NUMERICAL COLLISION ANALYSIS OF CONCRETE GUARD FENCES FOR PERFORMANCE-BASED DESIGN

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ABSTRACT：The performance-based design concept has been implemented in the code for guard fence designs in Japan, in which full-scale collision experiment for checking the performances of guard fences are required. However, field experiments need huge time and cost, and the performance-based design has not been prevalent. The numerical simulation of the full-scaled collision experiments is expected to check the performance in the design. In this study, appropriate FEM models of the vehicle and the concrete guard fences are developed to simulate the field collision experiments. Comparing the results of the simulations with those of the experiments, it is shown that the numerical analysis enables checking the performances of concrete guard fences and behaviors of the vehicle.

KEYWORD：concrete guard fence, numerical analysis, vehicle collision

1. INTRODUCTION

A new code for guard fence designs, based on the performance-based design concept was implemented and issued in April 1999 in Japan. 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.

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, FEM models of the concrete guard fence considering the base conditions and the strain rate effect are developed, and the models are verified comparing the simulation results with the results of the field collision experiment.

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2. FEM MODELS OF CONCRETE GUARD FENCE AND VEHICLE

2.1 The object of field collision experiment and guard fence

The full-scale field test was conducted in study on the concrete guard fences for high-speed collision. Fig.1 shows the Florida type concrete guard fence used in the experiment. The collision conditions of the experiment are, vehicle weight 20t, collision speed 100km/h, collision angle 17° and cross-point is 20m from an end.

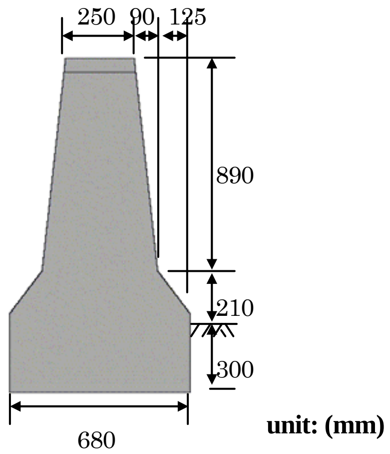


Figure 1. Florida type concrete guard fence

2.2 The boundary conditions of the guard fence

In order to consider subgrade resistance of embedded part, the subgrade reaction is modeled with the spring. The direction of subgrade resistances are right-angled horizontal direction by the back side of guard fence, the bottom perpendicular direction, and the bottom horizontal direction. Fig.2 shows of subgrade spring models. First, spring constant in road surface height about the back side of guard fence is 20 kN/mm. This value obtained experientially from the past field collision experiment of concrete guard fence for the embedding. Secondly, it uses the value that the guard fence maker is generally using also about the bottom perpendicular direction and the bottom horizontal direction. Additionally, the spring about the back side of guard fence and the bottom perpendicular direction resists only compressing.

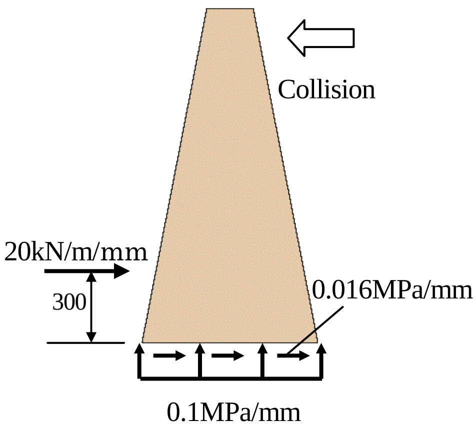


Figure2. Subgrade spring model

In order to verify the validity of this subgrade spring model, simulation results compare to the static loading examination results for the concrete guard fence with the single slope was conducted in research on development of the concrete guard fence for high-speed collision. Fig.3 shows the summary of the static loading examination.

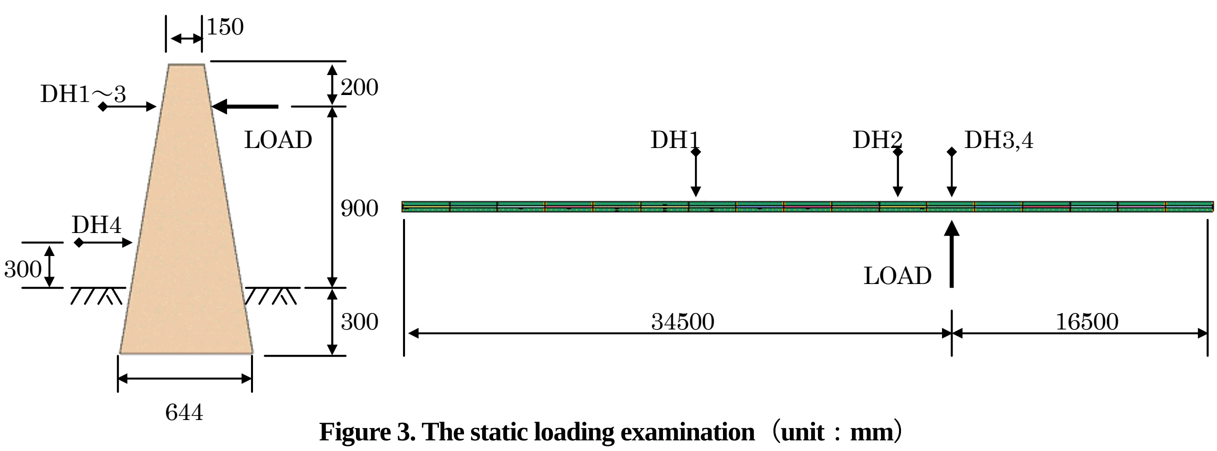


Figure 3. The static loading examination（unit：mm）

Fig.4 shows the corresponding load-displacement at the DH1 to DH4. Although it didn't become alignment because concrete guard fence took place plastic deformation, simulation results closer to alignment on the whole. Additionally, rigid deterioration is small because plastic spring is used. Nevertheless, the totally behavior of concrete guard fence can reproduce, it also use the subgrade spring model as mentioned above to the vehicle collision.

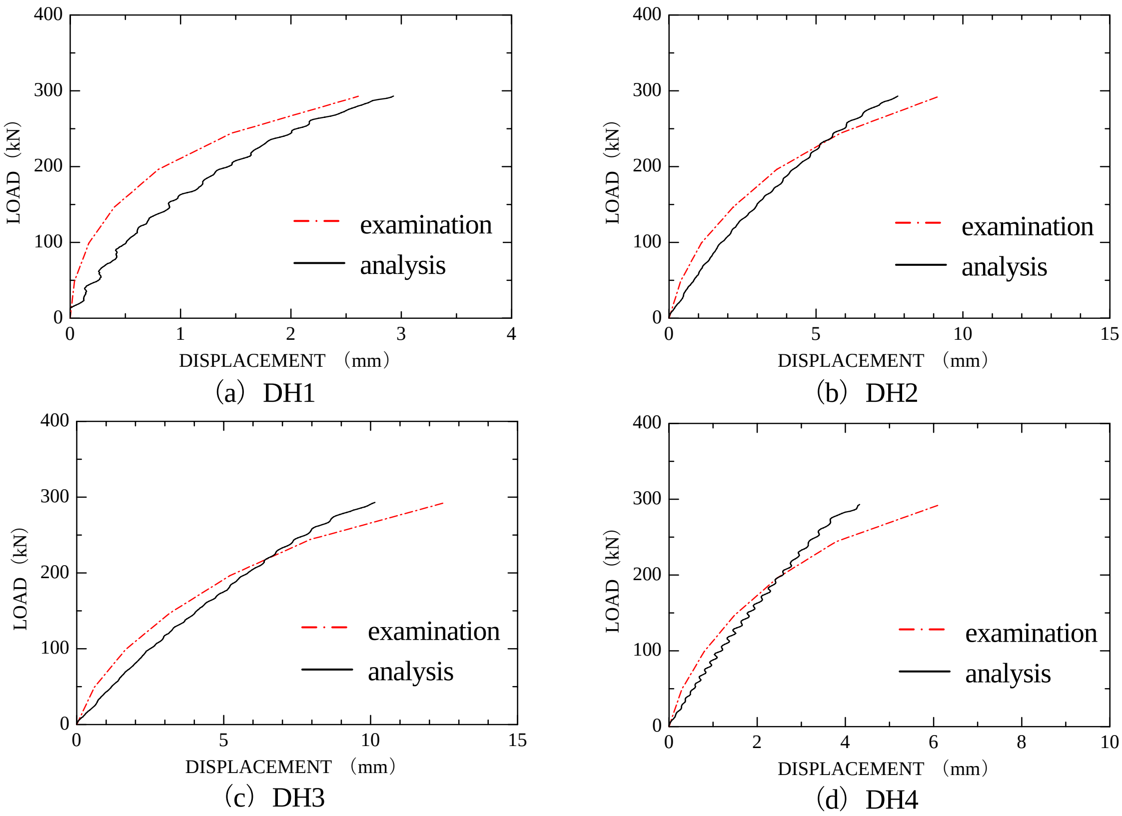


Figure 4. The corresponding load-displacement at the DH1 to DH4

2.3. Strain rate effect of concrete

Material constants of concrete have strain rate effect as well as steel, and the formulas about strain rate effect of compressive strength have been suggested by previous researches. Formula is presented below that was suggested by Yamaguchi as follows [3].

$$\dot{\varepsilon}_{oct}>2.44\times10^{-5}/\text{sec}: \quad {}_df_c'/{}_sf_c'=1.021-0.05076(\log\dot{\varepsilon}_{oct})+0.02583(\log\dot{\varepsilon}_{oct})^2$$
$$\dot{\varepsilon}_{oct}\leq2.44\times10^{-5}/\text{sec}: \quad {}_df_c'/{}_sf_c'=1.0 \qquad (1)$$

where, ${}_df_c'$: dynamic compressive strength, ${}_sf_c'$: static compressive strength, $\dot{\varepsilon}_{oct}$: volume strain rate

The material model considering strain rate effect of Drucker-Prager's failure criterion is not equipped in LS-DYNA of version 960. Accordingly, in this study, the material model considering strain rate effect of Drucker-Prager's failure criterion by Yamaguchi's formula is made by user subroutine. In order to verify the user subroutine, concrete test specimen shown Fig.5 is modeled, and simulated dynamic compressive analysis. Consequently, the dynamic response factor for the several strain rates shown Fig.6 is obtained. Fig.6 shows that the rate of increase of compressive strength conforms to Yamaguchi's formula. Therefore, the material model considering strain rate effect of Drucker-Prager's failure criterion by Yamaguchi's formula developed in this study is valid.

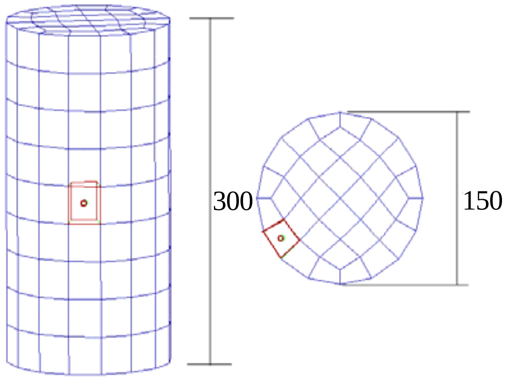


Figure 5. Concrete test specimen model (unit : mm)

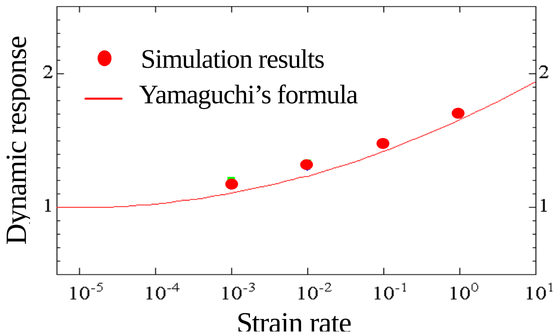
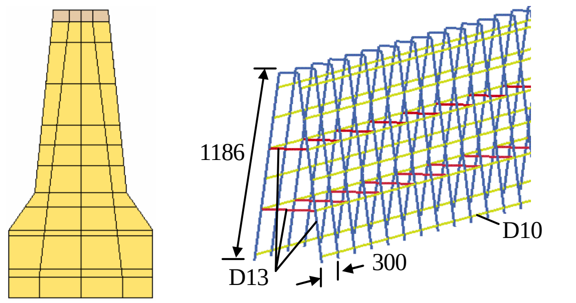


Figure 6. Dynamic response factors for strain rates

2.4 FEM models

Fig.7 shows the model of concrete guard fence. This model has 11845 nodes and 15703 elements. The boundary conditions modeled the subgrade spring as mentioned before. Concrete and reinforcing bars jointed elements each other. Material constants of the model of concrete guard fence shown Table 1 obtained from material test were used in the numerical analysis. Fig.8 shows the model of the vehicle developed at Nagoya University. Steel part of this truck model is not considering strain rate effect, because it didn't almost influence even if considered strain rate effect.



(a) Concrete body (b) Arrangement of reinforcing bars

Figure 7. The model of concrete guard fence (unit: mm)

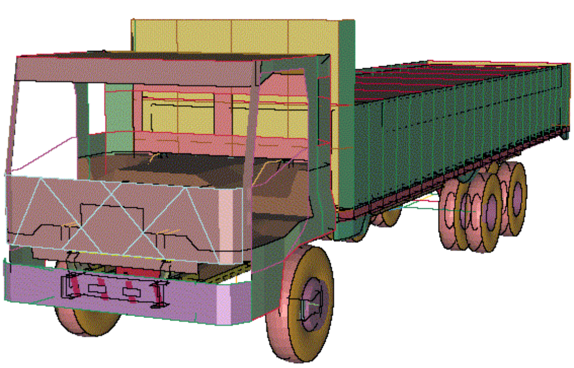


Figure 8. The FEM model of vehicle

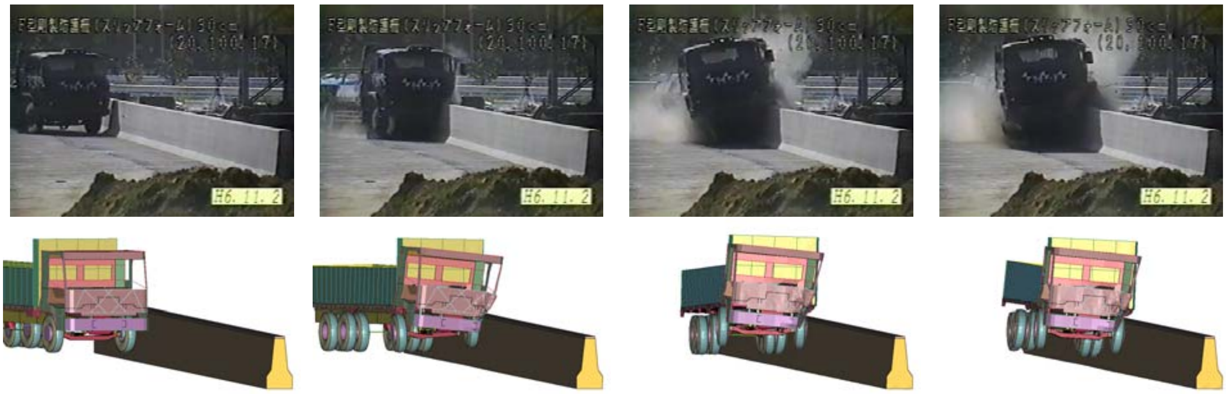
Table 1. The material constants (unit : MPa)

	Elastic coefficient	Compressive strength	Yield stress
Concrete	1840	34.2	—
Reinforcing bar D10	1670	—	373.8
Reinforcing bar D13	1700	—	407.6

3. RESULTS OF NUMERICAL ANALYSIS

3.1 Vehicle's behaviors

Fig.9 shows vehicle is behaviors of the numerical analysis compared with those of the field collision experiment, and Table 2 shows the principal results of the vehicle's behaviors. The vehicle's behaviors of the simulation that, the front part of vehicle body bounced in the first impact and the loading platform impacted the guard fence in the second impact, coincided well with the field collision experiment results. Besides, Table 2 shows that secession speed and angle also almost coincided. It is regulated by the code for guard fence designs in Japan that secession speed is more than 70% collision speed, and secession angle is less than 70% collision angle, those simulation results satisfy this regulation. Therefore, it is possible that check guiding vehicles to road.



(a) 0.0sec (b) 0.2sec (c) 0.4sec (d) 0.5sec

Figure 9. Vehicle behaviors compared with the field collision experiment results

Table 2. Secession speed and secession angle

	The field collision experiment	The simulation results
Secession speed (km/h)	78.6	72.5
Secession angle(°)	1.9	1.1

3.2 Displacement of concrete guard fence

Figure 11 shows the response displacement of concrete guard fence at point shown in Fig.10. Totally, the response displacement of the simulation results is a little larger than the field collision experiment results. Displacements of the guard fence terminal (DH1) and Displacement of the impact point (DH2) is equality in the field collision experiment. It could reproduce that in the simulation, the displacement of DH1and DH2 is equality. Additionally, the displacement of the ground (DH3) also reproduced the results of the field collision experiment, and the subgrade spring model is valid.

The maximum displacement by collision is not objecting of the estimation in rigid guard fence such as the concrete guard fence. However, it can verify the guard fence breaking by vehicle collision. Therefore, it is possible that check prevention of de rail.

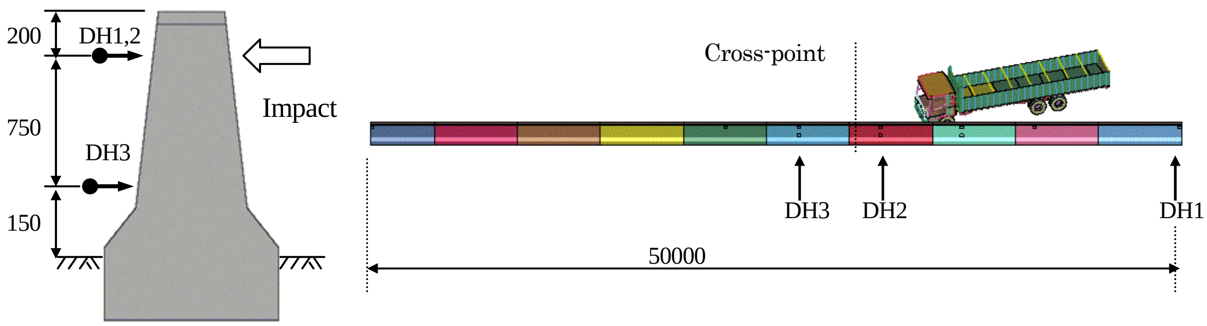


Figure 10. The location points of measured displacement

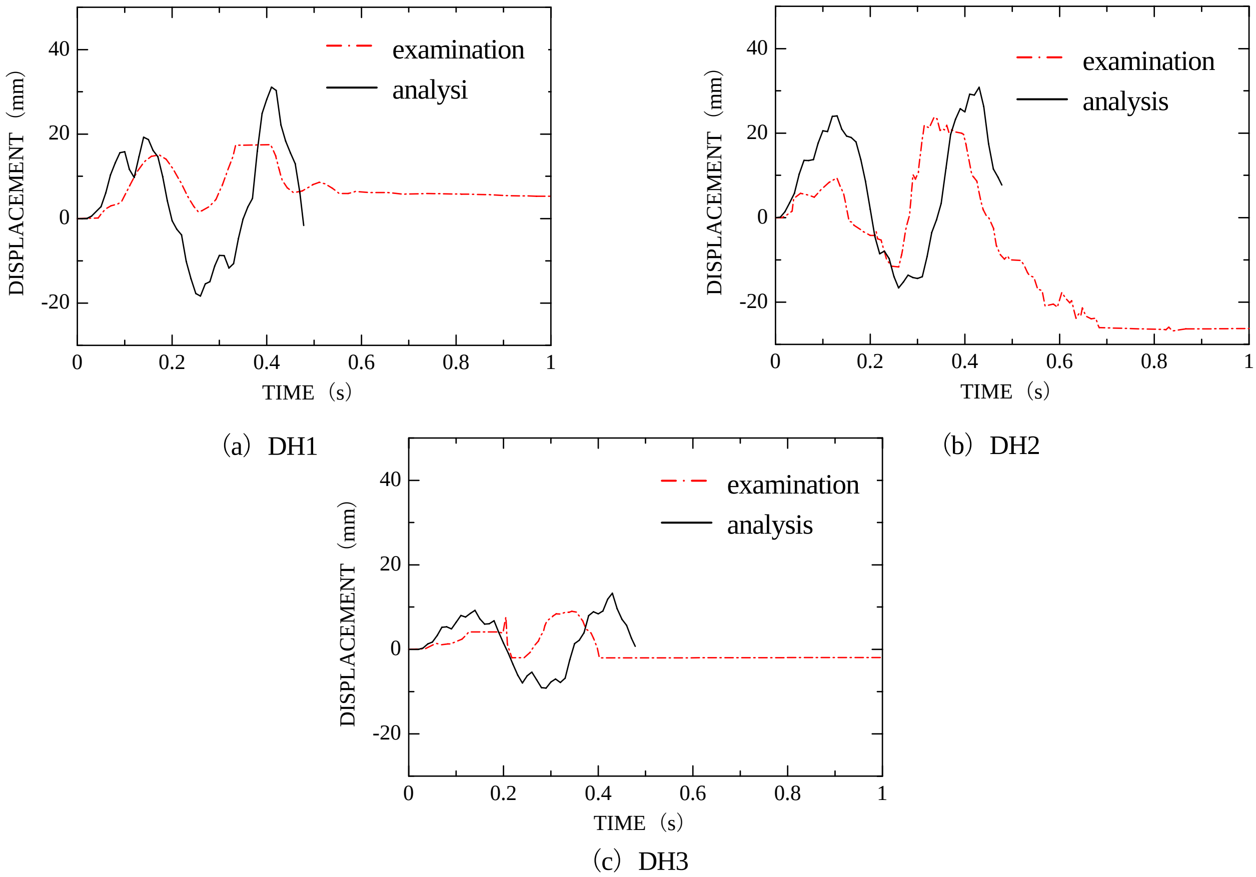


Figure 11. The response displacement of concrete guard fence

4. CONCLUSIONS

The following conclusions can be stated from the research.

1) The numerical analyses were carried out for simulating the static loading examination for concrete guard fence for the embedding to develop the appropriate subgrade spring model.
2) It can consider strain rate effect of concrete using the material model taking into account strain rate effect of Drucker-Prager's failure criterion by the user subroutine.
3) The FEM models of vehicle collision on concrete guard fence developed in this study can reproduce accurately vehicle behaviors and displacement of the concrete guard fence, it is possible to check the performances of guard fence guiding vehicles to road, and prevention of derail.

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