Assessment of bridges in aggressive maritime environment

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Summary

Research on development of assessment procedures for existing bridges exposed to wind load is presented in this paper. Both linear and the nonlinear methods are used and a probabilistic model of wind load is developed. The results were evaluated following the demands defined by current European design codes and specific location conditions. 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.

Keywords: existing bridges; wind load; linear and nonlinear methods; reliability analysis.

1. Introduction

A large number of existing Croatian bridges have been designed according to previously valid codes. Hence, changes in requirements of new standards, time-variability of loadings (such as traffic loading), together with deficiencies and degradation over the years, result in different reliability levels for these bridges. Traffic load increase is essential for the assessment of superstructure, but for concrete arches seismic action or wind load may be crucial for their ultimate limit state or serviceability limit state evaluation. For bridges exposed to wind load, for which limit states are unsatisfied, wind action on the bridge location is to be analyzed in detail, using more accurate methods of failure probability analyses and suitable software.

2. Procedure for Assessment of Limit States

In this paper the limit states assessment procedure for existing bridges exposed to wind load is presented. In the first step analysis, using geometrical non-linearity for elements under compression only, was performed. The performed analyses included the real arch reinforcement. Ultimate limit state was qualified acceptable if no additional reinforcement was necessary ($A_{s,eff.}/A_{s,nec.} = 1,0$). Serviceability limit state was qualified acceptable if limit concrete stress did not exceed ($\sigma_{c,limit.}/\sigma_c = 1,0$). If this was not the case, the next step of the evaluation was necessary. In the second step full non-linear analysis, with arch reinforcement limited to real values, was done. Using material and geometrical non-linearity, wind load was increased in steps until reaching the limit state. The ultimate limit state was defined as a prescribed ratio of lateral displacement of the arch crown d to the arch span L, and the serviceability limit state as a reduced value of concrete compressive stress $\sigma_{c,limit}$. The results of the analyses included partial factors for wind load, both for ultimate $\gamma_{w,ULS}$ and serviceability limit state $\gamma_{w,SLS}$. For the third evaluation step the probabilistic model of wind load according to Probabilistic Model Code [4], utilizing the Gumbel distribution was developed. This procedure runs through steps that become more complex and therefore more accurate: if limit states of the bridge are satisfied in the first step the following more complex steps are not necessary. If this is not the case, the next step of the evaluation, which will give more accurate results, is to be performed.

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3. Assessment of Adriatic arch bridges

This assessment procedure is validated by its application to major Adriatic arch bridges which are exposed to the effects of sea salt and bora - wind which, in some specific locations of the coast, with its turbulent action together with local terrain shape, exceeds the maximum reference wind velocity of 35-40 m /s. There are six major reinforced concrete arch bridges in Croatia located on the Adriatic coastline, with spans ranging from 200 m to almost 400 m. Four arch bridges, the Šibenik Bridge (246,4 m), the Pag Bridge (193,2 m) and the Krk Bridges (two arches 244 and 390 m) were built during the sixties and the seventies of the 20th century. Two major bridge structures Maslenica (200 m) and Skradin (203 m) Bridges were constructed more recently on Croatian motorways, Maslenica Bridge in 1997, and Skradin Bridge in 2005.

Over the years many deficiencies and rapid degradation were identified on older Adriatic bridges. The combination of aggressive exposure conditions, poor detailing, neglecting durability problems and construction errors resulted in serious deterioration of structural members, with reinforcement corrosion being a major issue. The analyses of these bridges designed according to different design codes, thus with different reliability levels, is a relevant issue of their maintenance strategy. According to the reference wind velocity map given in a new Croatian National Application Document for Sibenik bridge, reference wind velocity for the bridge without traffic loading is 36,1 m/s, for Pag bridge 36,4 m/s, for Krk bridge 42,7 m/s for Maslenica bridge 54,5 m/s and for Skradin bridge 37,24 m/s. For those bridges under traffic wind velocity of 23 m/s is used. According to a Croatian reference wind velocity map it is possible to reduce wind loads using a directional factor c_{DIR}. Based on the analysis presented in this paper limit states of arches exposed to wind are acceptable except for the large Krk I Bridge.

4. Detailed assessment of Sibenik arch bridge

Šibenik Bridge spanning 246 m with a rise of 30,8 m is located in the zone of reference wind velocity of 35 m/s. The bridge design concentrated on solving the construction problems since very small concrete cover was utilized, which subsequently led to durability problems.

In the first step analysis, the bridge exposed to wind load is assessed using geometrical non-linearity for elements under compression. The analysis is carried out in two horizontal directions separately for wind load acting longitudinally to the bridge axis and for wind load acting transversely to the bridge axis and results in necessary reinforcement for the arch and the piers. Based on the results of the linear analysis the following conclusions are established: The most critical zones of the arch are near the both arch springs in the 8% of arch length where the necessary reinforcement is 3-3,8 times larger then the provided amount; The most critical piers are those near the arch crown where the necessary reinforcement is 6 times larger then the existing value.

In the second step a full non-linear analysis, using material and geometrical non-linearity was done. Wind load was increased in steps until reaching the limit state with the real arch reinforcement. In this assessment step three analysis levels are done. At first, the analysis is done for all elements of the arch and of piers. The result of this analysis level is a partial factor for wind load $\gamma_W = 1,25$ which is less then a prescribed normative value $\gamma_W = 1,5$. As linear analysis showed that piers near the arch crown are the most critical ones, in the second non-linear analysis level these piers are disregarded which resulted with the acceptable partial factor $\gamma_W = 1,7$. In the third non-linear analysis level only arch elements are considered which results in the partial factor for wind load $\gamma_W = 1,9$. Hence, the arch has higher safety then arch together with the piers.

In the third assessment step, estimating the reliability index ß of the bridge, inversed first-order reliability method (FORM) with standardized sensitivity factors is adopted. The target reliability level for the ultimate limit state and the reference period of 50 years is chosen from the Probabilistic Model Code for large consequences of failure and high relative cost of safety measures as $\beta_{target,ULS}$=2,6. It was concluded that the estimated reliability level for Šibenik bridge is insufficient for the whole bridge. If the crown piers are disregarded, this results with acceptable reliability level of the arch and all other piers.

A more detailed analysis of Šibenik bridge shows different reliability levels of different elements of the arch bridge leading to a priority determination - which parts of a bridge are more critical and need adequate reinforcing.