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Comparative analysis of modal responses for reinforced concrete (RC) straight and curved bridges

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Abstract

On the territory of Montenegro, road straight and curved bridges with middle range spans are often frame structures with multi column bent type and a capping beam. This paper presents the response of tree RC bridges: two curved bridges (with radius R=250 m i R=150 m) and one straight bridge. Bridges under consideration are frame structures with multi column bent (two circular columns) and capping beam integrated into the deck. Skewness of the bridge bent is also considered in this paper. Tree angles of skew are analyzed: 0˚, 20˚ and 30˚. Significant mode shapes are obtained through modal analysis. Comparative analysis of modal responses is carried out and conclusions about the influence of skewness and horizontal curve on modal shapes and periods of vibrations are made. Static-nonlinear analysis was performed for all nine bridge prototypes. The obtained results were compared and conclusions about influence of considered geometric parameters were made.

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Keywords: RC curved bridge, modal analysis, skew bridges, multi column bent, pushover analysis

1. Introduction

Designing bridges on highway access roads as well as intersections in densely populated urban areas imposes specific requirements related to the geometry of these structures. The priority in contemporary bridge design is on saving time and space rather than the other socio-economic aspects such as direct costs of constructing. This approach shifts the traditional boundaries of conceiving, designing and constructing bridges. General tendencies in

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modern bridge engineering imply wider spans, smaller radius of curvature and increased column skewness. As a result of introduction of these geometric conditions the bridge becomes an irregular structure with irregular behaviour under both vertical and horizontal loads.

Designing bridges with horizontal curvature, as well as bridges with skewed columns is generally inadequately covered with Codes and Guidelines for design of bridges. In one of its parts, the EN 1998: 2 code for designing earthquake-resistant structures discusses bridges with skewed columns, prescribing additional torsion effects due to skewed bents. Curved bridges are not specifically treated in European standards. The 2003 AASHTO (American Association of Highway and Transportation Officials) specifications provide guidelines for designing horizontally curved steel bridges. Horizontally curved concrete box-girder bridges were analyzed in the research report issued by the American TRB association (Transportation Research Board) in 2008 [1]. The above report discusses modelling, treating of moving load, abutments unseating, dimensioning deck structure for shearing, as well as other problems occurring in the superstructure as a consequence of bridge curved alignment. The dynamic and seismic response of horizontally curved bridge structures and bridges with skewed columns were not discussed in this report.

This topic has been analyzed by several papers. Tondini and Stojadinović [2] in their research analyze the influence of the radius of curvature and the height of columns on dynamic properties and seismic response of the bridge. The research was carried out on bridges with columns with single circular cross section. The results showed that in some cases the reduction of radius of curvature leads to increased combination of modal responses in longitudinal and vertical direction. It was found that the reduction of the radius of curvature leads to an increase in elastic stiffness and shear capacity of tested bridges. The effect of column skewness on seismic response was investigated for straight bridges [3], [4]. It was concluded that increasing column skewness also increases the structural vulnerability, especially for bridges with seat-type abutments. Further research were also recommended, involving variations in the shape of central columns, influence of skewed columns on curved bridges, analysis of short bridges, analysis of collapse and other levels of damage.

This paper analyzes the dynamic properties of reinforced concrete (RC) tree span frame bridge with box girder deck section, by varying the following parameters: the radius of horizontal curvature and the column skewness angle. The box girder cross-section was selected for the deck structure as it is widely used in curved bridges due to its high torsional capacity. The bridges under consideration were frame structures with multi column bent (consisted of two circular sections) and capping beam integrated in the deck structure. In curved bridges central columns are rarely skewed, but an increase in the number of such solutions is expected for bridges in built areas [1]. The period and shapes of vibration were obtained using modal analysis. A nonlinear static ("pushover") analysis for the considered structural prototypes has also been conducted. The aim of the research was to define the effects of varied parameters on dynamic properties of the bridge, as well as on bearing capacity and deformation of these structures. The analysis of response was carried out on a total of nine structural prototypes. Three angles of column skewness in relation to the axis of the bridge were considered (0^o, 20^o, and 30^o) and three values for the radius of horizontal curve: straight bridge (R = inf), R = 250m and R = 150m).

2. Description of bridge prototypes and bridge modelling

A bridge prototype with three spans was investigated, with central span of 40m, and end spans of 32m (Figure 1). The total length of the bridge is 104m, including both the straight and the curved bridge alignment. In the curved bridges span length were measured along the circular arc. The box girder deck section is 10 m wide and 2.5 m high. The height of columns between the foundation and the deck structure is 10m. They are restrained in the foundation structure. The connection between the column and the deck structure was monolithic. The cross-section of the column bents are two circular column of 1.4m diameter, with the cap beam integrated in the deck structure. Above the abutments, the bridge structure rests over 4 elastomeric bearing with allowed movements in longitudinal direction. The characteristics of concrete correspond to class C30/37. The quality of reinforcement is B500B.

The structure was calculated using a spatial linear model constructed in the SAP 2000 v.14 software package [8]. In curved bridges, the actual curvature of the bridge was taken into account. Each span was modelled by ten line elements for the approximation of bridge deck curvature in horizontal plane. The deck structure was modelled using line "frame" elements with the properties of un-cracked concrete cross-section. Based on the column cross-sections, effective flexural stiffness was specified and calculated in accordance with Annex C: EN 1998-2 [7]. At the location