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Izvorni naučni članak

EFFECT OF RELATIVE LENGTH OF COLUMNS ON NONLINEAR RESPONSE OF RC GIRDER BRIDGE

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ABSTRACT
In seismically active areas, inelastic deformations of the members in predefined critical regions are allowed, as long as the structure integrity is provided during strong ground motions. To evaluate these deformations, a nonlinear analysis needs to be conducted. In this paper, nonlinear static and dynamic analysis of reinforced concrete girder bridge, designed according to Eurocode 8, is presented. Analyses are conducted for three cases of different relative length of columns supporting the bridge deck, and the results are discussed. Displacements are determined using the N2 method and compared with results of time-history analysis of the structure subjected to a chosen set of seven pairs of ground motions. Difference in relative column length has significant influence on the results obtained from the analyses.

KEY WORDS: pushover, time-history, nonlinear deformation, displacement, RC bridge

UTICAJ RELATIVNE DUŽINE STUBOVA NA NELINEARNI ODGOVOR AB GREDNOG MOSTA

REZIME
U seizmički aktivnim područjima dozvoljena je pojava neelastičnih deformacija elemenata u prethodno definisanim kritičnim područjima, pod uslovom da je obezbeđen integritet konstrukcije tokom jakih kretanja tla. Kako bi se izvršila procena ovih deformacija, neophodno je sprovesti nelinearnu analizu. U radu je prikazana nelinearna statička i dinamička analiza armiranobetonskog grednog mosta, dimenzionisanog prema Evrokodu 8. Analize su sprovedene za tri slučaja različitog međusobnog relativnog odnosa dužine stubova koji podupiru gredu mosta. i rezultati su diskutovani. Pomeranja su određena korišćenjem N2 metode i upoređena sa rezultatima vremenske analize konstrukcije izložene grupi od sedam parova kretanja tla. Razlika u relativnoj dužini stubova ima značajan uticaj na rezultate dobijene iz analiza.

KLJUČNE REČI: „pushover“, vremenska analiza, nelinearna deformacija, pomeranje, AB most

INTRODUCTION

The basic concept in designing structures in seismically active areas is to assume the development of significant inelastic deformations of the bearing members in predetermined critical regions on condition that the integrity of the entire structure remains preserved. Besides the strength capacity, the appropriate ductility of the structural elements in the critical regions needs to be provided, which is introduced through ductility classes and the behaviour factors. [3] Nonlinear deformations that will occur from the design seismic actions cannot be determined based on the linear design approach, but a more delicate, nonlinear analysis needs to be conducted.

In this paper, a reinforced concrete bridge structure, designed in accordance with Eurocode 8, part 2, is analysed. [4] The aim of the paper is to determine nonlinear response of the structure, depending on the difference in relative length of the columns that support the deck of the bridge

ANALYSED RC BRIDGE STRUCTURE WITH COLUMN LENGTH VARIATIONS

A reinforced concrete girder bridge structure, consisting of three spans, is analysed. Structural model of the bridge, as well as cross section of the deck and supporting columns, is given in Figure 1. The deck is supported on columns of variable length. Three cases are analysed, with the geometric properties given in Table 1.

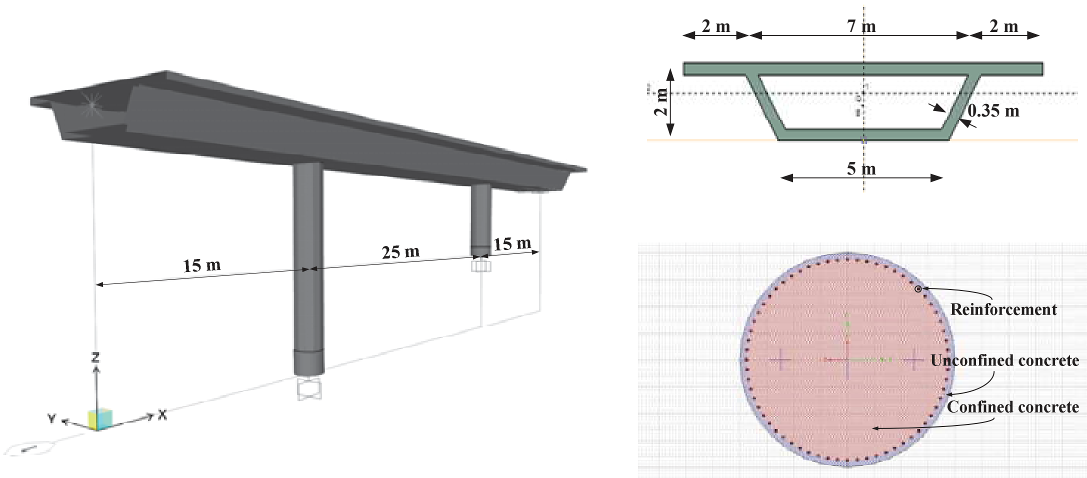

Figure 1. Structural model and the adopted deck and columns cross sections
Slika 1. Model konstrukcije i usvojeni poprečni preseci grede i stubova

Due to the development of diagonal cracks, resulting from the main tension stresses, the torsion rigidity of the deck is reduced to 50 % of the homogeneous cross-section. A ductile seismic behaviour is adopted for the columns, with the behaviour factor $q = 3.5$, which would assume a nearly bilinear monotonic force-deformation behaviour of the elements expected to develop inelastic deformations. Therefore, the analysis is performed using as elastic stiffness the secant-to-yield point flexural stiffness (Annex C [4]), ranging for the analysed cases between 35 % and 37 % of the uncracked section stiffness.

Structural analysis is performed using the software SAP2000 v15.2.1. [6] Modal analysis is conducted for the first five modes that contribute to the overall mass with more than 90 % with the effective modal masses. After estimating the second order effects in the critical regions, design effects are determined based on the combination of permanent and seismic actions, and the control of the adopted longitudinal reinforcement for the columns is shown in Figure 2. Both columns are reinforced with the same longitudinal and spiral reinforcement, adopted for the shorter column.

Table 1. Column properties in the analysed cases
Tabela 1. Karakteristike stubova u analiziranim slučajevima

	Case 1	Case 2	Case 3
Sketch diagram			
Column length (ratio)	14 m – 14 m (2 : 2)	14 m – 10.5 m (2 : 1.5)	14 m – 7 m (2 : 1)
Column diameter	1.7 m	1.8 m,	2.0 m
First mode period	2.07 s	1.52	0.71
Longitudinal reinforcement (ratio)	46Ø25 (1.0 %)	52Ø25 (1.0 %)	64Ø25 (1.0 %)
Spiral reinforcement (ratio)	Ø16/125 (0.8 %)	Ø16/100 (1.0 %)	Ø16/70 (1.2 %)

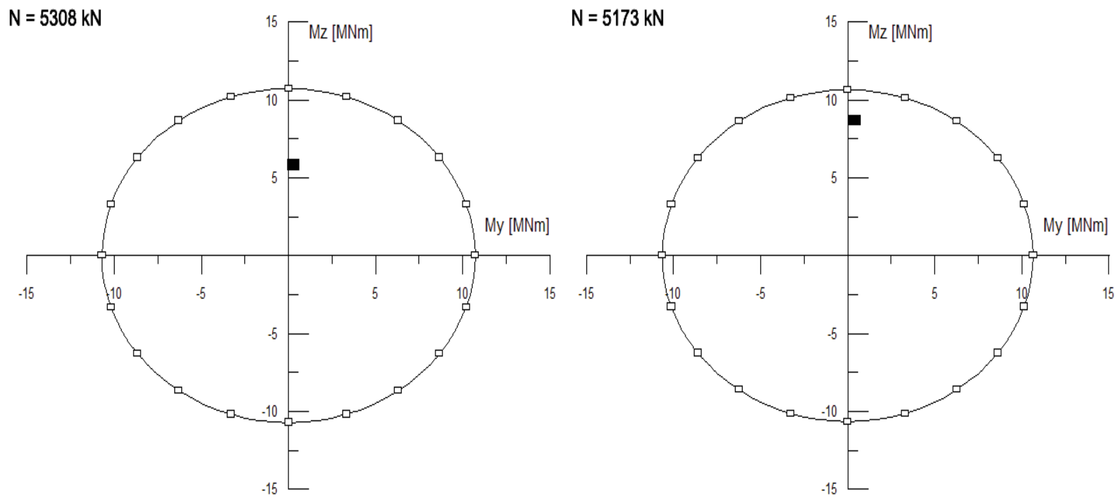

Figure 2. Control of the adopted longitudinal reinforcement – Case 2 (left and right column)
Slika 2. Kontrola usvojene podužne armature – Slučaj 2 (levi i desni stub)

Concrete class C30/37 is used, with nonlinear properties derived from Eurocode 2, part 1-1 [2] (concrete cover of 50 mm) and Eurocode 8, part 2 [4] (confined concrete core of the column). Steel S 500 class C is adopted as the longitudinal and spiral reinforcement. Figure 3 presents stress-strain relations for both concrete and steel reinforcement introduced into the fibre model of the plastic hinge zone, where nonlinear deformations are expected to occur. Geometric nonlinearity is introduced through the P-Δ effects.

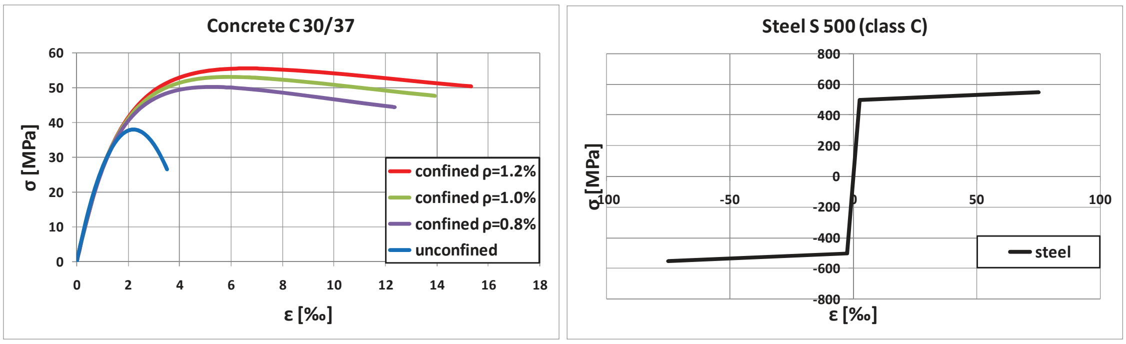

Figure 3. Stress-strain relation for concrete C30/37 and steel S 500
Slika 3. Veza napon-dilatacija za beton C30/37 i čelik S 500

NONLINEAR STATIC AND DYNAMIC ANALYSIS

The assessment of nonlinear deformations in the post-elastic region is performed using both static and dynamic analysis for the analysed cases.

Target displacements for design seismic action are determined based on the pushover analysis of the multi-degree-of-freedom (MDOF) model with the response spectrum analysis of an equivalent single-degree-of-freedom (SDOF) system (Fajfar, 2000) [5]. The so-called N2-method is embedded as a method for calculation of target displacement in Eurocode 8, part 1, Annex B. Pushover curves for the analysed cases are given in Figure 4.

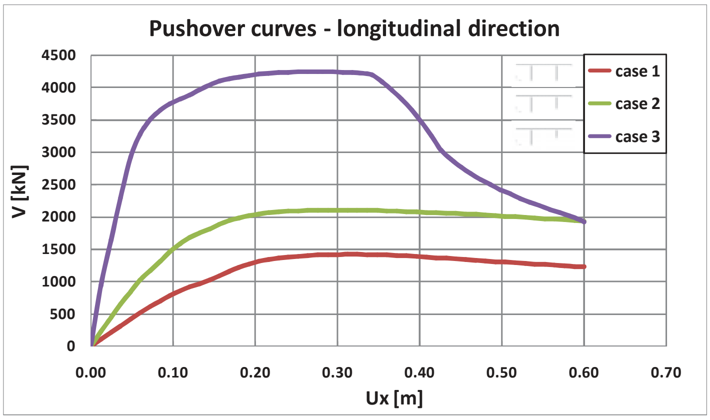

Figure 4. Pushover curves of the analysed cases
Slika 4. „Pushover“ krive za analizirane slučajeve

Time-history analysis is performed for the set of seven pairs of horizontal ground motion components. For each pair, the SRSS spectrum is determined by the square root of sum of squares of the 5 % damped spectrum of each component. The mean spectrum is then formed by taking the average value of the SRSS spectra of the individual earthquakes, and by scaling it so that it is not lower than 1.3 times the 5 % damped elastic response spectrum of the design seismic action. The ensemble response spectrum is shown in Figure 5.

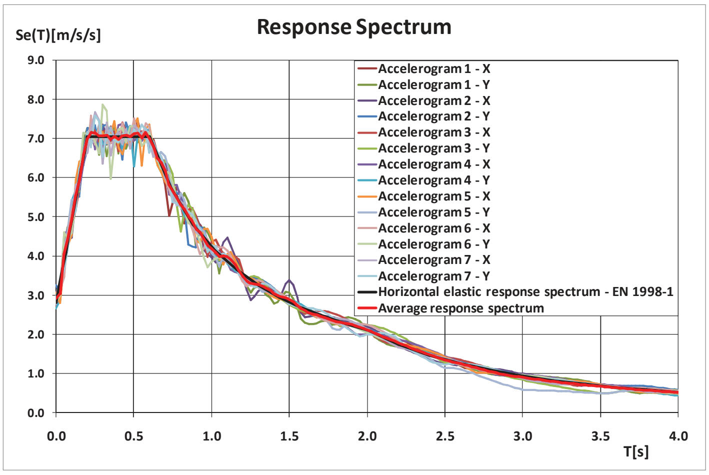

Figure 5. Forming of the mean response spectrum
Slika 5. Formiranje osrednjenog spektra odgovora

RESULTS OF THE STUDY AND DISCUSSION

Analyses results, in terms of displacements of the control node, as well as rotations in the plastic hinge regions of the shorter columns, calculated from the nonlinear static and dynamic analysis (NSA and NDA), are given in Table 2. Rotations are, for the target displacements, calculated based on the strains in the compressed concrete marginal fibres and in tensioned reinforcement.

Table 2. Results of the analyses
Tabela 2. Rezultati analiza

	Case 1	Case 2	Case 3
Sketch diagram			
Yield rotation	0.004694 rad	0.003764 rad	0.002283 rad
Target displacement NSA	21.4 cm	19.3 cm	10.5 cm
Rotation at TD NSA	0.005382 rad	0.010537 rad	0.010010 rad
Mean displacement (ext abs) NDA	18.9 cm	14.9 cm	6.5 cm
Mean rotation (ext abs) NDA	0.004426 rad	0.006672 rad	0.004158 rad
Max displacement (abs) NDA	20.8 cm	16.6 cm	7.2 cm
Max rotation (abs) NDA	0.005252 rad	0.007966 rad	0.005066 rad

Comparing the displacements of the control node, it can be observed that the largest displacements occur in case 1, while the smallest in case 3. In case 1, the first mode period is the longest (T_1 = 2.07 s, belonging to the long period range), which is why the relative displacement is practically independent from the system bearing capacity (Aničić et.al., 1990). [1] The difference between the displacement calculated from static and dynamic analysis is the smallest in case 1, and it increases in case 2 and 3 progressively.

Comparing the achieved local cross-section rotations with the yield rotations, a local ductility demand can be obtained. It can be concluded that the plastic deformation in the critical region of the shorter column has occurred in all three cases, but with much higher values in case 3 than in case 1, although ductile behaviour is assumed in all three cases with the behaviour factor $q = 3.5$. The results for the longer columns in case 2 and 3 have not been presented, as the members remain in elastic response region.

CONCLUSION

Reinforced concrete girder bridge (supported on two columns), designed according to Eurocode 8, part 2, was analysed. Three different cases were included in the analyses, which primarily differ in relative length ratio of the columns. Nonlinear static (pushover) and dynamic (time-history) analyses were performed, to evaluate post-elastic behaviour of the structure. Larger displacements are observed for the system with columns of equal length, while the achieved local rotations of the plastic hinges are larger for the system with columns of different length. Values of displacements obtained from dynamic analyses are lower than the ones determined from static analyses, in all cases that are analysed. Target displacements determined from the N2-method are therefore more conservative and on the safe side. However, both types of analyses confirmed that the fail mechanism was not developed in any case analysed.

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REFERENCES

[1] Aničić D., Fajfar P., Petrović B., Szavits-Nossan A., Tomaževič M: Zemljotresno inženjerstvo, Građevinska knjiga, Beograd, 1990
[2] Eurocode 2: Design of concrete structures, Part 1-1: General rules and rules for buildings, European Committee for Standardization, Brussels, 2004
[3] Eurocode 8: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings, European Committee for Standardization, Brussels, 2004
[4] Eurocode 8: Design of structures for earthquake resistance, Part 2: Bridges, European Committee for Standardization, Brussels, 2005
[5] Fajfar, P.: A Nonlinear Analysis Method for Performance Based Seismic Design. Earthquake Spectra 16(3), 2000: 573-592
[6] SAP2000: Linear and Nonlinear Static and Dynamic Analysis and Design of Three-Dimensional Structures, CSI – Computers and Structures, Inc. Berkley, California, 2009