Numerical simulation of curved bridge subjected to earthquake induced pounding

Zhipeng Wang, Guangjun Sun and Hongjing Li
School of civil engineering, Nanjing Tech university, No 30, PuzhuSouthouse Road, Nanjing 211800, china.
Email: wangzhipeng@njtech.edu.cn

Abstract. Due to the plane geometry of the deck of curved girder bridge, the girder of the bridge will revolve under the excitation of earthquake, leading to impacts between the curved girder and the bridge abutment. In this paper, the 3D finite element model of an actual curved girder bridge is established by combining the ABAQUS finite element software with the arbitrary contact search algorithm, and the influence of the impact effect on the seismic response of the curved girder bridge is analyzed. The results show that the impact effect increases the risk of beam falling at the outer corner, and reduces the risk of the axle direction. The impact of non-coaxial contacts on the internal force of the fixed support and the pier under fixed support is greater, and the internal force of the sliding bearing and the bottom of the pier are affected by the sliding direction of the bearing.

1. Introduction
The earthquake will cause the collision of the superstructure of the bridge, for example, the collision of adjacent beams across the expansion joints, the collision between the girder and the bridge abutments. The influence of impacts to the damage of bridge components and collapse of bridges cannot be ignored. Impacts with friction are a complex nonlinear problem. At present, the study of collision phenomenon is mostly through some simplified models. The previous scholars' research can be divided into two processes: first, explaining the impact phenomenon with the existing theoretical knowledge, and then various collision models (such as contact elements models, rigid body contact models, etc.) are established. The influence of various factors (geometry, contact stiffness, damping, etc.) is considered in these models; second, analyzing the seismic pounding behavior of an actual bridge with these proposed contact models and studying the influence of impacts on the whole bridge and the bridge components. Finally the influence of impact on the actual seismic performance of the bridge is obtained. Contact element model is a widely used simulation method. The method uses spring and dampers to model the contact process. The contact point is predefined. After the earthquake closes the contact point, the spring is used to simulate the force and the damper is used to simulate the energy dissipation. In the actual earthquake damage, the position of the collision is unknown, so this method has great limitation. In this paper, a more reasonable three-dimensional contact friction model is realized by using ABAQUS software.
2. Bridge Finite model
The object of this study is a three span continuous curved girder bridge, and the finite element model of the bridge is established in ABAQUS software. The material of girder and pier is C50 concrete. The detailed parameter is displayed in the following picture 2. Fixed bearing are set at the inner side of the bridge and sliding bearing are set at the outer side of the bridge.

This paper uses the concrete constitutive structure proposed by McKenna considering the tensile strength. The steel reinforcement constitutive model uses the multi-break line model proposed by QuZhe to consider the degradation of bearing capacity of steel bars. In most of today's finite element software, the bridge structures are usually simulated with solid elements, which will make the calculation more accurate, but greatly increase the workload of the calculation. In this paper, the solid element is adopted in the partial damage part, and the beam element and shell element are used in the rest, which can effectively shorten the computation time. The flat interface assumption and the internal force balance condition are used to deal with the interface connecting of different size models.

The three-dimensional contact friction model proposed by Zhu is realized in ABAQUS software to simulated contact. In this method, the contact search algorithm is used to determine to contact place. It can be point to surface contact or surface to surface contact and the contact is non-coaxial and frictional.
3. Ground Motion Input
The seismic wave input shown in Figure 4 is recorded by the Imperial Valley earthquake H-E04230 station. In order to expand the effect of earthquake induced impacts and make the law more obvious. The peak acceleration of ground motion is adjusted to 1g. The grounding motion is inputted along the End to end connection direction of the bridge. Only the first 10 seconds calculating results are selected. The influence of soil is not taking into account in this paper.

![Ground Motion Input](image)

**Figure 4.** Time history of grounding motion

4. Numerical Results
The impact will cause great changes in the girder displacement. The impact will aggravate the damage of the pier, support and other components, and ultimately lead to the beam falling. The impact of the collision on the displacement of the curved beam is shown in Figure 5. The non-uniform impact between the curved girder and abutment increases the axial positive displacement and tangential negative displacement of the deck. The axial positive displacement means the deck will move towards abutment, it will reducing the axial drop risk; Tangential negative displacement means that the curved beam moves towards the outside along the radius and the increasing of tangential negative displacement indicates that the collision effect may cause the tangential displacement of the deck to be too large, and then the falling failure occurs at the outer corner point.
The impact effect increases the displacement of the girder and the internal force of the pier changes. Taking pier 2 as an example, the influence of collision on internal force of pier is analyzed. Through the analysis, it is found that the increases of shear and torque of the pier are more obvious when the collision occurs and they are restored to the normal value after the end of the collision; The collision effect has a great influence on the axial moment of the outer pier and the tangential moment of the inner pier, which is related to the type of bearing arranged on the pier. The outer bearing is a tangential sliding bearing, the inner side is a fixed bearing, and the sliding direction affects the moment of the pier; the axial force of the pier is not affected by the collision.

**Figure 5.** Time history of deck

(a) Axial shear of inner pier (b) Tangential shear of inner pier (c) Axial force of inner pier

(d) Axial moment of inner pier (e) Tangential moment of inner pier (f) Torque of inner pier

(g) Tangential shear of outer pier (h) Axial shear of outer pier (i) Axial force of outer pier
Bearing is a very important structure in the bridge. It can transfer loads and coordinate the displacement between girder and pier. If the bearing is damaged under the earthquake, the whole bridge will probably collapse. Table 4-1 and Table 4-2 show the peak values of the horizontal and vertical forces of the four bearings, in which horizontal force is the resultant force of the bearing plane forces. It can be seen from the table that the peak force of bearing is always greater than that without impact, whether horizontal or vertical. In particular, the influence of horizontal force on the fixed bearing of curved bridge is most obvious. Under the excitation of the earthquake, the horizontal force of the fixed bearing is increased by 3 times. The influence of the horizontal force on the outer sliding bearing is not very large, and the vertical force increases with the impact, whether it is a fixed bearing or a sliding bearing.

Table 1. Max horizontal force of bearing (1×10^6N)

| Bearing number | 1      | 2      | 3      | 4      |
|----------------|--------|--------|--------|--------|
| Pounding       | 0.966  | 0.299  | 0.961  | 0.304  |
| No-pounding    | 0.352  | 0.247  | 0.337  | 0.267  |

Table 2. Max vertical force of bearing (1×10^6N)

| Bearing       | 1      | 2      | 3      | 4      |
|---------------|--------|--------|--------|--------|
| Pounding      | 1.98   | 2.11   | 1.84   | 2.14   |
| No-pounding   | 1.54   | 1.65   | 1.59   | 1.71   |

5. Conclusion
(1) The non-uniform impact effect increases the tangential negative displacement of the main beam, increases the risk of the falling beam at the outer corner of the deck, and increases the axial positive displacement, which reduces the possibility of the axial beam falling, but increases the impact opportunities between the curved deck and the abutment.
(2) The influence of the non-uniform collision on the pier internal force is influenced by the type of the bearing; it has great influence on the shear force and torque of the pier under the fixed support and it is effected by the sliding direction of sliding bearing, but it has few effect on the axial force of the pier.
(3) The non-uniform impact has a great influence on the horizontal force of the fixed bearing, the horizontal force of the sliding bearing is slightly increased, and the influence on the vertical force of the bearing is independent of the type of the fixed bearing.

References
[1] Amjadian M, Agrawal A K. Rigid-Body Motion of Horizontally Curved Bridges Subjected to Earthquake-Induced Pounding[J]. Journal of Bridge Engineering, 2016, 21 (12).
[2] Zhu P, Abe M, Fujino Y. Modelling three-dimensional non-linear seismic performance of elevated bridges with emphasis on pounding of girders[J]. Earthquake Engineering & Structural Dynamics, 2010, 31 (11):1891-1913.
[3] Banerjee A, Chanda A, Das R. Seismic analysis of a curved bridge considering deck-abutment pounding interaction: an analytical investigation on the post-impact response[J]. *Earthquake Engineering & Structural Dynamics*, 2017, 46 (2).

[4] Dimitrakopoulos E G. Seismic response analysis of skew bridges with pounding deck–abutment joints[J]. *Engineering Structures*, 2011, 33 (3):813-826.

[5] Muthukumar S, Desroches R. A Hertz contact model with non-linear damping for pounding simulation[J]. *Earthquake Engineering & Structural Dynamics*, 2010, 35 (7): 811-828.

[6] Amirihormozaki E. Analytical Fragility Curves for Horizontally Curved Steel Girder Highway Bridges[J]. *Dissertations & Theses - Gradworks*, 2013.