Numerical analyses on impact performance of steel and aluminum alloy bridge guard fences

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Abstract

A new code for the design of the guard fence performances was implemented and issued in April 1999 in Japan. The prescribed performances of the new code are: i) prevention of derail, ii) safety of occupant, iii) leading vehicles to road, and iv) prevention of spreading out the broken pieces. In the new code, the full-scale experiment for checking the performances of guard fences is required in the determination of the structure of the guard fence. However, it is very difficult to test the performance of full-scale guard fences in the field for the parametric examination because of the huge time and cost consumption. In this study, the numerical analysis using LS-DYNA under the simulated condition of the truck-to-fence crash has been carried out for the steel and aluminum bridge fences. The results of analyses are compared with the results of field experiments. The tensile experiment is conducted to determine the stress-strain relationship and the strain rate of materials. According to the calculation results, it was found that the strain rate has to be considered for the analysis and design of steel guard fences, but does not effect the results the aluminum guard fences.

1 Introduction

In Japan, the change of the allowable weight of trucks from 20 tf to 25 tf from November 1994 increases the percentage of heavy trucks and trucks with the higher gravity center. Therefore, it is needed to re-examine the design for infrastructures on roadsides and safety facilities as well as vehicles. The guard fence is one of the safety facilities. This is the reason why the code of guard fences in Japan was re-examined and the new revised code has been implemented from April 1, 1999 [1]. In the new code, the performance of guard fences was prescribed after the form of guard fences. The prescribed performances include: i) prevention of derail, ii) safety of occupant, iii) leading vehicle to road, and iv) prevention of spreading out the broken pieces.

When a vehicle collides with a guard fence, the displacement of the guard fence and the leaving angle, acceleration, inclination angle of the vehicle are various due to the material characteristic, the form of the guard fence, etc. Therefore, the prescribed performance must be checked by the final field crash experiment using a motorcar and a truck. In Japan, field crash experiments have been conducted for many times by PWRI (Public Works Research Institute) [2,3]. However, field experiments need huge cost and reproduction of the base and etc. Accordingly, numerical analysis are expected to reproduce and complement filed experiments. In Japan, simulation models of guard fences and trucks have been developed by Japan Automobile Institute. In USA, procedures for the safety performance evaluation of highway features were recommended by NCHRP (National Cooperative Highway Research Program) [4]. Following these procedures, experiments and numerical simulations were conducted. For example, some numerical simulations were carried out for various types of boundary conditions and crash cushion in order to strengthen the safety at the guard fences [5,6].

In this study, both of steel and aluminum alloy bridge guard fences are modeled, which were conducted for field crash experiments. A three-dimension crash simulation model of the truck has originally been developed by the authors. The conformity of analysis models is verified by comparing with the field crash experiment. Furthermore, the material of aluminum alloy is experimented to determine the stress-strain relationship considering the strain rate effect. A nonlinear, dynamic, three-dimensional finite-element code LS-DYNA is used in the calculation.

2 FEM models

2.1 Truck model

Figure 1 shows the present FEM model of a truck used in this research. This truck has been modeled in our laboratory [7,8]. The based weight of truck model was made for 25 tf trucks by modeling the truck frame, engine, driving room, cargo, tiers and so on. The 14 tf and 20 tf truck models can be easily developed by modifying the weight of the cargo because the structures of 14 tf and 20 tf truck are similar to the 25 tf truck except the strengthened frame and the loading capacity of the vehicle axles. The steel is assumed to be an isotropic elastic plastic material following the Von-Mises yielding condition.

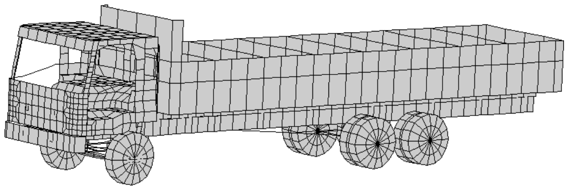

Figure 1: Truck model

2.2 Guard fence models

2.2.1 Steel bridge guard fence

Figure 2 shows the FEM models of the steel guard fences in the cross section. The fence column is made of the H-section. Both the main beam and sub-beam are made of pipe sections. The material that is called SS400 of 235 MPa in the yield stress is modeled as an isotropic elastic plastic material following the von Mises yielding condition. The experimental results are very close to the results obtained by considering the strain hardening and the strain rate. Therefore, these two factors will be taken into account in the following part of this paper. Strain rate effect about the concrete wheel guard under the fence is not considered because it contact with only tire. Its stress-strain relationship is used in previous papers [9,10]. The boundary condition at the concrete curb is considered as a fixed end, and one at the edges of beams is considered as a free end. The strength of column foundations must be verified by the maximum load carrying capacity on the load test, and the column foundation is not broken in field crash experiment by PWRI. Therefore the column foundation in this type guard fence is fixed to the concrete wheel guard in the analysis.

2.2.2 Aluminum alloy bridge guard fence

Figure 3 shows the FEM model of the aluminum alloy guard fence in the cross section. Both the shape of cross section of the column and beams are made of square sections. The material that is called A-6061-T6 of 265 MPa in the offset yield stress is modeled as an isotropic elastic plastic material following the von Mises yielding condition. The stress-strain relationship as shown in Figure 4 is obtained from the result of material tensile experiment. While as shown in Figure 5, it is trivial that strain rate effect of the aluminium alloy obtained from the result of the experiment comparing with that of the steel. The same boundary conditions of the steel bridge guard fence were formulated for the aluminum alloy bridge guard fences.

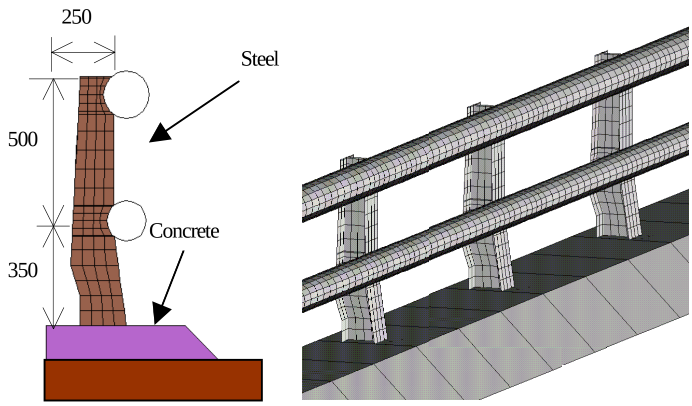

Figure 2: Steel fence model (mm)

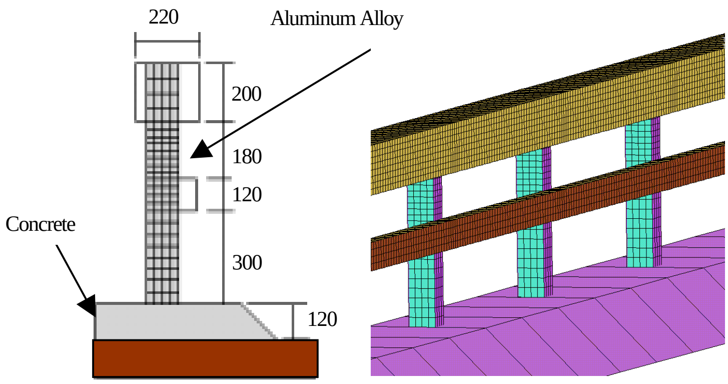

Figure 3: Aluminum alloy fence model (mm)

2.3 Analysis condition

Analysis conditions are formulated as same as the field crash experiment. The weight of truck is 14 tf, the crash speed is 80km/h, and the crash angle is 15^0. Figure 4 shows the stress-strain relationships for the steel and aluminum alloy guard fences. The strain rate effects of these two types of materials are shown in Figure 5. In the following simulations, four combined cases by considering the stain hardening and the stain rate or not are studied for the steel bridge guard fences, and compared with the results of the field experiments. In the simulation for the aluminum alloy bridge guard fence, the stress-strain relationship follows the dotted line in Figure 4 and the results with and without the strain rate effect are comparatively studied.

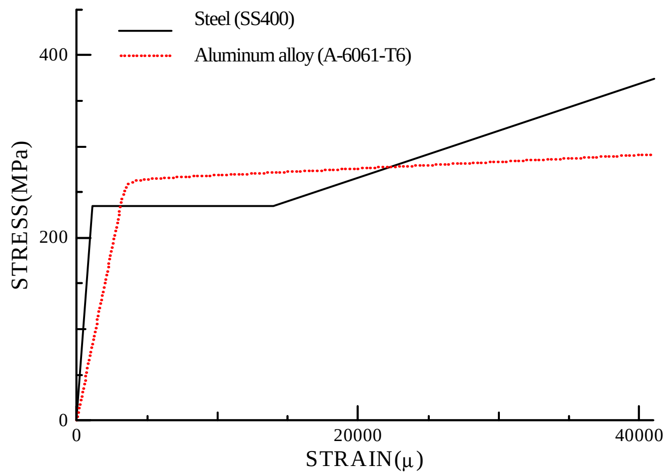

Figure 4: Stress-strain relationship

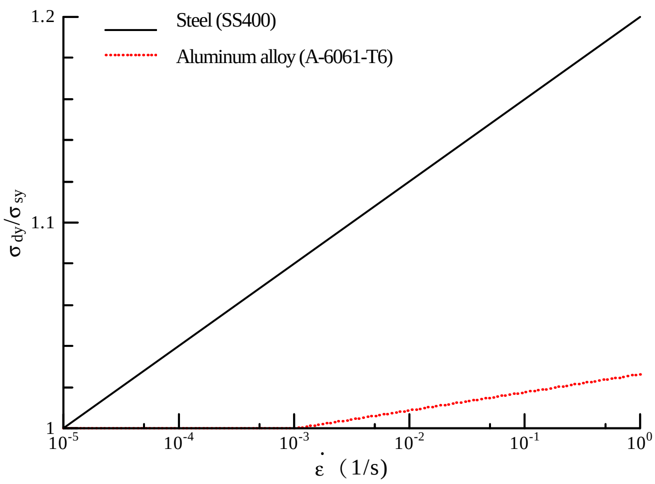

Figure 5: Strain rate effect

3 Numerical analyses

3.1 Results of steel bridge guard fence analyses

Figure 6 shows the comparison of the truck behaviors from the field experiment and the numerical analysis. The results of analysis are very close to the results of experiment.

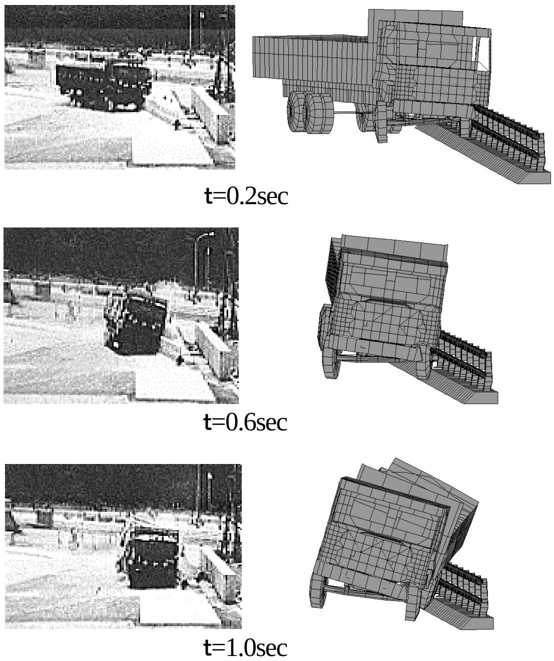

Figure 6: Truck behavior

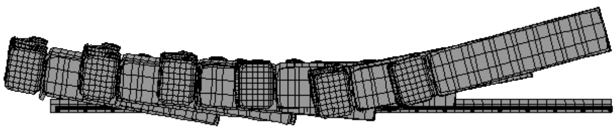

Figure 7: Movement track of a collision truck

Figure 7 shows the moving track of a truck during the collusion process. The front of the truck first touches the guard fence and the front wheel runs onto the curb very soon and impacts the guard fence. Then, the truck frame inclines, the direction of movement is changed suddenly, and the rear wheel runs onto the curb. Finally, the rear wheel of the truck touches the guard fence and the sloped angle of the back truck frame increases so that the truck frame shifts the moving direction and leaves the bridge guard fence.

Furthermore, Figure 8 shows the results of the displacement response at the top of the column. By comparing with the experimental results, both the stain hardening and strain rate should be considered into the simulation. It is very obvious that the maximum and residual response displacements 101 mm and 85 mm of the column10 are very close to the practical vehicle experiment values 97 mm and 84 mm, respectively. It can be concluded that this result of the simulation has a good fit with the behavior of guard

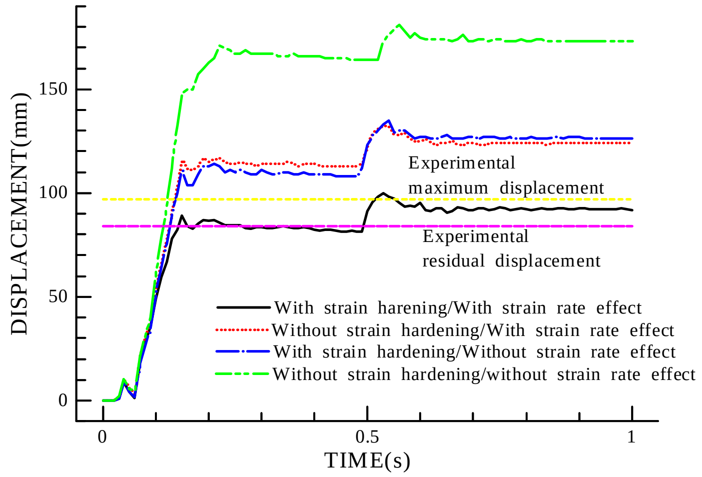

Figure 8: Displacement response at the top of column10
(Steel bridge guard fence)

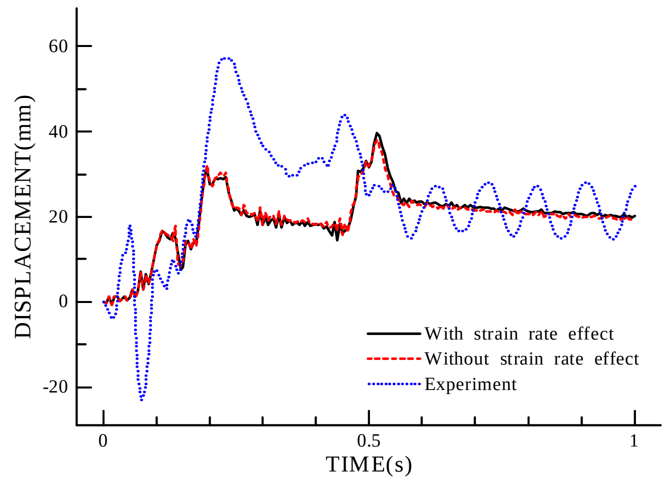

Figure 9: Displacement response at the top of column8
(Aluminum alloy bridge guard fence)

fences and a truck during the collision procedure.

3.2 Results of aluminum alloy bridge guard fence analysis

The numerical analysis results of aluminum alloy guard fence have good fit with the behavior of trucks as well as the result of steel guard fences. In addition, Figure 9 shows the result of displacement response from the top of column 8. The results with and without the stain rate effect are very similar. As shown in Figure 8, the value of maximum displacement of experiment is lager than that of analysis, but residual displacement has good fit with the experiment.

4 Comparative analyses

Comparing with the results of the field experiment for the steel and aluminum alloy bridge guard fences, both the maximum displacement and residual displacement of aluminum alloy bridge guard fence are smaller than those of the steel bridge guard fence. This may infer that the strength of a column of the aluminum alloy fence is greater than one of the steel guard fence. Another possible reason is that the elastic area of aluminum alloy is relatively wider because its Young's modulus is larger than the Young's modulus of the steel as shown in Figure 4. Different from the steel bridge guard fence, the effect of the strain rate is very minor in the case of the aluminum alloy bridge guard fences. This may be due to its extremely small strain rate effect as shown in the dotted line in Figure 5. Therefore, it is unnecessary to incorporate the strain rate into the collision analyses between a truck and the aluminum alloy bridge guard fences.

Figures 10 and 11 show the residual the displacements of the steel and aluminium alloy bridge guard fences respectively. As well as the results of the field experiments, the results of analyses could be concluded that displacement response of the aluminum alloy bridge guard fence is smaller than that of the steel guard fence. Figures 12 and 13 show the results of internal energy distribution of the steel and aluminum alloy bridge guard fences respectively. Comparing these results, value of aluminum alloy guard fence is very smaller than that of steel guard fences well as the displacement response.

5 Conclusions

In this research, the numerical analysis models are prepared for simulating the behaviors of both trucks and bridge guard fences due to the collision impact. The following conclusions can be stated from the research.

1) The truck, steel bridge guard fence and aluminum alloy bridge guard fence were originally modeled. The results of analyses using these models were compared with those of the field crash experiments.
2) For steel guard fences, the result of the analysis by considering the strain hardening and strain rate effect is very close to the result of the field crash experiment.
3) The strain rate effect for aluminum alloy is obtained by the offset yield stress from the results of the tensile experiments.

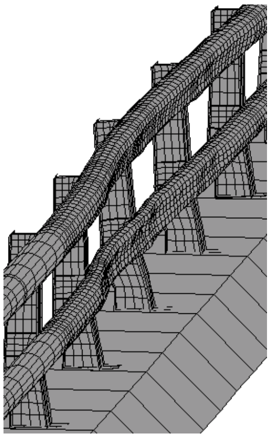

Figure 10: Mode shape of the steel guard fence

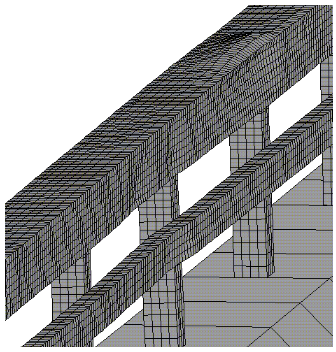

Figure 11: Mode shape of the aluminum alloy guard fence

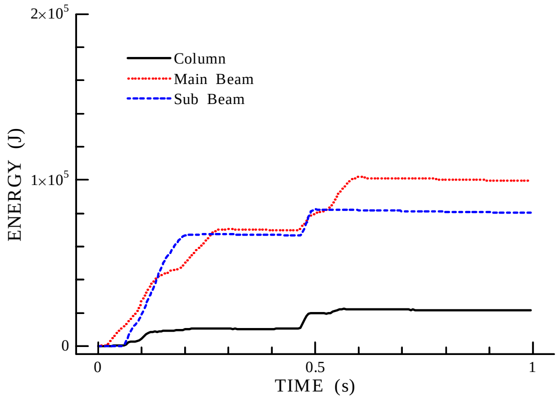

Figure 12: Energy distribution of the steel guard fence

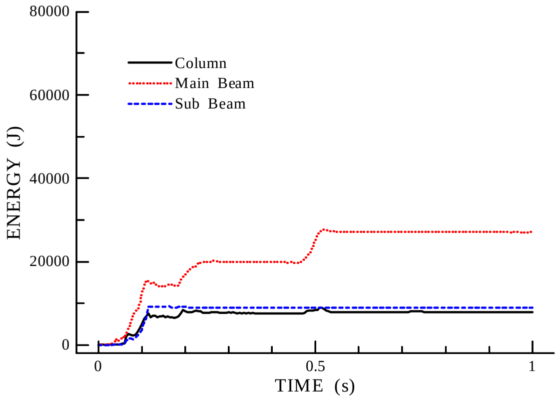

Figure 13: Energy distribution of the aluminum alloy guard fence

4) Different from the steel bridge guard fence, the effect of the strain rate is very minor in the case of the aluminum alloy bridge guard fences.

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