Numerical analyses of steel and aluminum alloy bridge guard fences

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ABSTRACT: The performances of the guard fence were prescribed in the new code of the guard fence issued in April 1999 in Japan [1]. In the new code, the full-scale experiment for checking the performances of guard fences is required in the design of the guard fence. However, it is difficult to test the performance of full-scale guard fences in the field for the collision parametric examination because of the enormous time and cost consumption. In this study, the numerical analysis procedures using finite element method for both guard fences and vehicle are dealt with to complement the field experiments. Initially, the materials of steel and aluminum alloy are experimented to obtain the stress-strain relationship considering the strain rate effect, which is used in the numerical analyses. In the case of steel guard fence, the results of the analyses considering the strain rate effect agree with the results of the field collision experiment. In the case of aluminum alloy guard fence, the differences of results with and without the stain rate effect configuration are very little.

KEYWORD: bridge guard fence, strain rate effect, numerical analysis of vehicle collision

1. INTRODUCTION

In Japan, the change of the allowable weight of trucks from 20tf to 25tf from November 1994 increased the percentage of heavy trucks and trucks with the high gravity center. This is the reason why the code of guard fences in Japan was re-examined and the new revised performance-based code has been implemented from April 1,1999. The prescribed performances include: i) prevention of derail, ii) safety of occupant, iii) guiding vehicles to road, and iv) prevention of spreading out the broken pieces, and it is required to test the performance of full-scale guard fences in the field. If guard fences can be designed to satisfy these performances, any materials and types of guard fence are available. Steel materials SS400, STK400 and aluminum alloy A6061S-T6 are decrypted clearly as the materials of guard fences in the code.

Field experiments for checking the performance of guard fences need enormous cost, efforts and time. Accordingly, numerical analyses using finite element method are expected to complement field experiments. In this study, firstly the materials of steel and aluminum alloy are experimented to obtain the stress-strain relationship considering the strain rate effect. Secondly the mechanical characteristics of both steel and aluminum alloy of bridge guard fences are modeled using results of dynamic tension tests. Finally the models are verified comparing the analysis results with the results of the field collision experiment.

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2. DYNAMIC TENTION TESTS

2.1 Objectives and procedure of tests

The dynamic tension tests were conducted to obtain the stress-strain relationship of steel and aluminum alloy considering the strain rate effect. The mild steel of both grade SS400 and STK400 having the yield stress of 235MPa was first tested. SS400 and STK400 are used in the columns and offset pipe beams of steel guard fence, respectively. Aluminum alloy A6061S-T6 was also tested. The servo-valve-type material test machine (MTS) was used in the test. The strain rate of dynamic tension test was from about 10^{-5} (1/s) to 10^{0} (1/s).

2.2 Results of steel coupon tests

Figures 1 and 2 show the test results of static stress-strain relationships for SS400 and STK400, respectively. The solid line and dashed line indicate the nominal stress-nominal strain and true stress-true strain curves, respectively. SS400 showed a typical virgin stress-strain relationship having the yield plateau. On the other hand, STK400 did not have such yield plateau because of plastic bending process forming the pipe.

Figures 3 and 4 show the strain rate effects on yield stress and ultimate stress of the steels, respectively. The vertical axes of Figures 3 are the dynamic response factor σ_d / σ_s where σ_d is the dynamic yield

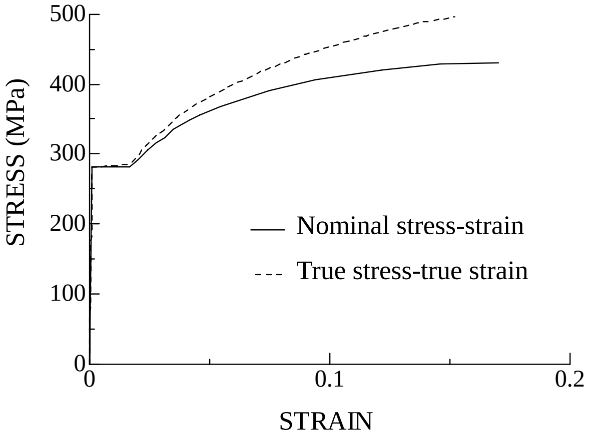


Figure 1: Stress-strain relationship of SS400

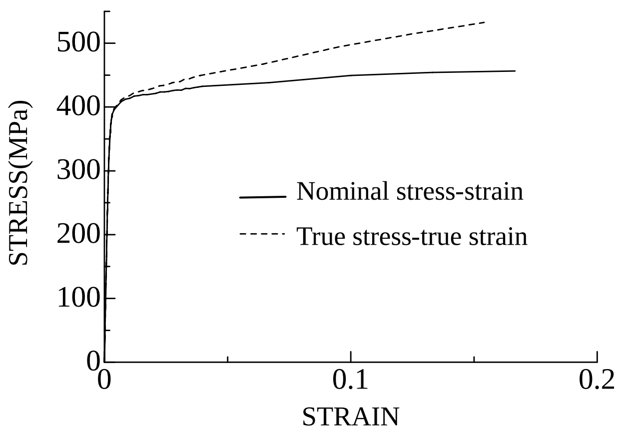
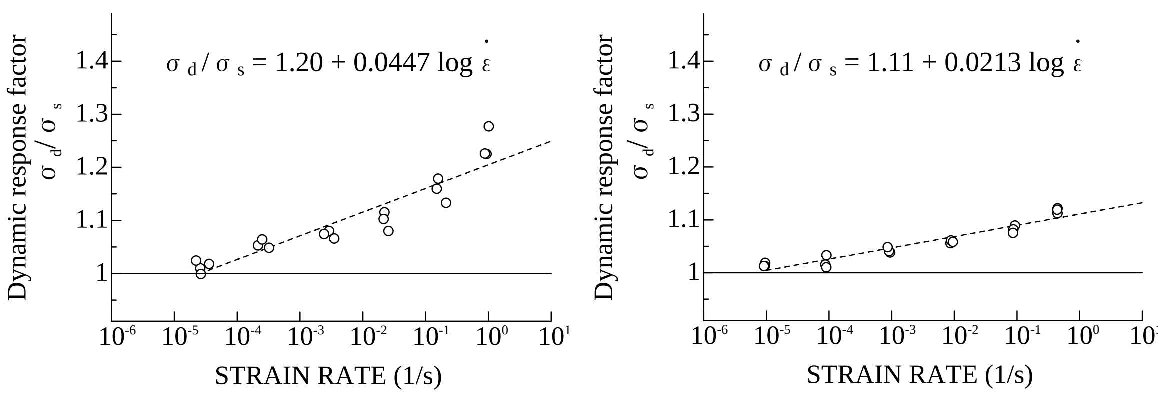


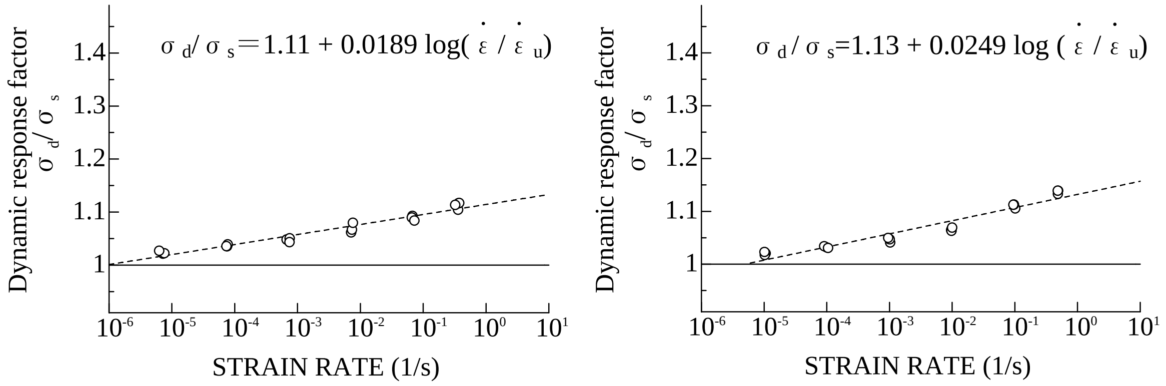
Figure 2: Stress-strain relationship of STK400



(a) SS400 (b) STK400

Figure 3: Strain rate effects on yield stress

stress and σ_s is the static yield stress. Similarly, the vertical axes of Figures 4 are the dynamic response factor on the ultimate stress. The dashed lines in these figures indicate logarithmic functions that were recurred with least squared method. The strain rate effect on the yield stress in the case of STK400 is half times as small as that of SS400 approximately, as shown in the Figure 3 (a) and (b). Accordingly, the strain rate effect on yield stress is small due to the plastic bending process forming the pipe. The strain rate effects on ultimate stress that is shown in Figures 4 (a) and (b) possessed the same tendency.



(a) SS400 (b) STK400

Figure 4: Strain rate effects on ultimate stress

2.3 Results of aluminum alloy coupon tests

Figure 5 shows the static stress-strain relationships of aluminum alloy A6061S-T6. The solid line and dashed line have the same meaning to the case of the steel. The yield stress of 0.2% offset and the ultimate stress were 265MPa and 313MPa, respectively.

Figures 6 and 7 show the strain rate effects on the yield stress and the ultimate stress of the aluminum alloy, respectively. The strain rate effect on the ultimate stress was less than that on the yield stress.

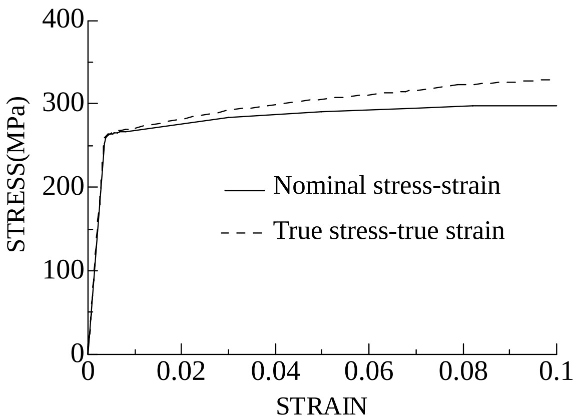


Figure 5: Static stress-strain relationship

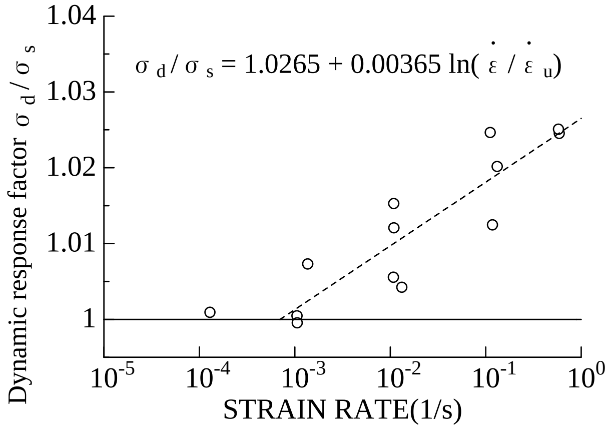


Figure 6: Strain rate effects on yield stress

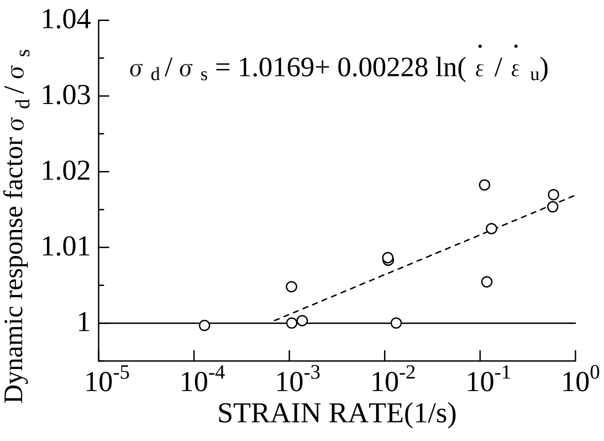


Figure 7: Strain rate effects on ultimate stress

Also, compared with the case of the steel, the strain rate effects of aluminum alloy were very small.

3. FEM MODELS

3.1 Truck model

Figure 8 shows the FEM model of a truck used in this research, which was modeled by the authors and had 3904 elements [2]. The weight of the truck was 25tf and the almost parts such as the truck-frame, the driving room, the cargo and the tiers were composed in the model. In order to have different weight of trucks, weight of the cargo was changed.

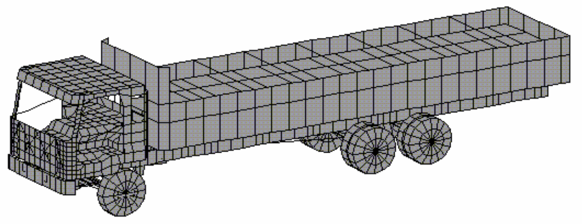


Figure 8: Truck model

3.2 Steel bridge guard fence

The full-scale field test of a steel bridge guard fence was conducted in 1992 at the Public Work Research Institute of Japan [3]. The finite element model of the steel guard fence adopted in the field test was made using shell elements shown in Figure 9. The number of elements was 6152.

The guard fence columns were H-section steel whose web and flange were 158mm wide and 6mm thick, and 150mm wide and 9mm thick respectively, and its material was SS400. The upper beam and the lower beam were pipes of STK400. The pipe diameter and thickness of the upper beam were 165mm and 7mm, respectively. The pipe diameter and thickness of the lower beam diameter were 140mm and 4mm, respectively.

In accordance with the field collision experiment, the simulation was carried out under the condition where the truck impact speed was 80km/h and the impact angle was 15^o relative to the spanwise direction of the guard fence.

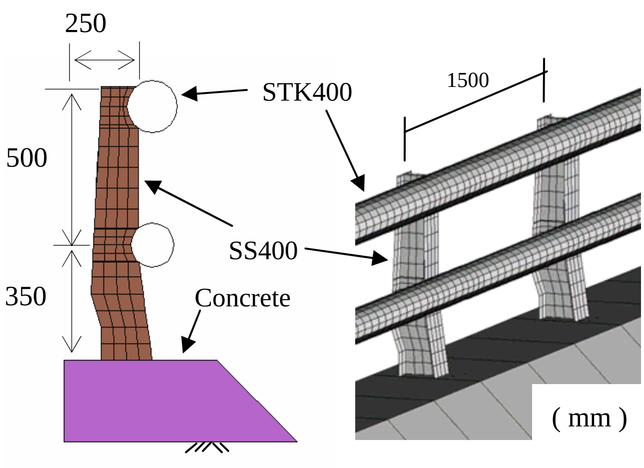


Figure 9: Model of steel guard fence

3.3 Aluminum alloy bridge guard fence

The full-scale field test of the aluminum alloy bridge guard fence was also conducted in 1990 at the Public Work Research [4]. Figure 10 shows the FEM model of the aluminum alloy bridge guard fence used in the experiment. Both the cross section of the column and that of beams shaped hollow square, and their materials were A6061S-T6. The conditions of the truck approaching to the guard fence were the same as those of the steel guard fence.

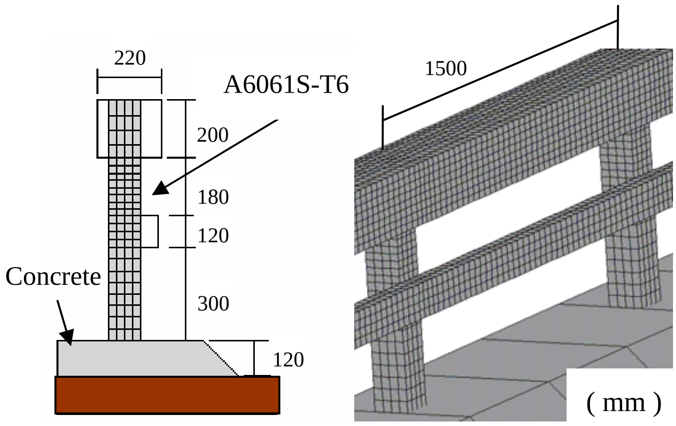


Figure 10: Model of aluminum alloy guard fence

4. RESULT OF NUMERICAL ANALYLSIS

4.1 Results of steel guard fence analysis

Figure 11 shows the results of displacement response at the top of the column. In the model-a, the strain rate effect was not considered. In the model-b, the strain rate effects that were obtained from the result of this study were taken into account. In both the analyses and the experiment, the front of the truck first touched the guard fence (the first impact) around 0.1s, and the rear wheel of the truck touched the guard fence (the second impact) around 0.5s. When the first impact occurred, the response displacements of the model-b were closer to the results of the experiment than the case of model-a. After the second impact, the displacement in the experiment almost took the value between the result of model-a and model-b. Totally, model-b simulates the collision behavior more accurately than model-a.

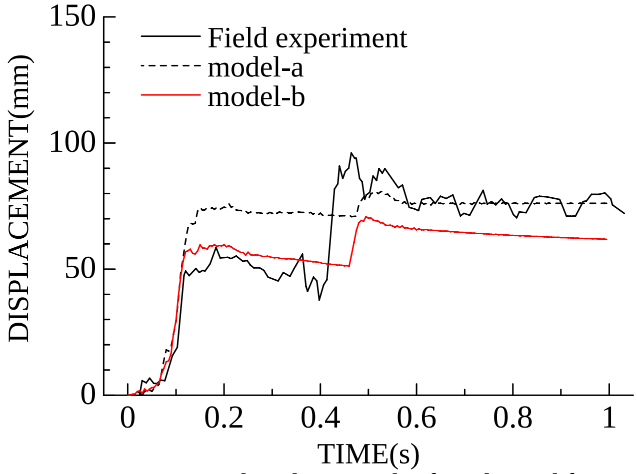


Figure 11: Numerical analysis result of steel guard fence

4.2 Results of aluminum alloy guard fence analysis

Figure 12 shows the result of the response displacement of the column top of the aluminum alloy guard fence. The numerical analysis of aluminum alloy guard fence has good fit with the behavior of trucks as well as the result of steel guard fences. The case of the model without the strain effect (model-c) and the model with the strain effect (model-d) indicated similar time-displacement histories. While the maximum displacement of the experiment was larger than those of analyses, the residual displacement in the analyses had good agreement with that of the experiment. As a result, the strain rate effect is less sensitive to the response displacement in the case of the aluminum alloy guard fence.

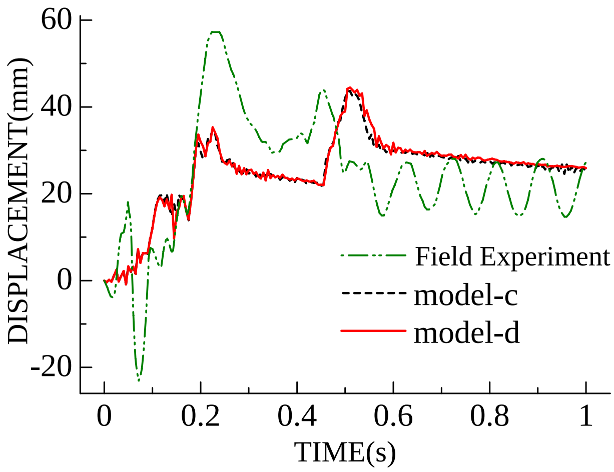


Figure 12: Numerical analysis result of aluminum alloy guard fence

4. CONCLUSIONS

The numerical analyses were carried out 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 stress-strain relationships of steels and aluminum alloy of guard fence considering the strain rate effect were obtained from the dynamic tension tests.
2) The FEM model of steel guard fence considering the strain rate effects that were newly modeled in this study gives a good result to the simulate the behaviors of steel guard fence and truck in the field experiment.
3) It is found from the numerical analyses that the strain rate effect in the dynamic behavior of aluminum alloy guard fence is little.
4) It is almost possible to simulate the collision behavior due to the collision impact subjected to heavy truck based on the FEM models for truck and guard fences.

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