom radu se analizira uticaj izbora zapisa zemljotresa i skaliranja na procjenu odgovora AB mosta. Izbor i skaliranje urađeno je prema dvije različite metode koje su uobičajene u praksi i istraživanju: metoda prikazana u EN 1998-2 i skaliranje prema CMS-u kao ciljnom spektru umjesto uniformnog spektra hazarda navedenog u propisima. Izabrani zapisi će poslužiti kao ulazni podaci za NDA. Analize su urađene za AB most na dva polja. Različita predviđanja odgovora mosta su upoređena sa "realnim" odgovorom konstrukcije. Ovaj "realni" odgovor zapravo je procjena stvarnog odgovora konstrukcije usljed svih nesigurnosti zemljotresa kao opterećenja.

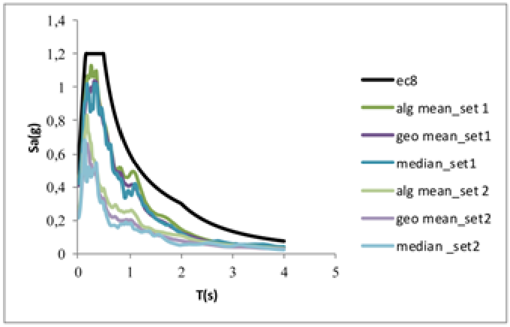
2. OPIS OCJENJENIH MEDODA IZBORA I SKALIRANJA

Preliminarni izbor zapisa zemljotresa obavlja se u skladu sa zadatim scenarijem zemljotresa. Zemljotresni scenario prikazan je kroz vrijednosti magnitude, udaljenosti od rasjeda i karakteristika tla (vidi (1)). Iz preliminarnog seta zapisa zemljotresa korišćenjem pravila definisanih u istraživanim tehnikama, izabrani su setovi od po 7 parova horizontalnih pomjeranja tla. Prva metoda koja se istražuje u ovom radu je izbor i skaliranje sa ciljem podudaranja sa uniformnim hazardnim

$$6.2<M<7.6;\ \ 15km <R<30km \text{ i } 360m/s<v_{s,30}<800m/s \qquad (1)$$

First method evaluated in this paper is selecting and scaling to match uniform hazard spectrum as it is defined in EN 1998-2. From preliminary search by random choice 7 pairs of horizontal ground motion were selected. SRSS spectrum was formed by applying SRSS rule (square root sum square) on horizontal components of every motion record. Average spectrum of 7 SRSS spectrums was found. Scaling of records was necessary because not enough number of unscaled records to match criteria were found. The scaling factor is calculated so that this average spectrum is greater than 1.3 times elastic spectrum corresponding to design seismic action in period range of 0.2 T1 to 1.5 T1. T1 is fundamental period of structure. In order to evaluate effects of scaling factor magnitude on seismic response prediction accuracy, two sets each consisting of 7 pairs of motion were formed. Maximum values of scaling factors are 2 and 4 for Set 1 and Set 2 respectively. Figure 1. shows average (mean, geometric mean and median) of unscaled SRSS spectrum for two sets.

spektrom definisanim u EN 1998-2. Iz preliminarne pretrage slučajnim odabirom izdvojeno je 7 parova horizontalnog pomjeranja tla. SRSS spektar je formiran primjenom SRSS pravila (kvadratni koren sume kvadrata), primjenjenim na horizontalnim komponentama svakog zapisa. Za svaki set sračunat je srednji spektar od 7 SRSS spektra. Skaliranje zapisa bilo je neophodno jer nije pronađen dovoljan broj neskaliranih zapisa koji bi odgovarali postavljenom kriterijumu. Faktor skaliranja izračunat je tako da je srednji spektar veći od 1,3 puta elastičnog spektra odgovora u opsegu od 0,2 T_1 do 1,5 T_1. T_1 je osnovni period vibracija konstrukcije. Kako bi se procijenili efekti vrijednosti faktora skaliranja na preciznost predviđanja seizmičkog odgovora, formirana su dva seta od kojih se svaki sastoji od po 7 parova zapisa pomjeranja. Maksimalne vrijednosti faktora skaliranja su 2 i 4 za Set 1 i Set 2, respektivno. Na slici 1. prikazani su prosječne (aritmetičke i geometrijske sredine i medijana) neskaliranog SRSS spektra za dva seta.



Slika 1 – Srednji SRSS spektar za dva izabrana seta
Figure 1 – Average SRSS spectrum for two selected sets

Second method used is scaling to match CSM spectrum. CSM spectrum is calculated according to [6]. The selection of the earthquake record according to the calculated target CMS spectrum can be done by extracting a certain number of records whose spectra "resemble" it. By the term

Druga metoda koja je korištena je skaliranje da odgovara CSM spektru. CSM spektar je izračunat prema [6]. Izbor zapisa zemljotresa u skladu sa izračunatim ciljnim CMS spektrom može se izvesti izdvajanjem određenog broja zapisa čiji spektri "podsjećaju" na CSM spektar. Pod pojmom "podsjeća" "resemble" it is assumed that the amplitudes of the target spectrum and record spectrum are equal. Since very few records satisfy that condition, records must be scaled by a specific scaling factor in order to bring their spectra closer to the target spectrum, or to be equal for certain values of the vibration period. Scaling can be performed so that record spectrum and the target spectrum have the same amplitude for only fundamental period of structure, or to coincide for several vibration periods. Also two sets of earthquake record were considered here which differ by scaling factor. In Set 1 the scaling factor for the earthquake i is calculated so that the target spectrum and the record have the same spectral acceleration value for fundamental period of vibration (equation (2)). In Set 2, the scaling factor is calculated so that the amplitude of the target spectrum and record are approximately same in more than 50 amplitudes (equation (3)).

pretpostavlja se da su amplitude ciljnog spektra i spektra zapisa jednake. Budući da vrlo malo zapisa zadovoljava ovaj uslov, zapisi moraju biti skalirani određenim faktorom skaliranja, kako bi spektri bili bliži ciljnom spektru (CSM) ili bili jednaki za određene vrijednosti perioda vibracija. Skaliranje se može izvesti tako da spektar zapisa i ciljni spektar imaju istu amplitudu samo za osnovni period vibracija konstrukcije ili da se podudaraju za nekoliko tonova vibracija. Tako da su i ovdje razmatrana dva seta zapisa koji se razlikuju po faktoru skaliranja. U setu 1 faktor skaliranja za zapis je izračunat tako da ciljni spektar i zapis imaju istu vrijednost spektralnog ubrzanja za osnovni ton vibracija (jednačina (2)). U setu 2 faktor skaliranja izračunava se tako da je amplituda ciljnog spektra i zapisa približno jednaka u više od 50 amplituda (jednačina (3)).

$$SF_i = \frac{Sa_{CMS}(T_1)}{Sa_i(T_1)} \tag{2}$$

$$SF_i = \sum_{j=1}^{70} \frac{Sa_{CMS}\left(T_j\right)}{\sum_{j=1}^{70} Sa_i\left(T_j\right)} \tag{3}$$

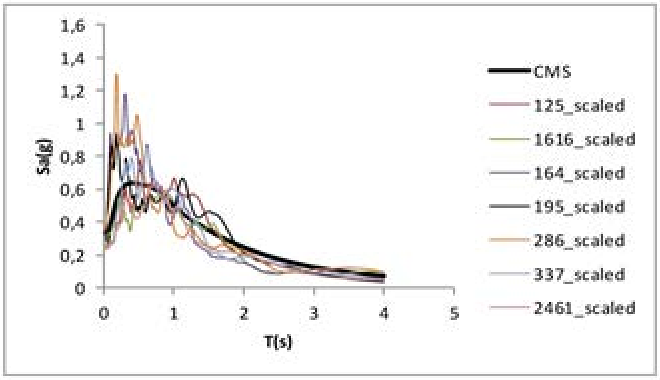
In both sets, only scaled records that are closed to target spectrum were chosen. Criteria of similarity was established by minimizing Sum Square Error calculated like in (4).

U oba seta odabrani su samo skalirani zapisi koji su bliski (slični) ciljnom spektru. Kriterijum sličnosti definisan je minimiziranjem sume kvadrata grešaka SSE izračunate kao u (4).

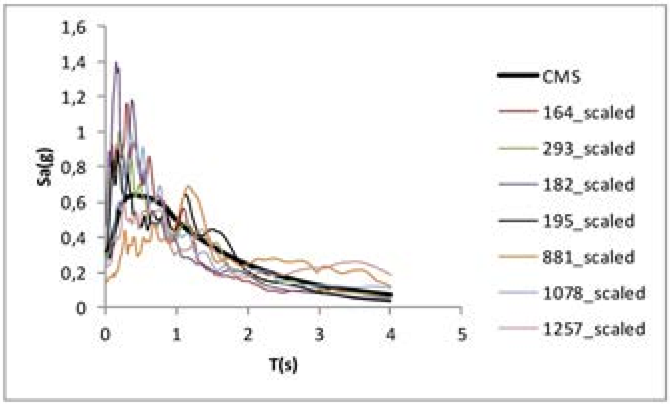
$$SSE = \sum_{i=1}^{n} (ln[SF \cdot Sa(T_i)] - ln[Sa_{CMS}(T_i)])^2 \tag{4}$$

Figure 2. (a) and (b) shows CSM and scaled spectrums of selected earthquake data for Set 1 and Set 2 respectively.

Slika 2. (a) i (b) prikazuju CSM i skalirane spektre odabranih zapisa zemljotresa za Set 1 i Set 2, respektivno.



(a)



(b)

Slika 2 – Spektri ubrzanja zemljotresa (a) Set 1- skaliranje prema osnovnom tomu (b) Set 2- skaliranje prema više tonova

Figure 2 – Earthquake acceleration spectrum for (a) Set 1- Scaling according to the fundamental tone (b) Set 2- Scaling for multiple tones

3. CALCULATION OF BRIDGE RESPONSE AND COMPARISON

To examine accuracy predicting of bridge seismic response it is necessary to evaluate true bridge response. This value is called point of comparison POC and values obtained as average from sets will be compared to it. This value is evaluated by conducting NDA for 40 earthquakes scaled by 1, 2, 4

3. SRAČUNAVANJE ODGOVORA MOSTA I UPOREĐENJE

Za ispitivanje tačnosti predviđanja seizmičkog odgovora mosta potrebno je procijeniti realni odgovor mosta. Ta se vrijednost naziva tačka poređenja (point of comparison) POC sa kojom će biti upoređene srednjim vrijednostima dobijenim iz setova zapisa. Tačka predviđanja (POC) sračunava se na and 8. So totally 160 NDA were conducted and from each analysis demand parameter was registered (EDP) and adequate intensity measure (IM). For EDP relative displacement of column is considered. Following IMs were noted: spectral acceleration for fundamental periods of vibration in two principal directions and PGV.

In this paper evaluation of selection and scaling techniques is conducted for RC two span (40 m long each) bridge curved in plane. Bridge deck is concrete box girder. Pier is 10 m high with hollow cross section. Concrete class is C 30/37. Bridge was designed in accordance to EN 1992 and EN 1998-2 (see fig. 3.). Nonlinear model was built in SeismoStruct [8]. Nonlinear fibre element is used for column with distributed plasticity. Column cross section is divided into concrete core-confined concrete, concrete cover-unconfined concrete and reinforcement material. Geometric and material nonlinearity is taken into consideration. Elastic element was used for deck. Columns are fixed at the base. Horizontal components of every record are simultaneously applied at transversal and longitudinal direction by random choice.

To calculate bridge response functional relationship between EDP and IMs were generated in form given in (5).

osnovu sprovedenih NDA za 40 zapisa svaki skaliran sa faktorima 1, 2, 4 i 8. Na ovaj način sprovedeno je ukupno 160 NDA, a iz svake analize je registrovan parametar odgovora konstrukcije (EDP) i odgovarajuća mjera intenziteta (IM). Za EDP usvojeno je relativno pomjeranje vrha stuba. Takođe iz svakog zapisa registruju se i sljedeći intenziteti (IM): spektralno ubrzanje za osnovni period vibracija u dva ortogonalna pravca i PGV (vršne brzine tla).

U ovom radu su vrednovane tehnike izbora i skaliranja zapisa zemljotresa za AB zakrivljeni most. Rasponska konstrukcija je sandučastog poprečnog presjeka. Srednji stub je visok 10 m sandučastog poprečnog presjeka. Kvalitet betona je C 30/37. Most je projektovan prema EN 1992 i EN 1998-2 (vidi sliku 3). Nelinearni model izgrađen je u SeismoStructu [8].

Stubovi su modelirani nelinearnim elementima po principu distribuirane plastičnosti. Presjek stuba je podijeljen na vlakna jezgra-utegnuti beton, vlakna zaštitnog sloja-neutegnuti beton i materijal čelika za armiranje.

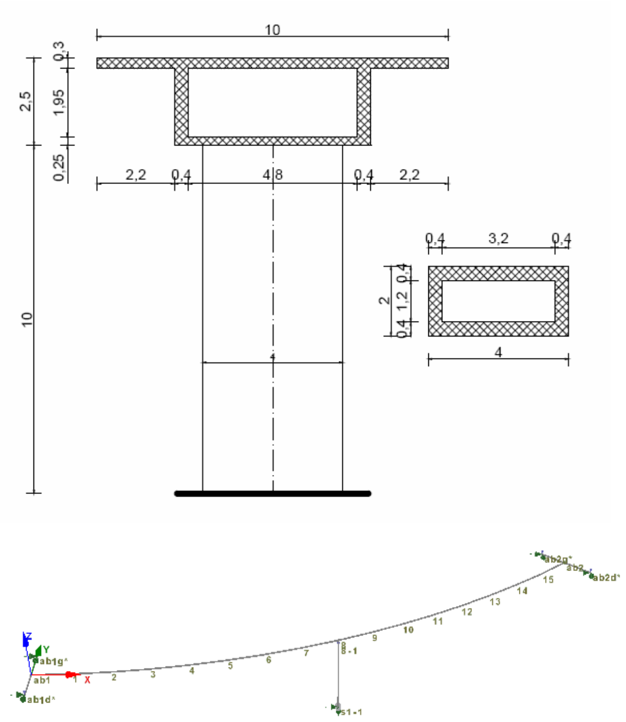
Geometrijska i materijalna nelinearnost je uzeta u obzir. Elastični element korišten je za rasponsku konstrukciju. Stub je fiksiran u osnovi. Horizontalne komponente svakog zapisa istovremeno su nanete u dva ortogonalna pravca.

Uspostavljena je funkcionalna veza između odgovora konstrukcije (EDP) i intenziteta (IM) kao u jednakost i (5).

$$\ln EDP = a_1 + a_2 \ln S_a(T_1) + a_3 ln S_a(T_2) + a_4 ln S_a(2T_1) + a_5 ln PGV \quad (5)$$

Regression analysis was conducted and regression coefficients as well as dispersions and determination coefficient is calculated for transversal and longitudinal direction (see table 1.).

Sprovedena je regresiona analiza, a regresijski koeficijenti kao i disperzije i koeficijent determinacije izračunati su za parove odgovor –intenzitet u poprečnom i uzdužnom smjeru (vidi Tabelu 1.).



Slika 2- Rasponska konstrukcija, poprečni presjek stuba i nelinearni model
Figure 2- Deck, column cross section and nonlinear model

Tabela 1 – Regresioni koeficijenti i koeficijent determinacije za sračunavanje POC
Table 1 – Regression coefficients, dispersion and determination coefficient for calculating POC

	a1	a2	a3	a4	a5	σ	R
EDP transversal	0.8759	0.0129	0.1826	-0.021	0.3417	0.195	0.8512
EDP longitudinal	0.3865	-0.087	0.1713	-0.005	0.3765	0.2898	0.7174

As it is shown high value for determination coefficient is obtained and relatively small value of dispersion. It can be said that using established relation in equation (5), realistic bridge response can be obtained. Here equation (5) will be used to calculate POC. To value of POC average values for EDP obtained from sets will be compared.

Kao što je prikazano, dobija se visoka vrijednost za koeficijent determinacije i relativna mala vrijednost disperzije. Može se reći da se upotrebom uspostavljenog odnosa u jednačini (5) može dobiti pouzdana vrijednost odgovora mosta. Ovdje se jednačina (5) koristi za izračunavanje POC. Ova vrijednost POC dalje će biti upoređena sa srednjom vrijednošću EDP iz NDA za formirane setove zapisa.

4. RESULTS AND COMPARISON

For given earthquake scenario: M 7, R=20 km; 360 m/s<vs,30<800 m/s and bridge characteristic computed from modal analysis : T1=1.04 s, T2=0.739 s, using equation (5), value for POC were calculated. In the transverse direction, the expected mean value of relative displacement of the top of the column is 4.74% and in the longitudinal direction 3.874%. Average bridge response for particular set (consisted of 7 ground motion records), were considered to be mean value of maximum column relative displacement calculated for each record from the set. As it was explained in pervious step, 4 different sets were formed, 2 by method investigated. In table 2. Overview of results for EDP obtained from NDA from each method /set were presented. As can be seen from Table 2., all the results for EDP when using considered methods of selection and scaling give results above the mean expected response of structure (POC). Higher demand is obtained for transversal direction of bridge for all investigated methods. The most conservative results were obtained when the method proposed in European regulation EC 8-2 was used. In the transverse and longitudinal direction, this method significantly overestimates the response of the structure. This is especially true when the scaling factor in this method is limited to smaller value.This result is expected, as target spectrum is increased by 1.3 times in relation to the elastic spectrum of the project seismic force. It can be concluded that the European regulation is here con-servative and that evaluating structure, for the purpose of its rehabilitation or design, based on these results would lead to conservative solutions when compared to scaling to CSM spectrum. Using non-uniform hazard spectrum as CSM can lead to more realistic results. Limitation of scale factor has no much sense in

4. REZULTATI I UPOREĐENJE

Za zadatii zemljotresni scenario: M 7, R = 20 km; 360 m / s $<v_{s,\,30}<$800 m / s i karakteristike mosta izračunate iz modalne analize: T_1 = 1,04 s, T_2 = 0,739 s, koristeći jednačinu (5), izračunate su vrijednost za POC. U poprečnom smjeru, očekivana srednja vrijednost relativnog pomjeranja vrha stuba iznosi 4,74% u poprečnom smjeru i 3,874% u podužnom smjeru.

Srednji odgovor konstrukcije za određeni set (koji se sastojao od sedam zapisa zemljotresa), smatra se srednjom vrijednošću maksimalnih relativnih pomjeranja izračunatih za svaki zapis iz seta. Kao što je objašnjeno u prethodnom koraku, formirana su 4 različita seta: po 2 za svaku istraženu metodu. U tablici 2. prikazani su rezultati za EDP dobijeni iz NDA iz svake metode odnosno seta.

Na osnovu rezultata uočava se da sve očekivane vrijednosti EDP iz različitih metoda izbora i skaliranja skaliranja iznad prosječnog očekivanog odgovora konstrukcije (POC). Za sve ispitivane metode dobija se veći odgovor konstrukcije u poprečnom pravcu mosta. Najkonzervativniji rezultati dobijeni su kada je korišćena metoda predložena u evropskim propisima EC 8-2. U poprečnom i podužnom smjeru ova metoda značajno prevazilazi odgovor konstrukcije. To je naročito izraženo kada je faktor skaliranja u ovoj metodi ograničen na manju vrijednost. Ovakav rezultat se objašnjava činjenicom da se ciljni spektar povećava za 1,3 puta u odnosu na elastični spektar odgovora. Može se zaključiti da su evropske norme ovdje konzervativne i da ocjena konstrukcije u svrhu njihove sanacije ili projektovanja, na temelju ovih rezultata može dovesti do konzervativnih rješenja u poređenju sa drugom evaluiranom metodom. Korištenje neuniformnog hazardnog spektra kao što je CSM, vodi do realnijih rezultata. Ograničenje faktora skaliranja nema puno smisla u slučaju izbora metode prema EN case of selecting method according to EN standards, because limitation leads to larger differences of mean EDP to POC. Satisfying small differences were found between mean EDP (arise for 7 selected earthquakes) for both sets in scaling according to CSM.

standardima, jer ograničenje dovodi do većih razlika srednje vrijednosti EDP-a i „stvarnog” odgovora – POC. Zadovoljavajuće male razlike su pronađene između srednjeg EDP za oba seta u okviru dva načina skaliranja prema CSM.

Tabela 2 – EDP iz NDA u kojima su korišćene različite metode skaliranja
Table2 – EDP obtained from NDA using investigated methods of scaling

Set	Method (Metoda)	Number of records by set (Broj zapisa)	Mean EDP (%) (Srednja vrednost)	POC/EDP
1	**Selection and scaling accord to EN 1998-2** (Scale Factor <2) (Izbor I skaliranje prema EC 8)	7	Transversal (Poprečno) 9.14 Longitudinal (Podužno) 7.74	1.92 1.99
2	**Selection and scaling accord to EC 1998-2** (Scale Factor <4)		transversal 7.42 longitudinal 6.52	1.565 1.683
3	**Selection and scaling according to CMS** (scaling according to spectral acceleration for fundamental period of vibration) (Izbor I skaliranje prema CMS)		transversal 5.84 longitudinal 4.18	1.232 1.08
4	**Selection and scaling according to CMS** (scaling according to spectral acceleration for more several periods)		transversal 5.35 longitudinal 4.38	1.128 1.132

5. CONCLUSIONS

In these paper two methods of scaling and selecting earthquake data (to be used in NDA) were investigated: scaling in accordance to EN 1998-2 and scaling to non-uniform spectrum –CSM

5. ZAKLJUČCI

U ovom radu su istraživane dvije metode skaliranja i izbora zapisa zemljotresa (za korišćenje u NDA): skaliranje prema EN 1998-2 i skaliranje prema neuniformnom hazardnom spek-

(Conditional Mean Spectrum). It was noted that for both investigated techniques of selecting records, scaling was necessary in order to establish sets of 7 earthquakes that satisfy imposed conditions. The method of selecting and scaling that gives the best estimate of the bridge structural response is a scaling to CMS. Between two variations within this method a slightly higher accuracy was obtained when the scaling factor is determined so that the spectral acceleration amplitudes of the target CMS spectrum and the considered records are approaching in several vibration periods The disadvantage of CSM method is that for each site considered, i.e. earthquake scenario, and structural characteristic (T_1) target CMS must constructed. This, of course, increases both time and effort invested in the ultimate goal, which is an assessment of the structural response. Method of scaling presented in EN 1998-2 significantly overestimates structural response and leads to conservative decision making regard to seismic evaluating of bridge structures. Limiting scaling factor to certain value in code method does not lead to more accurate prediction of response.

tru-CSM (Conditional Mean Spectrum). Uočeno je da je za obije istražene tehnike izbora zapisa potrebno skaliranje kako bi se uspostavili setovi od 7 dvokom-ponentnih zapisa zem-ljotresa koji zadovoljavaju postavljene uslove. Metoda izbora i skaliranja koja proizvodi najbolju procjenu seizmičkog odgovora mosta je skaliranje prema CMS. Između dvije istražene varijacije unutar ove metode, dobijena je nešto veća tačnost kada se faktor skaliranja određuje tako da se amplituda spek-tralnog ubrzanja ciljnog CMS spektra i izabranih zapisa približavaju za nekoliko perioda vibracija. Nedostatak CSM metode je činjenica da se za svaku razmotrenu lokaciju, tj. Zem-ljotresni scenario, i karakteristiku konstrukcije (T_1), ciljni CMS spektar mora iznova konstruisati. To, naravno, povećava vrijeme i trud uložen u konačni cilj, a to je procjena seizmičkog odgovora konstrukcije. Metoda skali-ranja predložena u EN 1998-2 znatno precjenjuje odgovor konstrukcije i dovodi do konzervativnog odlučivanja u slučaju potrebe za procjenom seizmi-čke otpornosti mosta. Ograničavanje faktora skaliranja na određenu vrijed-nost kod metode iz evropskog propisa ne dovodi do tačnijeg predviđanja odgovora.

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