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Seismic Vulnerability Assessment of Horizontally Curved Multi frame RC Box-Girder Bridges Considering the Effect of Column Heights and Span Numbers

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ABSTRACT: Bridges are known to be one of the most vital and vulnerable components of any transportation system. A majority of highway bridges in the world have curved superstructure configurations and also have in-span hinges. The curvature and in-span hinges in multi-frame bridges lead to significant differences in bridge dynamic response during seismic excitations. This article explores the seismic response of concrete curved bridges considering columns height differences and the effects of span number. Five bridge models have been studied including: a four-span bridge model with equal column height as the base model, two bridge models with non-uniform columns height, a three-span bridge and a five-span bridge models having different span numbers. Several dynamic non-linear time history analyses are performed based on seven different records. The results showed that increasing the height of columns and reducing the number of spans in this subclasses of bridges lead to increase the peak of columns drifts and consequently the bridge seismic vulnerability.

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1- Introduction

Bridges are known to be one of the most vital and vulnerable components of any transportation system. The loss of one or multiple bridges in a region can hamper recovery activities and can severely impact the economy of that region. Therefore, it is vital that bridges remain operational in earthquakes [1-3]. A majority of highway bridges in the world have curved superstructure configurations and also have in-span hinges. The curvature and in-span hinges in multi-frame bridges lead to significant differences in bridge dynamic response during seismic excitations.

Due to the large number of curved concrete bridge structures in high seismic zones, the effects of bridge irregularity on their seismic vulnerability should be investigated. Curved bridges need more attention than straight bridges because of their complicated seismic behavior.

Tondini and Stojadinovic (2012) [4] studied the influence of deck radius on the seismic behavior of one simple type of curved box-girder concrete highway overpass bridges commonly built in California. In their study, analytical samples were based on five-span, concrete box-girder bridges. All considered bridge models had single-bent columns and no uncertainties were assumed for material properties or bridge geometry. The only variable parameter in their study was the bridge deck radius. The effects of foundations, abutments, shear keys, and bearings on overall seismic response of bridges were neglected in their research. They considered the bridge column drift ratio as a demand parameter. Their findings showed an increase in the demand for curved models. Mohseni (2012) [5] studied the curved highway bridge responses using fragility analysis. The analysis results declared noticeably higher vulnerability of curved steel bridges, compared with straight bridges with the same structural system.

This article explores the seismic vulnerability of RC curved bridges considering columns height differences and the effects of span numbers.

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2- Analytical Models

Three-dimensional analytical models considering geometric and material nonlinearities are created in the [1]CSI Bridge platform. Figures 1 to 3 illustrate the configuration of the bridge models.

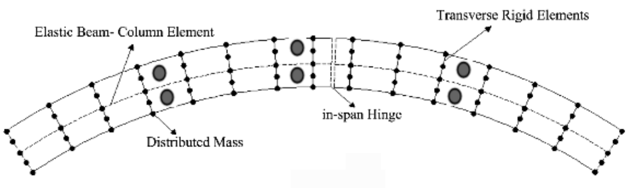

Figure 1. Analytical model of the bridge: (deck horizontal plane)

1 Computers and Structures, Inc

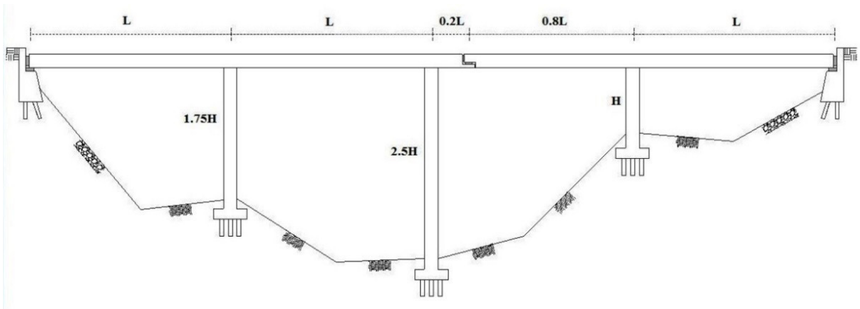

Figure 2. Considered bridge model elevation having non uniform columns height

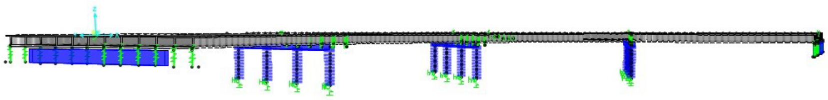

Figure 3. 3D considered bridge model having uniform columns height

Table 1. The geometric configurations for considered bridge models

Specifications of the bridge model	Unit	5 span	3 span	h-h-h	1.25h-1.5h-h	1.75h-2.5h-h
Number of columns for each bent	number	4	4	4	4	4
Height of the columns	m	5.8	5.8	5.8	5.80-8.70 -7.25	5.80-14.50-10.15
Diameter of each column	m	1.53	1.53	1.53	1.53	1.53
Number of column rebars (11#)	number	42	42	42	49	54
Stirrap gaps in columns (4#)	m	0.3	0.3	0.3	0.3	0.3
span length	m	26.48	44.13	33.1	33.1	33.1
Span winth	m	33.5	33.5	33.5	33.5	33.5
Box girder segments	number	11	11	11	11	11
Deck total heigth	m	1.46	1.46	1.46	1.46	1.46
Top flang thikness of boxgirder	m	0.2	0.2	0.2	0.2	0.2
Bottom flang thikness of boxgirder	m	0.2	0.2	0.2	0.2	0.2
Web thikness of boxgirder	m	0.3	0.3	0.3	0.3	0.3
Axe to axe distence of deck segments	m	2.86	2.86	2.86	2.86	2.86
Foundation displecemental stiffness	kN/mm	7.06	7.06	7.06	7.06	7.06
Foundation rotationall stiffness	kN/mm	0	0	0	0	0

The results of non-linear time history analyses are used to develop seismic demand models. To consider the effects of column heights and span numbers on the vulnerability of the bridges, beside basic model having uniform columns height, four different bridge models having different column height and different span numbers are considered for four-span curved bridges with the typical span length of 33 m which is the median span length of this bridge inventory in California (Ramanathan 20120) [6]. Structural characteristics are assumed to be constant during modeling changes. Bridge geometric configurations, column specifications, the box-girder specifications and other structural details for considered bridge models are adopted from (Ramanathan 2012) and the box girder section properties can be calculated accordingly. The geometric configurations for considered bridge models are summarized in Table 1 [6].

3- Insights from non-linear Dynamic Analysis of Considered Bridge Models

Three dimensional analytical models considering geometric and material non-linearities are created in the CSI bridge platform. The results of non-linear time history analyses for seven different records are used to develop bridges seismic demands. In order to find the effect of column heights and span numbers on the vulnerability of bridges, five subclasses of multi-frame curved bridges are produced to compare the columns lateral drifts considering different column heights and span numbers. Figure 4 shows the average column drifts in the longitudinal and transvers directions. The Visual screening of this figure indicates that the bridge model having columns irregularity becomes more fragile and also by decreasing the bridge span numbers the columns drifts increased.

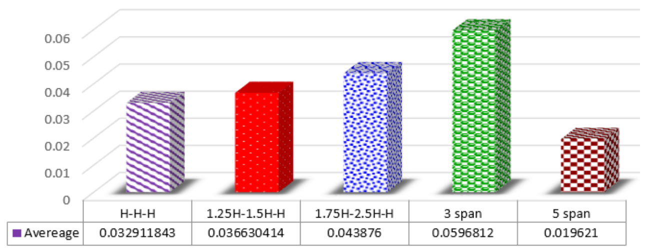

Figure 4. The average column drifts in longitudinal and transvers direction for bridge models

4- Conclusions

This article investigates the effect of bridge column heights and span numbers on the seismic vulnerability of horizontally curved multi-column RC box-girder highway bridges with in-span hinge, seat type abutments and seismically designed columns. The impact of column heights and span numbers is investigated for longitudinal and transvers bridge column drifts that represents the main seismic demand parameter in this class of highway bridges.

Comparison of the average drift values of bridge columns for various column heights revealed that columns irregularity is an important parameter that results in elevated seismic demands and adversely affects the seismic vulnerability of this bridge type.

In comparison to investigated base bridge model having uniform column height (namely H-H-H), the maximum drift ratio of bridge columns in bridge models with 1.25H-1.5H-H and 1.75H-2.5H-H columns height in longitudinal direction of the bridge deck increased 11 and 33 percent, respectively. Moreover, it is found that by decreasing the bridge span numbers, the columns drift ratio would be increased. The maximum drift ratio of columns in bridge models having 3 spans in longitudinal and transvers directions increased 63 and 81 percent, respectively in comparison with 4 span bridge model. Whereas in bridge model having 5 spans, in longitudinal and transvers directions the maximum columns drift ratio decreased 27 and 40 percent, respectively in comparison with 4 span bridge model. Finally, it is found that the maximum drift ratio of columns in bridge models increased significantly by increasing the column height and decreasing the span numbers.

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