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COLLISION PERFORMANCE OF NEW BRIDGE GUARD FENCES USING THE NUMERICAL SIMULATION

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Abstract. *The Japanese design specifications of guard fences were revised in 2004. Since this revision, when guard fences are produced, it has been regulated to improve the choking rate from vehicles, and also to satisfy the requirements of the design specifications, the development of new bridge railing guard fences has been done in Japan. In this study, firstly, the impact performance of the fence posts of new bridge railing guard fences was verified in the heavy steel ball collision experiment. Secondly, the Finite Element models of the fence posts of new types for numerical analysis were developed. The analytical results were compared with the experimental results, and the FE models were proved to be valid and practical. Thirdly, the impact performance of the fence posts of new types was quantitatively verified by comparing the difference between the fence posts of new types and the fence posts of existing type. As a result, it was verified that the fence posts of new types had better performances at shock-absorbing properties than the fence posts of existing types. In addition, it was verified whether the impact performance of the fence posts of new types was equally demonstrated as guard fences in the full-scale truck collision analysis.*

1. INTRODUCTION

Guard fences are one of the most important structures to ensure the safety of roads. The design specifications for guard fence based on the performance-based design concept were implemented and issued 1999 in Japan [1]. 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 [3]. If guard fences can satisfy these performances, any materials and types of guard fences are accepted in design. According to the design specifications, the on-site full-scale collision experiments should be carried out to examine the behaviors of both guard fences and vehicles when vehicles collided with them. The experimental method was determined by the classification of guard fences and the types of guard fences [2]. However, because of the huge consumption in time and cost, it is difficult in the field to measure the collision performances of the guard fences for various cases. In Nagoya University, FEM models have been developed for colliding vehicles and various types of guard fences to re-enact their behaviors in

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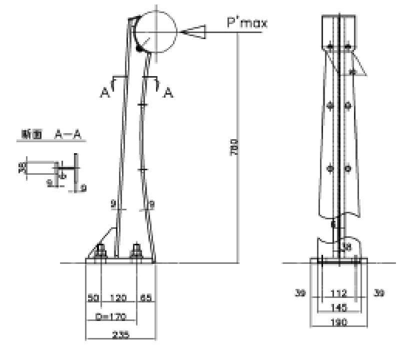
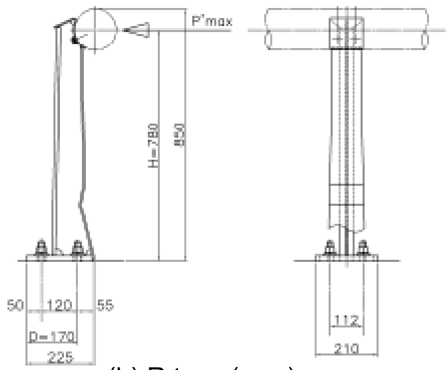
on-site test [3,4,5,6,7]. The design specifications for guard fences designs were revised in 2004 [8]. Since this revision, when guard fences are produced, it has been regulated to improve the choking rate from vehicles, and also to satisfy the requirements of the new design specifications, the development of new bridge railing guard fences has been done in Japan [9]. The large difference between new types and existing types is the deformation characteristics of fence posts. In the case of existing types, the fence posts become deformed with the occurrence of the local buckling at the narrow parts in the bottom of the back side of the fence posts. The fence posts of existing types need to enlarge the cross sections except the narrow parts in order to occur the local buckling at the narrow parts. So, the fence posts of existing types are very large and deformed shapes, and have large choking rate from vehicles. On the other hand, in the case of new types, the fence posts become deformed with the occurrence of the lateral torsional buckling at the entire compressive flanges. So, the fence posts of new types are able to be slender, and have smaller choking rate view from vehicles than that of existing types.

In this study, firstly, the impact performance of the fence posts of new bridge railing guard fences is verified in the heavy steel ball collision experiment. Secondly, the Finite Element models of the fence posts of the new types for numerical analysis are developed. The analytical results are compared with the experimental results, and the FE models are proved to be valid and practical. Thirdly, the impact performance of the fence posts of new types is quantitatively verified by comparing the difference between the fence post of new types and that of existing type. In addition, it is verified whether the impact performance of the fence posts of new types is equally demonstrated as guard fences in the full- scale truck collision analysis.

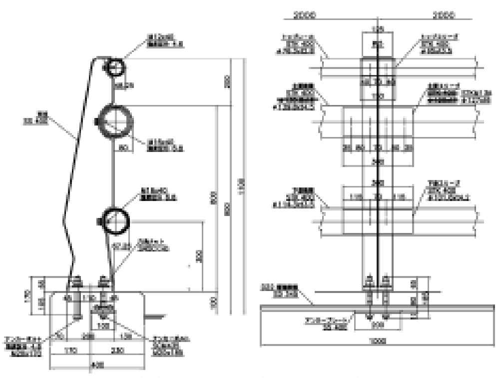
2. TYPES OF GUARD FENCE POSTS



(a) M type (new)



(b) R type (new)



(c) N type (existing)

Figure 1: Fence posts dealt with in the study

Impact index(kJ)	Classification
over 45	C
over 60	B
over 130	A
over 160	SC
over 280	SB
over 420	SA
over 650	SS

Table 1: Classification of guard fences

Figure 1 shows the fence posts dealt with in the study. The type (a) is named M type, the type (b) is named R type, and the type (c) is named N type. The names are decided from the product names of each type. According to the design specifications, the three types are classified into bridge railing guard fences made of steel, and the category of guard fences is classified into “A” by the level of impact shown in Table1 [2]. The level of impact index means the vertical kinematic energy toward guard fences. M and R types are new bridge railing guard fences produced in order to secure the less choking rate view from vehicles in 2005 and 2007 [10,11]. The fence posts of both new types have the above-mentioned deformation characteristics for new types. In addition to that, R type has the narrow part in the bottom of the front of the fence post, and it becomes straight after the collision. N type is existing bridge railing guard fence setting up Hokkaidoh in Japan produced before 2004, and has the above-mentioned deformation characteristics for existing types.

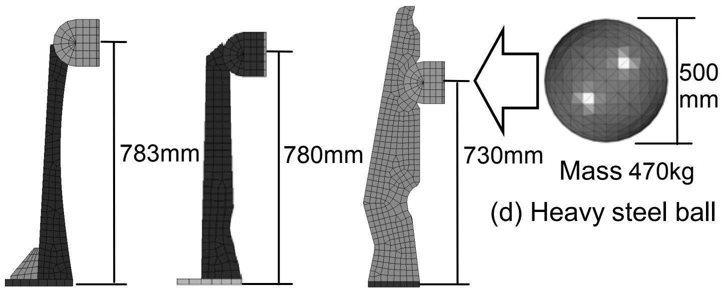
3. IMPACT PERFORMANCE OF FENCE POST OF NEW TYPES USING HEAVY STEEL BALL COLLISION

3.1 Heavy steel ball collision

A heavy steel ball collision experiment shown in Figure 2 is directly into a fence post joined to a steel floor by anchor bolts. An impact performance of a fence post can be verified by this experiment [13]. In the case of M and R types, this experiment and the numerical analysis of the experimental models were done, and the precision of the FE models of the fence posts was confirmed by comparing with the analytical results and the experimental data. In the case of N type, only numerical analysis was done, and the impact performance of the fence posts of M and R types was verified by comparing the analytical results with M and R types and N type.

3.2 FE models for numerical simulation and collision conditions

Figure 2: Overview of experiment

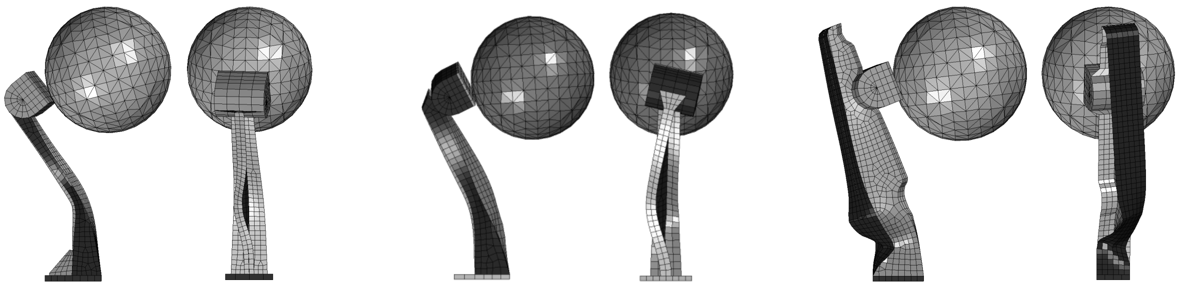


(a) M type (b) R type (c) N type

Figure 3: FE models of Fene posts and heavy steel ball

Figure 3 shows the FE models of the fence posts and the heavy steel ball. The numerical analysis has been carried out using non-linear dynamic analysis software (LS-DYNA). The fence posts are made of the H-shape steel (SS400). The fence posts are modeled as isotropic elastic plastic materials following the von Mises yielding criterion. When the analysis of collision is performed, strain hardening and strain velocity rate effect must be considered for steel materials [3]. Stress-strain relationship depended on strain velocity rate effect given from the results of kinetic tests for steel materials is inputted in these FE models [13]. The boundary conditions at the bases of the fence posts are considered as a fixed end. The collision conditions for M and R type are set to meet the experiment, which the heavy steel ball collision speed for M type is 6492mm/s and that of R type is 6714mm/s. To compare with the result of collision simulation for M and R type and that for N type, the condition for N type is equal to the condition with M type, which the ball collision speed for N type is 6492mm/s. The heavy steel ball collision point for each type is at the locating the main railing beam.

3.3 Results of collision simulations



(a) M type (b) R type (c) N type

Figure 4: Fence post behaviors after collision

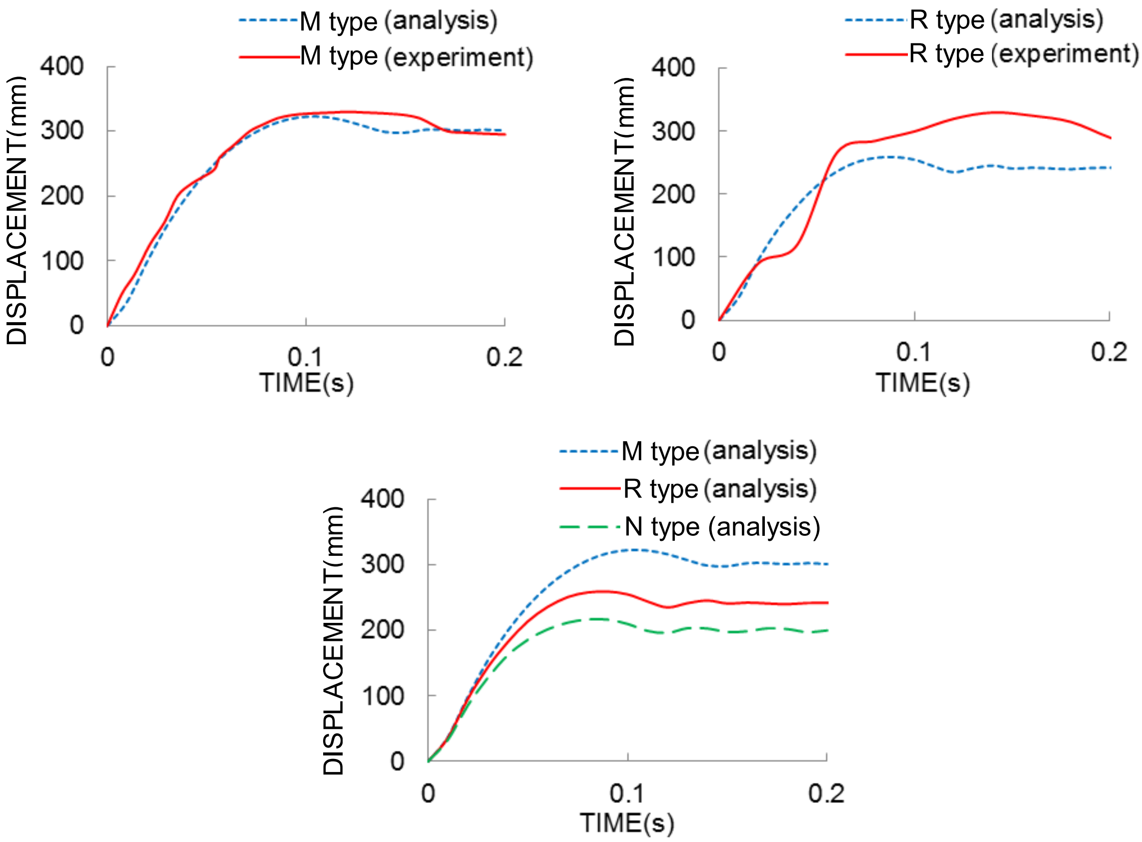


Figure 5: Displacement history

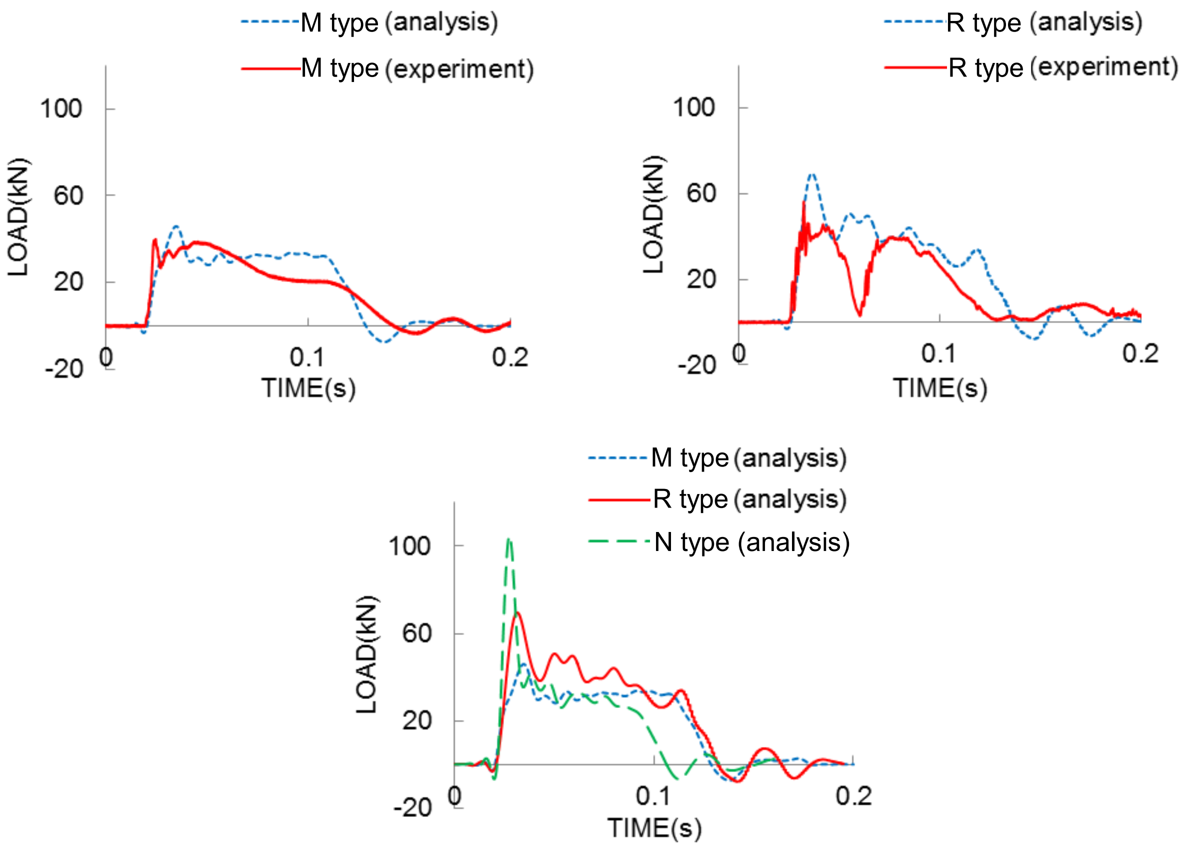


Figure 6: Impact load history

Firstly, in order to prove the FE models are valid, the analytical results are compared with the experiment results. Figure 4 shows comparison of fence post behaviors after the collision. In the case of M and R types, the lateral torsional buckling occurs at the entire compressive flanges. In the case of N type, the local buckling occurs at the narrow part in bottom of the back side of the fence post. In the case of M type, from Figure 5 and Figure 6, the analytical results of displacements and the impact loads correspond with the experiment values of them, so it can be always said that the FE model of the fence post of M type is useful and effective to evaluate the displacement and the impact load. In the case of R type, there are the small differences of the displacements and the impact loads between the analytical results and the experiment data. This seems to be caused by the margin of error in the experiment which a little eccentricity at the loading point and the excessive twist at the fence post was occurred. The reason of the excessive twist at the fence post is probably that the load cell was set at the collision position in the case of R type experiment. However, from Figure 4, the deformation such as the lateral torsional buckling occurred, so it can be always said that the FEM model of the fence post of R type is also useful and effective to evaluate the displacement and the impact load.

Figure 5 shows the out-of-plane displacement history at the collision point of the fence posts. In the case of numerical analysis, the maximum displacement of M type is 322mm, that of R type is 259mm, and that of N type is 217mm. In the case of experiment, the maximum displacement of M type is 330mm, and that of R type is 330mm. Figure 6 shows the impact load history at the collision point of the fence posts. In the case of numerical analysis, the maximum impact load of M type is 46.0kN, that of R type is 56.4kN, and that of N type is 104.7kN. In the case of experiment, the maximum impact load of M type is 39.8kN, and that of R type is 69.6kN. Comparing the maximum displacement with M and R types and N type, M and R types are 48 % and 19 % larger than N type. On the other hand, comparing the maximum impact load with M and R types and N type, M and R types are 56 % and 34 % smaller than N type. Therefore, it can be said that the fence post of new types has better performances in shock-absorbing properties than that of existing type after the collision.

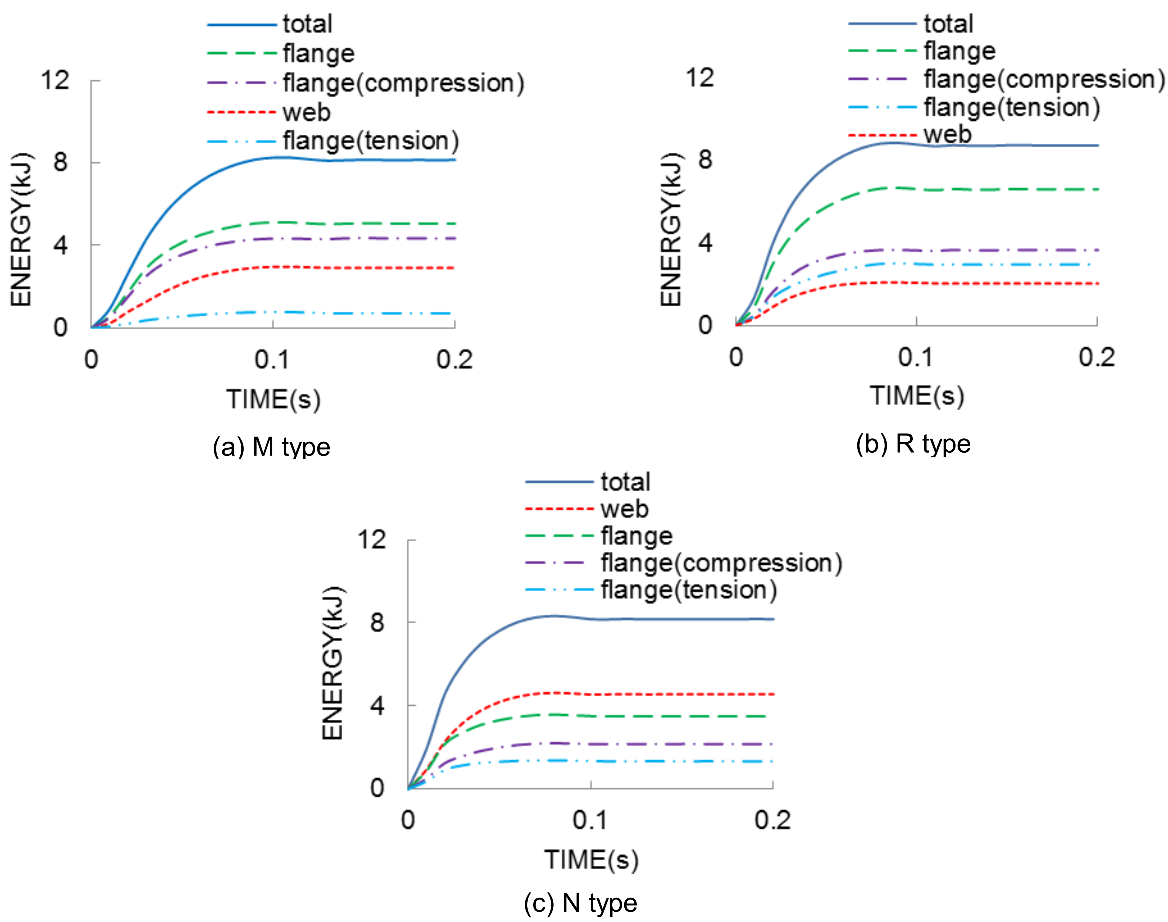


Figure 7: Distribution of internal energy

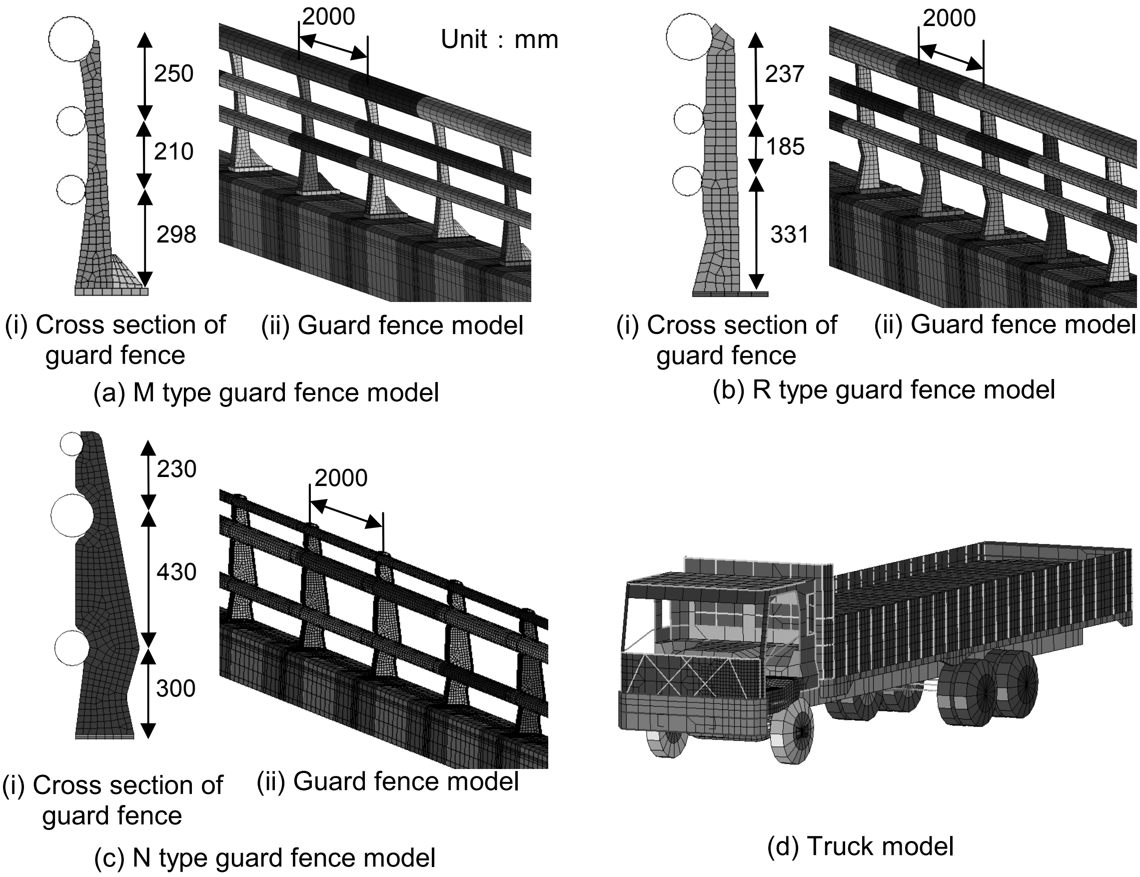
Figure 7 compares the distribution of the internal energy between three types. Comparing the internal energy with the web and the flange, in the case of both M and R types, the internal energy of the flange is respectively 26% and 53% larger than that of the web. On the other hand, in the case of N type, the internal energy of the web is 19% larger than that of the flange. Especially, in the case of both M and R types, the internal energy of the compressive flange is respectively 44% and 8% larger than that of the tensile flange. Therefore, it can be said that it analytically confirmed that fence post of new types absorbs the impact energy by the lateral torsional buckling at the entire compressive flanges, while the fence post of existing types does by the local buckling at the narrow parts in the bottom of the back side of the fence posts.

4. TRUCK COLLISION PERFORMANCE OF GUARD FENCE OF NEW TYPES

4.1 Full-scale truck collision

In Chapter 3, the impact performance of the fence posts of new bridge railing guard fences was shown by developing the FE models of the fence posts of new types in the heavy steel ball collision and comparing them with that of existing type. Then, in Chapter 4, the FE models of guard fences of each type (M, R, N) for numerical simulation based on the developed FE models of the fence posts were developed, and the full-scale truck collision numerical analysis was performed. Comparing the analytical results with three types, it is verified whether the impact performance of the fence post of new types is equally demonstrated as guard fences. The full-scale truck collision analysis is based on the full-scale truck collision experiment with N type at Tsukuba in Japan in 2010 [14]. When the FE models were developed, the FE models of bridge railing guard fences given from Ref. [3.15] were used.

4.2 FE models for numerical simulation and collision conditions



(i) Cross section of guard fence (ii) Guard fence model
(a) M type guard fence model

(i) Cross section of guard fence (ii) Guard fence model
(b) R type guard fence model

(i) Cross section of guard fence (ii) Guard fence model
(c) N type guard fence model

(d) Truck model

Figure 8: Guard fences and truck models

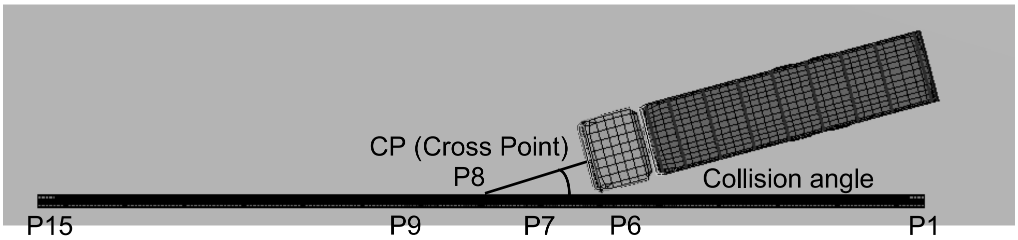
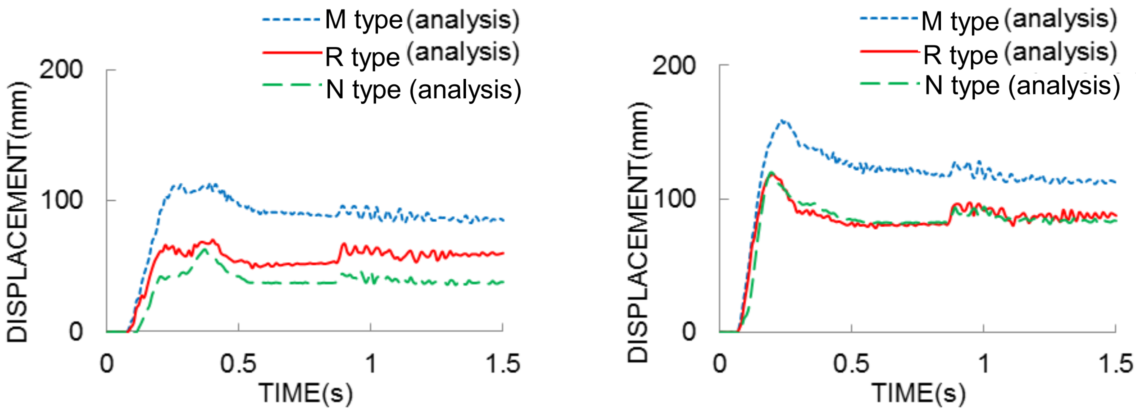


Figure 9: FE model of collision simulation

Figure 8 shows the FE models of the guard fences. The fence posts are similar to the models in the heavy steel ball collision analysis. Both the main railing beam and sub railing beam are made of pipe steel sections (STK400). The beams are modeled as isotropic elastic plastic materials following the von Mises yielding criterion. Stress-strain relationship depended on strain velocity rate effect given from the results of kinetic tests for steel materials is inputted in these FE models [13]. The bases of guard fences are made of concrete curb which has some reinforcement steels. The concrete constructed in the curb is assumed as a general elasto-plastic material. This means that the concrete is in the general elasto-plastic condition while the concrete in the compressive side reaches the yield point and only the cut-off stress is available once the tensile stress increases to the tensile strength. The boundary condition at this concrete curb is considered as a fix end. The fence posts are joined to concrete curbs by anchor bolts. Figure 8 (d) shows the FE model of a truck dealt with in this study. This truck has been developed in our laboratory having the assistance of automobile engineers [3,4,5,6,7]. The weight of truck model was 25tf (245kN) The steel is assumed to be isotropic elastic plastic materials with von Mises yielding criterion [3], and strain velocity rate effect is considered in steel. The collision conditions of three types are set to meet the level of impact of classification “A” shown in Table1, which the collision speed is 45km/h, the collision angle is 15 deg, the mass of truck is 25 tf (245kN) and the impact index is 130.8 kJ. Figure 9 shows the FE model of the collision simulation.

4.3 Results of truck collision simulations



(a) Post-8 (Cross Point)　　(b) Post-7

Figure 10: Displacement history

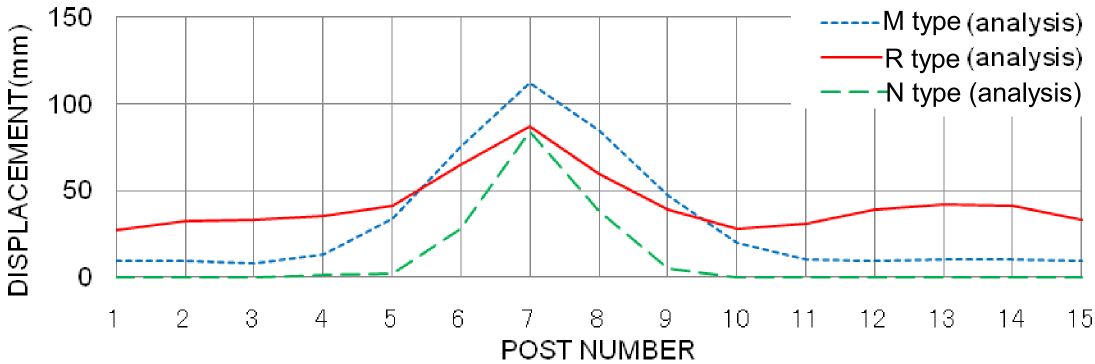
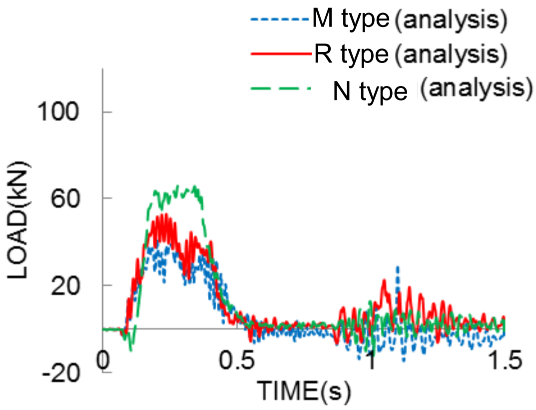
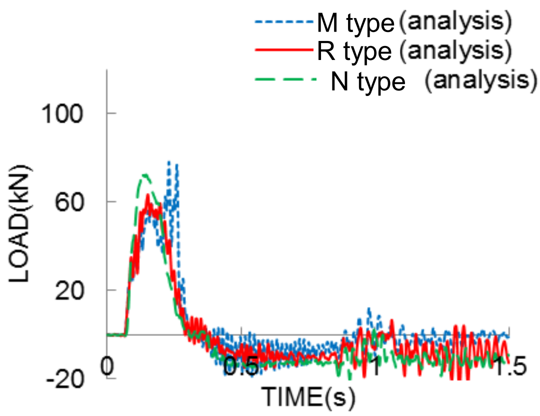


Figure 11: Residual displacement

In order to compare the difference between the guard fence of new types and that of existing type, three types of analyses was carried out. Figure 10 shows the out-of-plane displacement history at the top point of each fence post. In the case of Post-8 (Cross Point), the maximum displacement of M type is 114mm, that of R type is 70mm, and that of N type is 63mm. In the case of Post-7, the maximum displacement of M type is 159mm, that of R type is 119mm, and that of N type is 120mm. Figure 11 shows the out-of-plane residual displacements at the top point of each fence post. The largest residual displacements of each type are recorded at Post-7, which M type is 112mm, R type is 87mm and N type is 84mm.



(a) Post-8 (Cross Point)



(b) Post-7

Figure 12: Impact load history

Figure 12 shows the impact load history of each fence post. In the case of Post-8 (Cross Point), the maximum impact load of M type is 41.5kN, that of R type is 53.0kN, and that of N type is 65.9kN. In the case of Post-7, the maximum impact load of M type is 78.2kN, that of R type is 63.5kN, and that of N type is 72.8kN.

Comparing the maximum displacement with M and R types and N type, M type at Post-8 (Cross Point) and Post-7 are 81 % and 33 % larger than that of N type. R type at Post-8 (Cross Point) and Post-7 are similar to N type. Additionally, Figure 10 shows that the residual displacement of M and R types are larger than that of N type. On the other hand, comparing the maximum impact load with M and R types and N type, the maximum impact load of M type at Post-8 (Cross Point) is 37 % smaller than N type. But, in the case of Post7, that of M type is 7 % larger than that of N type. R type at Post-8 (Cross Point) and Post-7 are 20 % and 13 % smaller than N type. As a result, It shows that the guard fences of new types have better performances in shock-absorbing properties than that of existing types. Moreover, it was verified that the result of numerical simulation satisfies the performance required by the design specifications.

5. CONCLUSIONS

The following conclusions can be stated from these researches.

1) The impact performance of the fence posts of new bridge railing guard fences was verified by the heavy steel ball collision experiment.

2) Two FE models of the fence posts of new railing bridge guard fences for numerical simulation were developed. The analytical results were compared with the experimental results, and the FE models were proved to be valid and practical.

3) The impact performance of the fence posts of new bridge railing guard fences was quantitatively verified by comparing the difference between the fence posts of new types and that of existing type. It was verified that the fence posts of new types had better performances in shock-absorbing properties than that of existing type.

4) From the results of heavy steel ball collision analysis, the distribution of the internal energy of the fence post of new bridge railing guard fences was quantitatively verified. It analytically confirmed that the fence posts of new types absorbed impact energy by the lateral torsional buckling at the entire compressive flanges, while the fence post of existing type did by the local buckling at the narrow parts in bottom of the back side of the fence posts.

5) The FE models of guard fences of new types for numerical simulation based on the developed FE models of the fence posts were developed, and the full-scale collision analysis was done. It was verified that the result of numerical simulation satisfy the performance required by the design specifications and the guard fences of new types has better performances in shock-absorbing properties than that of existing type.

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