UTICAJ INTERAKCIJE TLA I KONSTRUKCIJE NA DINAMIČKI ODGOVOR MOSTA VELIKE DUŽINE

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REZIME

U ovom radu prikazani su rezultati parametarske dinamičke analize mosta na Dunavu kod Beške. Cilj istraživanja je da se odredi uticaj tla i asinhronog pomaranja oslonaca na dinamički odgovor mosta velike dužine. Dinamička analiza podužnih vibracija sprovedena je u programu SAP2000 za slučaj 4 scenarija zemljotresa i 4 numerička modela mosta. U formiranju modela korišćene su preporuke *Caltrans Bridge Design Practice*. Analiza je sprovedena za uklještenu konstrukciju i za slučaj kada je interakcija tla i objekta uzeta u obzir. Uticaj asinhronog pomeranja oslonaca je posebno razmatran. Opis modela i analiza rezultata su prikazani u radu.

KLJUČNE REČI: dinamička analiza dugačkog mosta, interakcija tla i konstrukcije, asinhrono pomeranje oslonaca

INFLUENCE OF SOIL-STRUCTURE-INTERACTION ON DYNAMIC RESPONSE OF A LONG BRIDGE

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ABSTRACT

In this paper the parametric dynamic analysis of the Danube river bridge “Beska” is presented. The scope of this investigation is to analyze the effects of soil-structure interaction (SSI) and asynchronous earthquake excitations on dynamic response of a long bridge. Dynamic analysis was carried out using the computer program SAP2000, considering four real earthquake records and four different bridge models. For numerical model the recommendations of the *Caltrans Bridge Design Practice* were taken. The analysis was performed for fixed-base and flexible-base structure (SSI). The influence of asynchronous support motions was analyzed. The descriptions of the cases studded as well as the results analysis are presented.

KEY WORDS: dynamic analysis of a long bridge, soil-structure-interaction, asynchronous support excitations

INTRODUCTION

Due to spatial and temporal variations of seismic motion, the amplitudes and phases of supports motions of a long structure can differ considerably. Different supports displacements combined with the soil-structure interaction (SSI) could play an important role in the seismic response of a long multi-span bridge. Since '90s many analytical solutions have been proposed to estimate spatial variability of Earthquake Ground Motion (SVEGM) on long bridges [1], [2], [3], (Petronijevic, 2002). To take SVEGM into account, modern seismic codes recommended some indirect measures, as involving larger seating deck lengths or simplified code-based calculation [ATC-32]. Only EC8-2 [3] proposes both a simplified and more detailed procedure. Sextos and Kappos (2009) gave detailed review of this phenomenon and evaluate the EC8-2 approach through comparison with more comprehensive methodology proposed by Sextos at al. (2003a), (2003b).

The fact that a long structure is expected to be excited with asynchronous and partially uncorrelated seismic forces is evident and well documented today. The question is which method is adequate for dynamic analysis of a long multi-span bridge and how different seismic motions of the bridge supports should be taken into account. In this paper presented is the dynamic analysis of long multi-span bridge "Beska", where two distinct parameters – temporal variability of the input motions and soil-structure interaction were taken into account.

OVERVIEW OF THE BRIDGE STRUCTURE AND INPUT MOTIONS

The Dynamic analysis was performed for the conceptual design of the long multi-span Danube's bridge "Beska", made for the International competition (B. Stošić, Dipl. Civ. Eng.). The total length of bridge is 2212.55 m. It consists of five independent structures:

- RC structure, length 7.55 m,
- Composite 3-span structure 3x45=135 m
- Composite 6-span structure 6x(5x45) =6x225=1350 m
- Steel 5-span structure 60+105+210+105+60=540 m
- Composite 4-span structure 4x45=180 m.

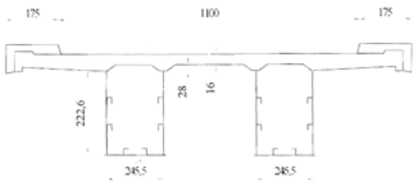

Figure 1. Cross-section of composite deck
Slika 1. Poprečni presek spregnutog nosača

Table 1. Characteristic of deck cross-section
Tabela 1. Geometrijske karakteristike poprečnog preseka

	t = 0	t_s (skupljanje)	t_t (tečenje)
F (cm^2)	3800.625	2466.18	2008.911
I (cm^4)	22838150	19902626	18021418.9
z* (cm)	48.375	68.569	81.659

Characteristics of the composite deck cross-section are given in Figure 1 and Table 1. The properties in time t_t were used for dynamic analysis (shrinkage and creep effects were taken into account). All piers have the box cross-section 600x80 cm; box-width d_p=20 cm. The length of piers is between 5.56 m and 38.76 m. They rest on the pile foundations (4x∅1500), given in Figure 2. The length of piles is 35 m.

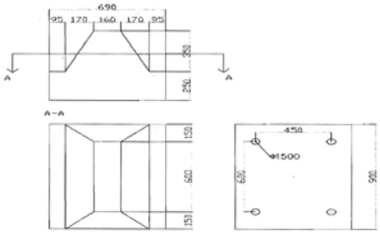

Figure 2. Piers foundation
Slika 2. Temelj stuba

Table 2. Characteristics of soil layers
Tabela 2. Karakteristike slojeva tla

sloj	$\rho\,[kNs^2/m]$	$V_s\,[m/s]$	$G\,[kN/m^2]$	ν	ξ [%]
1	2,05	120	29520	0,29	5
2	2,15	300	193500	0,28	5
3	2,20	450	445500	0,24	5

In order to take SSI into account, the impedance of each pile foundations were derived in frequency domain for characteristic frequency, (Petronijevic, 1995). The characteristics of soil layers are given in Table 2. The depths of layers are changeable, with bedrock at 150 m. The abutment stiffness in longitudinal direction was obtained according to Caltrans [2] as:

$$k_l = 47000 \cdot l \cdot h + 7000 \cdot n \quad [kN/m], \tag{1}$$

where l and h are abutment width and height respectively; n is the number of piles ($n=0$ in this case).

Four different earthquake acceleration records, proposed by the Seismological Institute RS, were used in the analysis, Figure 3. Peak ground accelerations are between 0.025-0.072 m/s^2.

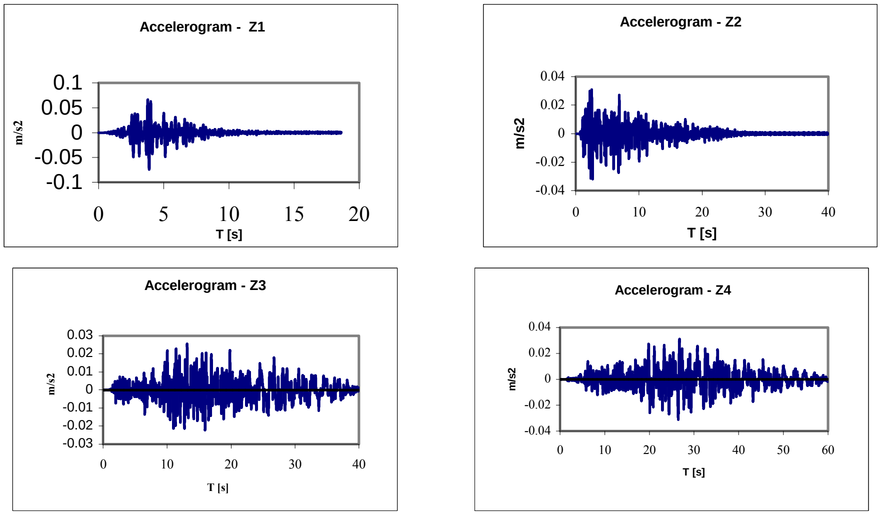

Figure 3. Accelerograms Z1-Z4
Slika 3. Akcelerogrami zemljotresa Z1-Z4

NUMERICAL ANALYSIS

The numerical analyses were carried out for the left part of the bridge, a multi-span composite structure of an overall length of 7.55+3x45+6x(5x45)=1492.55 m. Parametric study was performed using 4 models, according to Caltrans [2], Figure 4. In each model the truncated parts of structure were replaced by appropriate link elements. Stiffness k_x of these link elements were obtained in separate analyses.

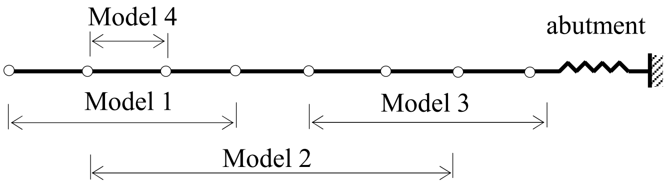

Figure 4. Models used for parametric analysis
Slika 4. Modeli korišćeni u parametarskoj analizi

The levels of earthquakes intensities (PGA less than 0.08g) provided elastic dynamic analysis (EDA). All the analyses were performed in time domain using the computer program SAP2000.9 [6]. Beam elements were used to model the piers and the deck, abutment stiffness was introduced in the form of nonlinear spring, while foundations springs and dashpots were modeled using linear link elements.

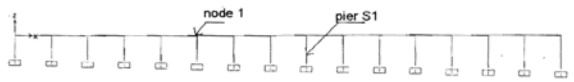

Figure 5. Model 1
Slika 5. Model 1

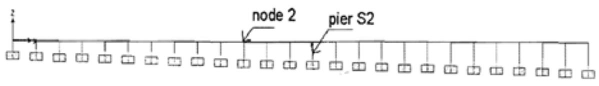

Figure 6. Model 2
Slika 6. Model 2

In order to capture at least 90% of the mass participation in multimodal time history analysis, a certain number of Ritz vectors must be used. For example, 56 Ritz vectors were used in Model 1 with fixed-base.

The analyses were carried out for the following cases:

a) fixed-base structures,
  - synchronous motions,
  - asynchronous motions.

b) flexible-base structures,
  - synchronous motions,
  - asynchronous motions.

In order to propose asynchronous motion the displacements were applied in each support. The displacement time histories were obtained by numerical integration of accelerograms Z1-Z4 after appropriate baseline correction. Time delay between two supports is equal $\Delta t = \Delta l_x / v_s,$ where Δl_x is the distance between the supports and v_s is shear wave velocity.

The response due to the multi-support input motions was obtained from the dynamic equilibrium equation:

$$\mathbf{M}\ddot{\mathbf{u}} + \mathbf{C}\dot{\mathbf{u}} + \mathbf{K}\mathbf{u} = -\left(\mathbf{M}\mathbf{r} + \mathbf{M}\right)\ddot{u}_g , \qquad (2)$$

where **M, C** and **K** are mass, damping and stiffness matrix respectively; $\ddot{\mathbf{u}}$, $\dot{\mathbf{u}}$ and $\mathbf{u}$ are acceleration, velocity and displacement vector; $\ddot{u}_g$ is acceleration of the free-field; **r** is transformation matrix [10]. Transformation matrix **r** relates displacements of the structure $\mathbf{u_s}$ and displacements of its base $\mathbf{u}_b$. It is derived from the static equilibrium equation:

$$\mathbf{K}_{ss}\mathbf{u}_s + \mathbf{K}_{sb}\mathbf{u}_b = \mathbf{0} \quad \Rightarrow \quad \mathbf{u}_s = -\mathbf{K}_{ss}^{-1}\,\mathbf{K}_{sb}\mathbf{u}_b \quad \Rightarrow \quad \mathbf{u}_s = \mathbf{r} \cdot \mathbf{u}_b \quad \Rightarrow \quad \mathbf{r} = -\mathbf{K}_{ss}^{-1}\mathbf{K}_{sb} \, . \qquad (3)$$

In Eq. (3) *s* denotes the structural node and *b* denotes the base nodes.

RESULTS OF ANALYSIS

Due to paper length limitations, presented are only the effects of asynchronous motion and soil-structure interaction (SSI) on the response in longitudinal direction for Models 1 and 2, Figures 5 and 6. The results indicate that SSI effect is negligible. The moments at the base of piers S1 and S2, as well as the displacements of nodes 1 and 2, are almost the same for fixed- and flexible-base structures. Precisely, moments and displacements are smaller due to SSI (max 10%), which means that SSI has beneficiary effect on dynamic behavior of this bridge, Figures 7-10.

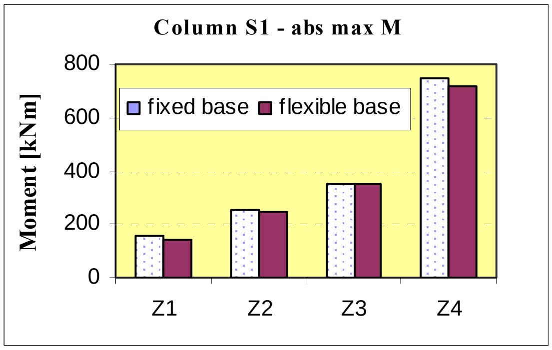

Figure 7. M_{max} pier S1 , fixed and flexible base
Slika 7. M_{max} stub S1, fiksna i fleksibilna baza

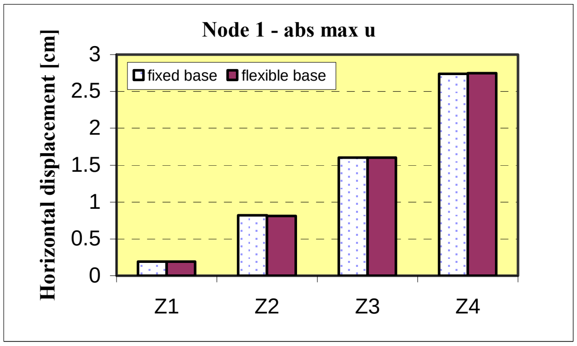

Figure 8. $u_{1,max}$, fixed and flexible base
Slika 8. $u_{1,max}$, fiksna i fleksibilna baza

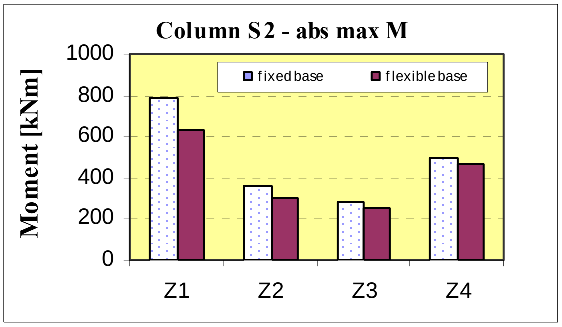

Figure 9. M_{max} pier S2 , fixed and flexible base
Slika 9. M_{max} stub S2, fiksna i fleksibilna baza

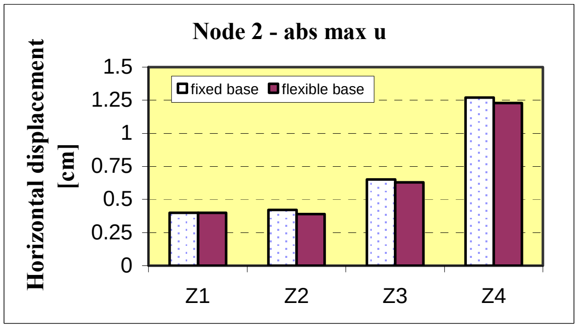

Figure 10. $u_{2,max}$, fixed and flexible base
Slika 10. $u_{2,max}$, fiksna i fleksibilna baza

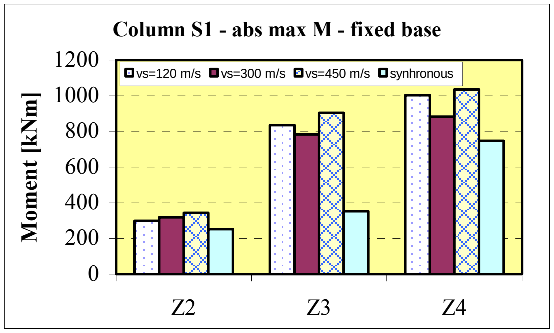

Figure 11. M_{max}, pier S1, fixed-base
Slika 11. M_{max}, S1, uklještenje

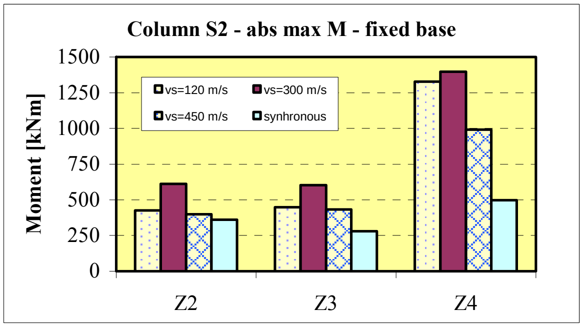

Figure12. M_{max}, pier S2, fixed-base
Slika 12. M_{max}, S2, uklještenje

The temporal variability of the input motions were analyzed for 3 different soil types, with shear wave velocities 120, 300 and 450 m/s respectively. In Figures 11 and 12 shown are the moments at the fixed-base of pier S1, Model 1, and pier and S2, Model 2, due to asynchronous motions of the base, for each soil type, caused by earthquakes Z2, Z3 and Z4, as well as, the moments in the piers due to synchronous motions. Asynchronous motion of supports caused higher values of maximum moments at the base of piers S1 and S2. The maximum bending moment increase observed is 64.4% at pier S2 due to Z4 for the soil characterized with v_s=300 m/s. The increase of the maximum base moment depends on the pier placement and pier height, the velocity of shear waves v_s and the type of earthquake motions. For both piers it is in-between 15 and 65%, which cold not be neglected in the bridge design.

CONCLUSIONS

Having examined impact of the SSI and temporal variability of the input motions on the study of two models of bridge Beska, the following conclusion can be drown:

- The effect of soil-structure interaction on the bridge response is negligible, so the bridge can be treated as fixed in the base of piers.
- The effect of asynchronous motions on pier base bending moments is detrimental. For both studied cases, the increase in the base moments reached 65%, which means that this effect can not be neglected and must be checked for the bridges longer than 400 m [3].

The effects of incoherency and phase changes of earthquake waves as well as the local site effects on seismic motions could be significant, and it will be considered in a future study.

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ACNOLEDGMENT

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