1st Croatian Conference on Earthquake Engineering
1CroCEE
22-24 March 2021 Zagreb, Croatia

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.141

# Seismic performance of existing bridges in Croatia – shortcomings, hidden reserves and vulnerability assessment perspective

**Gordana Hrelja Kovačević[1], Mladen Srbić[2], Ana Mandić Ivanković[3]**
[1] *PhD Student,* Faculty of Civil Engineering Zagreb, *gordana.hrelja.kovacevic@grad.unizg.hr*
[2] *PhD*, Faculty of Civil Engineering Zagreb, *mladen.srbic@grad.unizg.hr*
[3] *Full Professor*, Faculty of Civil Eengineering Zagreb, *ana.mandic.ivankovic@grad.unizg.hr*

## Abstract

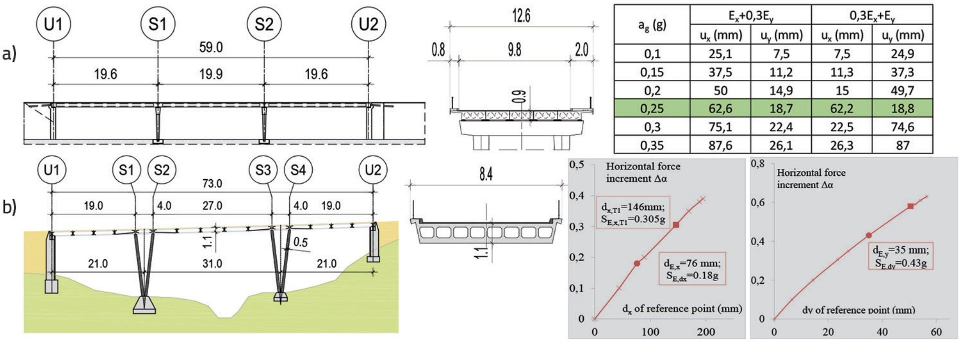
Croatian bridges have been built in different times, always in step with or even ahead of the world's achievements. In seismically active areas it is of paramount importance to design bridges with ductile behaviour. Many bridges built before the modern Eurocodes came into force, were designed according to standards which did not offer provisions for structural detailing facilitating their ductile behaviour. Unfortunately, we learnt hard way that earthquake is a natural phenomenon which can be expected to happen in our country, and which needs to be appropriately considered in the management of the existing transport infrastructure. This is because bridges are often its key elements, and the ability to use them immediately after an earthquake is extremely important.

***Key words:*** existing bridges, seismic load, limit state, fragility curves, capacity curve

Croatian bridges have been built in different times, always in step with or even ahead of the world's achievements. In seismically active areas it is of paramount importance to design bridges with ductile behaviour. Many bridges built before the modern Eurocodes came into force, were designed according to standards which did not offer provisions for structural detailing facilitating their ductile behaviour. Unfortunately, we learnt hard way that earthquake is a natural phenomenon which can be expected to happen in our country, and which needs to be appropriately considered in the management of the existing transport infrastructure. This is because bridges are often its key elements, and the ability to use them immediately after an earthquake is extremely important. The first and most important step in the strategy of bridge infrastructure anti-seismic management is to determine the present state and capacity of existing bridges in regard to their seismic resistance. Depending on the structural system and the materials used, existing bridges may have advantages (e.g., hidden reserves in integral/frame bridges), but also disadvantages (large displacements, insufficient overlap lengths in girder bridges). Ductility levels of older bridges columns with neglected current structural detailing for ductile behaviour, especially those of non-standard cross-sections, the development of plastic hinges and in general their non-linear behaviour, are still subject of research. Thereby, one of the key indicators of seismic capacity is the bending moment-curvature curve. One of the best ways to gain insight into the condition of bridges and to assess seismic vulnerability are fragility curves, which express the probability of a bridge element reaching a certain damage state for a given earthquake parameter [1]. The process of obtaining data for fragility curves involves performing static and/or dynamic analyses on a bridge model for different levels of seismic intensity. Thereby, it is important to determine the input parameters, especially the properties of the elements, as accurate as possible, in order to determine advantages or disadvantages of a single bridge or a group of bridges with similar properties. Two typical bridges are discussed in the following text, regarding seismic behaviour. The bridges are located in high seismicity area with the peak ground acceleration of $a_g = 0.3g$.

The first one is one of the most commonly built bridge types, made of precast prestressed girders, that were built in 1980's [2]. Initially, the cross-section of such bridges consisted only of precast girders, without in-situ concreted slab, such as that comprising precast "SAN" type girders, utilized especially in overpasses and smaller bridges. The static system of each span is simple supported beam, and the girders are supported by elastomeric bearings. These bearings are anchored neither to the superstructure nor to the substructure. The typical span of the bridge is 19,9 m (Fig. 1). The critical elements under the seismic load are bearings, which, at that time, were not designed for displacements due to the earthquake actions. To gain insight into the behaviour of such bridges, linear dynamic analysis – response spectrum method was performed. The analysis was made for different intensities of seismic action and for ground type A. The bearings' displacement ($u_x$, $u_y$) for different seismic intensities, represented by $a_g$ (peak ground acceleration), are shown on Fig. 1. The bearings that were installed on such bridges are elastomeric 200*150*50 mm, so that the maximum displacement due to the earthquake is 70 mm, and it is reached at approximately $a_g$=0.25g. In longitudinal direction, the movement of the superstructure is limited by the abutment, and every displacement larger than the one allowed by the expansion joint, would result in bridge deck pounding into the abutment wall, with probable damage to both, and with crushing of expansion joint device. In the transverse direction, there are no elements limiting the displacements of the bridge deck, so that after breakage of bearings, large displacements may occur, depending on the intensity of the seismic action.

The second bridge type is reinforced concrete frame bridge with "V" shaped piers built in 1963 [3]. The seismic assessement is discussed in [3]. The bridge deck is a reinforced concrete voided slab with the longest span of 27 m. It is supported by V-shaped pier bents and concrete hinge bearings at the abutments. In this case, a linear dynamic analysis does not give a complete insight into the behaviour of the bridge. It was more appropriate to perform a nonlinear static analysis (pushover analysis), in which the bridge structure was loaded with a horizontal load until the target displacement of the reference point was reached. The target displacement was obtained from the linear response spectrum analysis. Pushover analysis was performed in both horizontal directions, longitudinal and transverse. One of the main objectives of the static nonlinear pushover analysis was to determine the force-displacement curve of the structure ("capacity curve") and the deformation requirements of the plastic hinges up to the target displacement. The capacity curves of the bridge in the x-longitudinal and y-transverse directions obtained from the pushover analysis are shown in Fig. 1. For both directions, the target displacement was attained at a level of horizontal seismic force smaller than the largest seismic design load $S_d$.



| $a_g$ (g) | $E_x$+0,3$E_y$ | | 0,3$E_x$+$E_y$ | |
|---|---|---|---|---|
| | $u_x$ (mm) | $u_y$ (mm) | $u_x$ (mm) | $u_y$ (mm) |
| 0,1 | 25,1 | 7,5 | 7,5 | 24,9 |
| 0,15 | 37,5 | 11,2 | 11,3 | 37,3 |
| 0,2 | 50 | 14,9 | 15 | 49,7 |
| 0,25 | 62,6 | 18,7 | 62,2 | 18,8 |
| 0,3 | 75,1 | 22,4 | 22,5 | 74,6 |
| 0,35 | 87,6 | 26,1 | 26,3 | 87 |

**Figure 1. a) Prestressed girder bridge: Longitudinal layout, cross-section and displacements of bearings Reinforced concrete frame bridge: Longitudinal layout, cross-section and capacity curves**

Results of analyses of these two bridge types reveal that they both do not possess sufficient load-bearing capacity for seismic actions, according to currently valid seismic codes. Future investigations should cover analyses of other bridge types in order to obtain data for the construction of fragility curves. Detailing and boundary conditions of each examined bridge type should be considered to find out the appropriate method of analysis and the critical limit states to be investigated.

## References

[1] Hrelja Kovačević, G., Mandić Ivanković, A. (2020): Seismic vulnerability assessment of existing bridges by using fragility curves, 6th Symposium on Doctoral Studies in Civil Engineering, Zagreb, Croatia, 8 pages (in Croatian).

[2] HRVATSKE AUTOCESTE (2007), Monografija,Zagreb: Hrvatske autoceste, HAC.

[3] Franetović, M., Meštrović, D., Šavor, Z. (2012.) Seismic assessment of Obod Bridge in Croatia, The 8th Central European Congresses on Concrete Engineering - The Durability of Concrete Structures, SECON – CSSE, Plitvička Jezera, Croatia, 8 pages.