STUDY ON COLLISION PERFORMANCES OF CONVEX-CURVED STEEL RAILING

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ABSTRACT

This paper presents numerical results of heavy truck impacts with convex-curved steel railings. The railings named M-type are developed to meet new improvement functions in the Japanese specifications revised since 2004. LS-DYNA 3D is used to analyze the collision of railings under impact with heavy truck. Japanese specifications require four standard performances for railing as: (1) to prevent vehicles from leaving the road; (2)to guide vehicles back to the line of the road; (3) to protect occupants; and (4)to prevent projection hazard of the railing. However, analysis and design of convex-curved railings have not concerned in such specifications and some engineers suspected that curved railings are more disadvantageous than the straight one. Thus, the objective of this study is to satisfy the collision performances of M-type convex-curved railings and to verify the above suspicion of engineers.

Keywords: dynamic numerical analysis, impact collision, curved steel bridge railing, performances of railing, LS-DYNA 3D, finite element model.

1. INTRODUCTION

The curved railings are safe facility installed on the curved bridges and roads. The railings are made of concrete and metal materials, and classed into the rigid and flexural types, respectively. Railings are required to meet four standard performances by the Japanese specifications - (Japan Road Association 2008) following as: (1) prevent vehicles from leaving the road; (2)guide vehicles back to the line of the road; (3) protect occupants; and (4) prevent projection hazard of the railing.

The performances of straight and curved railings were reported by some researchers. The design and analysis of an bridge railing were satisfied under test level three and four conditions of NCHRP report 350 - (Ray et al. 2009). The performances of concave-curved railings were investigated under impact with larger angles of heavy truck collision - (Thanh and Itoh 2012). Collision performances of curved railing were studied by using the numerical simulations by LS-DYNA 3D - (Thanh and Itoh 2013). New type railings met improvement functions in Japanese specifications revised since 2004 were developed and satisfied by numerical model - (Thanh et al. 2013). Performances of curved railings were investigated and compared with that of straight one in the same collision conditions - (Itoh and Thanh 2014).

The convex-curved railings used on the convex-curved bridges and roads have to meet four standard requirements similar to the other ones. However, the Japanese specifications have not concerned the design and analysis of curved railings and some engineers have suspected that the curved railings are more disadvantageous than the straight one. In addition, since 2004, a landscape-friendly appearance and a flow in the road user's view from bridges are two improvement functions involved in the Japanese specifications for design and analysis of railings. Those functions lead to change the railing design concept with requirements of slender and smaller form. Thus, the objective of this study is to investigate the collision performances of new railing type with improvement designed form and to verify the above suspicion of engineers.

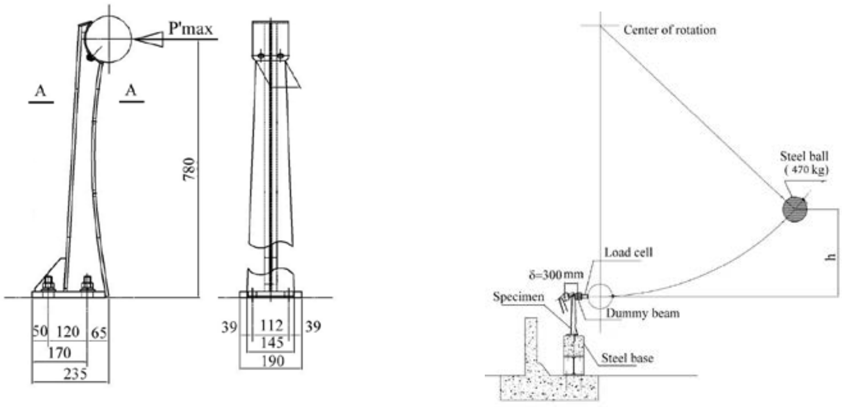
A full-scale test is the ideal methodology for this study but such kind of test requires much effort and extensive cost. Thus, numerical simulation is relied for this study, in which, the collision performances of railing posts are satisfy by experiment test. Finite element models of post are developed. Those models are qualified by comparing the numerical and experimental results. LS-DYNA 3D is used to model the collision of railings under impact with heavy truck. The railings investigated in the present research are designed with grade A and subjected to collision conditions of truck with weight 25 tons (245 kN) and velocity 45 km/h and impact angle 15^o. The results of study are presented in Chapters 2 and 3. The last chapter is conclusions and summaries of this study.

2. DEVELOPMENT OF NEW TYPE OF POSTS

New type of railing post named M-type is developed in this study with its geometry and feature as showed in **Figure 1 (a)**. Collision performances of post are verified by an experimental test, in which the post is subjected to a heavy steel ball with mass 470 kg as shown in **Figure 1 (b)**. The experimental test of post is studied by finite element model using LS-DYNA 3D. The numerical simulation is verified by comparing the curve of displacement – time relationship between experimental and numerical results as shown in **Figure 2**.

The post flanges and web are made of SS400 steel and modelled as an isotropic elasto-plastic material conforming to von Mises yield criterion with Young's modulus of 206 GPa, Poisson's ratio of 0.3 and yield stress of 235 MPa. The post flanges and web modelled as four-node shell elements. The steel material is considered an effect of strain rate. The post is end-fixed.

The comparison of numerical and experimental results for M-type post in **Figure 2** shows that the numerical displacement curve is close to the experimental one with the maximum displacements of 322 mm and 330 mm, respectively. The collision behaviors of post studied by using LS-DYNA 3D are close to that of experimental one. The posts meet standard requirements in the Japanese specifications. The simulations of post can be adopted to investigate the performances of railing subjected to the truck collision.



(a) (b)

Figure 1. Railing post features: (a) M-type post and (b) the experimental collision test of posts (Unit: mm)

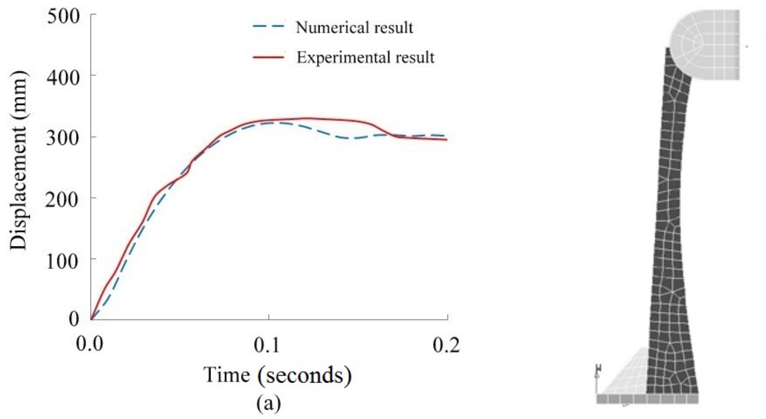


Figure 2. Numerical results of post subjected to heavy ball load: (a) Comparison of numerical and experimental results and (b) Finite element model of posts

3. PERFORMANCES OF CONVEX-CURVED RAILINGS

The post model successfully developed in the previous chapter is adopted to improve the railing simulations. Similar to post name, new type of railing model is called as M-type. The railing is simulated including post, beam and concrete curb. All railing types have the grade A and under impact with truck weight 25 tons (245 kN) and velocity 45 km/h and impact angle 15^{o}.

3.1. Finite element model of railings

Figure 3 presents the finite element model of M-type railing. The railing top, upper and lower beams are of tubular cross-section and created as four-node shell elements. The steel material of beam is modelled as an isotropic elasto-plastic material following to von Mises yield criterion with Young's modulus and yield stress of 206 GPa and 281 MPa, respectively. The material model in

LS-DYNA is considered the strain rate effect of steel with the strain hardening started from 0.0014 and an initial strain hardening modulus of 4.01 GPa (2% of the Young's modulus). The concrete curb is simulated as a typical elasto-plastic material and considered as end fixed.

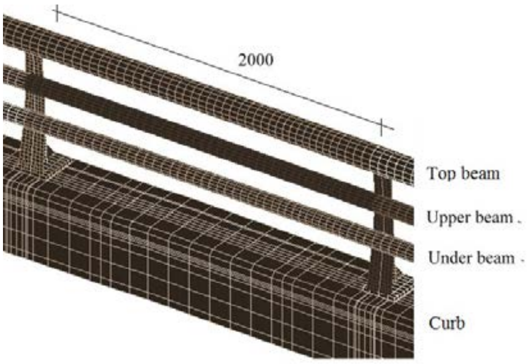
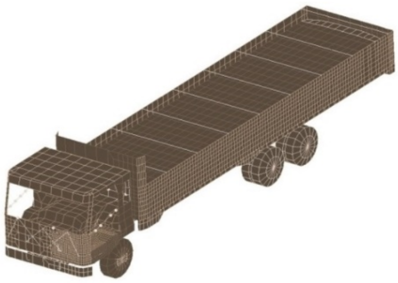
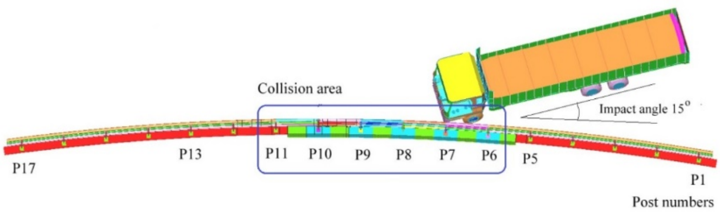


Figure 3. Railing simulation created by LS-DYNA 3D

3.2. Finite element model of truck

The finite element model of the truck originally developed at Itoh's laboratory is presented in **Figure 4 (a)**. The four-node shell elements are used to create the sides, frame, cab, fuel tank and so on. Eight-node solid elements are used for the engine, freight load and transmission. The truck has total weight of 25 tons (245 kN), which is summed of the vehicle components and the freight load. **Figure 4 (b)** shows a collision simulation of railing under impact with the heavy truck.





(a) (b)

Figure 4. Numerical simulations: (a) Truck model and (b) Truck crashed into the railing

3.3. Displacement responses

The numerical displacement of M-type convex-curved railing is compared with those of the same type concave-curved and straight ones subjected to the same truck collision conditions as shown in **Figure 5**. The displacement-time relationship shows that there are two collision stages occurred during the impact collision. The first stage occurs when front bumper crashed the railing. The second one happens when the rear part of truck hits the railing.

The Japanese specifications permit the largest displacement occurred on the railing, which is smaller than 300 mm. For the study railings, the maximum displacement occurs on the post number 8. The displacement tracks as shown in **Figure 5** demonstrates that the largest displacements on

M-type convex-curved railing is smaller than 300 mm. Thus, M-type convex-curved railing meets the displacement requirements in the Japanese specifications. However, the displacement result of convex-curved railing is larger than those of concave-curved and straight ones.

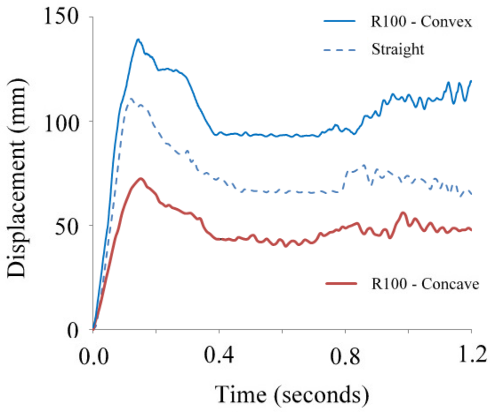


Figure 5. Displacement response

3.4. Truck behaviors

According to the Japanese specifications, two behaviors of vehicle considered in the verification progress of collision performances of railing under impact collision load are the decrement of vehicle's velocity and the vehicle's movement.

3.4.1. Decrement of truck velocity

Figure 6 presents the decrement of truck velocity for concave-curved, convex-curved and straight railing cases. It shows that the truck response in the M-type railing case is similar to those of concave and straight ones. After the two stages of impact collision the remained speed of truck still is larger than 60 percent of initial velocity (27 km/h). The decrement of truck's velocity when crashing into M-type convex-curved railing meets Japanese specifications requirements.

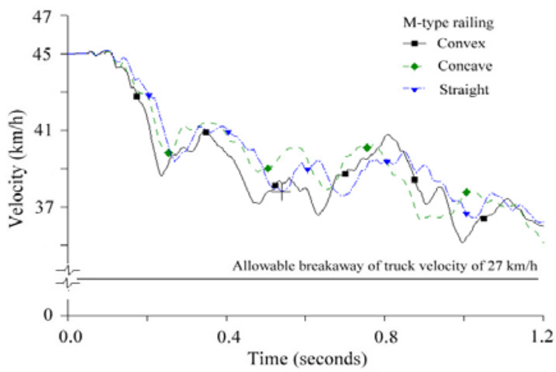


Figure 6. Decrement of truck's speed

3.4.2. Truck movement response

The movement of truck during the impact collision is presented in **Figure 7**. The time occurred two collision stages is around 1.2 seconds. The plan view of truck movement in **Figure 7 (a)** shows that two collision stages discussed in the displacement responses are related to the crash of front bumper of the truck around time 0.15 seconds and the hit of rear part of the truck body at time 0.9 seconds, respectively. After the impact collision the truck is guided back to the line of road by railing.

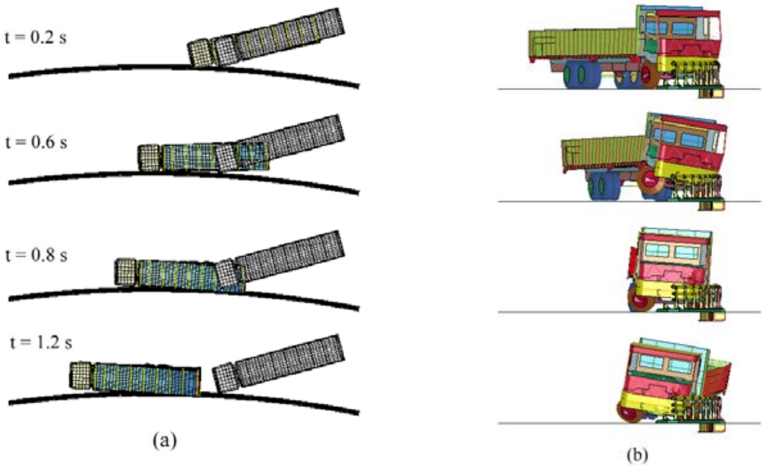


Figure 7. Truck's movement (a) Plan view and (b) Elevation view

The numerical results presented in **Figures 6** and **7** demonstrate that the truck behaviors meet requirements when the truck crashes into M-type convex-curved railing. The M-type railing satisfies the standard requirements in the Japanese specifications. The collision performances of convex-curved railing can be studied by using the numerical simulation. Thus, M-type railing can be adopted to install on the convex-curved bridges and roads.

4. CONCLUSIONS

The present study reports the investigation of convex-curved railing using the numerical simulations. The research successfully develops the collision simulation of M-type railing subjected to heavy load by LS-DYNA 3D. The conclusions and summaries as follows:

(1) The collision performances of convex-curved railing under impact with the heavy truck can be investigated by using the numerical simulation.

(2) The performances of M-type convex-curved railing meet the standard requirements in the Japanese specifications. M-type railing can be adopted to install on the convex-curved bridges and roads.

(3) The displacement results show that the convex-curved railing is more disadvantageous than the straight and concave-curved ones.

5. REFERENCES

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