Seismic Assessment of existing bridges in Croatia

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Summary

Research on development of seismic assessment procedure for existing bridges will be presented in this paper. Both the linear response spectrum analysis and the nonlinear static pushover method are used and results were evaluated following the demands defined by current European seismic design codes. At first, this procedure is validated by its application to major Adriatic arch bridges with spans ranging from 200 m to almost 400 m as a part of an extensive project to develop their appropriate maintenance strategy. Seismic assessment is further developed and their suitability is proved at different bridge types.

Keywords: existing bridges; seismic assessment; linear response spectrum analysis; nonlinear static pushover method.

1. Introduction

A great number of existing Croatian bridges have been designed according to former design codes with no seismic actions taken into the account, so changes in requirements of new standards and deficiencies and degradation during years of service result in different reliability levels for these bridges. In this paper research on development of seismic assessment procedure for existing bridges, is presented. This assessment procedure composed of linear response spectrum analysis and nonlinear pushover analysis is further developed with additional evaluation steps of these assessment methods results.

2. Limit state assessment procedure

In the first step linear multimodal spectral analysis was performed. The performed analyses included the really built in arch reinforcement. Ultimate limit state was deemed as acceptable if no additional reinforcement was necessary ($A_{s,eff.}/A_{s,nec.} = 1.0$). If this was not the case the next step of the evaluation based on non-linear static (pushover) analysis with arch reinforcement limited to real values was necessary. In the second step nonlinear pushover analysis was performed. In the pushover analysis an incremental-iterative solution of the static equilibrium equations is carried out to obtain the response of a structure subjected to monotonically increasing lateral load pattern. The structural resistance was evaluated and the stiffness matrix updated at each increment of the forcing function, until convergence was reached. The non-linear static analysis was carried out in two horizontal directions: in the longitudinal direction x until a target displacement $d_{Tx} = d_{Ex}$ was reached at the reference point at arch crown and in the transverse direction y until a target displacement $d_{Ty} = d_{Ey}$ was reached at the reference point in the quarter point of the arch span. Target displacements in x and y directions d_{Ex} and d_{Ey} were obtained from an equivalent linear multi-mode spectrum analysis with the behaviour factor q=1,0 due to E_x+0,3E_y and E_y+0,3E_x seismic loadings, respectively, applying the effective stiffness of ductile members. The results of the analysis were the partial factors for seismic load γ_{Ex} and γ_{Ey} indicating the level of seismic arch reliability. If partial factors were at least equal to 1,0 ultimate limit states in seismic situation were

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deemed satisfied, if not, the third step of the evaluation was necessary. This step requires development of a probabilistic model of seismic load effect.

3. Assessment of major Adriatic arch bridges

At first the procedure is validated by its application on major Adriatic arch bridges. All arches, except Šibenik Bridge arch, satisfy ultimate limit state in the first step of linear evaluation. However second step of non-linear evaluation is performed for all arches to compare their reliability levels. It is established that linear response spectrum analysis covers the assessment of arches quite good enough because their response under seismic event is generally linear as a consequence of their robustness. Although some authors question the applicability of pushover analysis on arch bridges, the results of this analysis may indicate the level of seismic arch reliability. Additionally, pushover analysis should not be rejected so easily because it is quite applicable on a complete arch bridge structure, especially when we want to evaluate the spandrel columns response and the bridge deck displacements which respond generally in horizontal directions. So, further development of this assessment procedure was necessary.

4. Further development and assessment of three different bridge types

Seismic assessment procedure is applicable for whole bridge structure and it indicates the most critical bridge details and elements in seismic response, which usually are not the aforementioned arches. It is developed from 1st and 2nd step of previously shown procedure for seismic assessment of arches with more evaluation checks taken into the account and its applicability is shown on example of three different bridge types constructed in 1960's.

Assessment method is consisted of linear response spectrum analysis as a first step and nonlinear static pushover analysis as a second step. Each evaluation step gives us answer if appointed demand is fulfilled or not. With these answers we can bring quite precise decisions for seismic retrofit of assessed bridge, which than can be presented to owner of the bridge who will bring the final decision to retrofit the bridge or not. If retrofitting measures will be taken, it is important to apply this same procedure again on the model of retrofitted bridge and evaluate the results in same steps.

In the 1st step the target displacements d_t, retrieved from linear response spectrum analysis, are evaluated and compared with displacements allowed by movement capacity of expansions joints d_{allow}. In the 2nd step the P-Δ curves retrieved from pushover analysis are evaluated. If target displacement d_t is reached under horizontal load P whose intensity is higher than the design seismic load S_e (T_{dom}) bridge condition is classified as satisfactory. In the 3rd step the rotations at locations of potential plastic hinges are evaluated. The verification is performed in a way that the plastic hinge rotation demands $\theta_{p,E}$ are safely lower than the relevant design rotation capacities $\theta_{p,d}$. If the aforementioned steps are fulfilled evaluation is to be continued. Otherwise, the decisions for limitation of displacements may be brought to design table and the most appropriate retrofit measure may be proposed. Even if these steps are not fulfilled it is advisable to continue the evaluation because the following steps can indicate additional weak elements and details of assessed bridge. In the 4th evaluation step the stresses in constitutive materials of the bridge are controlled when target displacement is reached. In regions of potential plastic hinges concrete stresses σ_c should not be larger than the ultimate strength of confined concrete $f_{cm,c}/\gamma_{c,acc}$, and outside of the plastic hinge regions these stresses should not be larger than mean strength of unconfined concrete $f_{cm}/\gamma_{c,acc}$. Stresses in reinforcement σ_s should not be larger than $f_{ym}/\gamma_{s,acc}$. In the 5th step shear force check is done taking into the account additional safety factor against brittle failure ($\gamma_{Bd,1}$= 1,25), so the shear force in elements should not amount more than V_{Rd}/γ_{Bd1}. In the 6th step the possibility of buckling of the longitudinal compression reinforcement A_s between transverse ties A_t is evaluated. If all demands from steps 4 to 6 are fulfilled bridge condition is classified as satisfactory. Otherwise, decisions for strengthening of bridge elements can be brought and in agreement with the owner of the bridge retrofit measures can be undertaken.

As authors expected, some of Eurocode defined design demands are not fulfilled for all bridges. Also, with this assessment procedure quite precise guidance for seismic retrofit of most critical elements of assessed bridges is achieved. So the authors conclude that the presented seismic assessment procedure due to its straightforwardness could easily find its place as everyday tool in bridge weakness detecting, retrofit decision making and seismic retrofit design.