Numerical Analysis on Pounding Superstructures with Shock Absorber

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ABSTRACT:

In this paper, we carried out numerical analyses on pounding superstructures, which consist of concrete floor slab and steel girder, by using the 3-dimensional finite element method. To be more precise, the maximum impact force is calculated when the installation site of the natural rubber are changed. In addition, the damage of the superstructure ends is investigated. From the numerical analyses, the damage of the superstructure varies widely depending on the installation site of the natural rubber. The steel girders yield even if the natural rubber is installed when the collision velocity becomes faster. Moreover, the edge of the concrete floor slab is also cracked even if the natural rubber is installed in front of the concrete slab. It is difficult to replace a damage member of the steel girder. Therefore, from the perspective of the damage control, it is thought that installation of the rubber at the concrete floor slab end is much better.

KEYWORDS: Pounding girders, Natural rubber, Steel girder

1. INTRODUCTION

After the 1995 Hyogoken-Nanbu Earthquake, bearings have been replaced by rubber bearings in order to improve earthquake resistance. When the rubber bearings are used, the inertial force of the superstructure subjected to the pier can be reduced so that the damage of the pier is lessened. However, the displacement response of the superstructure increases. Therefore, it is expected that frequency of the pounding phenomena will become large, e.g., the pounding girders and the collision between the superstructure and the abutment, etc., will increase.

When a girder collides with another girder, an abutment and a device which prevents a girder from falling off, the girder is subjected to the impulsive force. So, there is a possibility that the girder ends will be damaged. In the worst case, an emergency car cannot traverse the bridge shortly after a strong earthquake occurs because of the damage of the girder ends. Therefore, in order to reduce the impact force during a collision, the Japanese Specifications of Highway Bridges requires that shock absorbers, such as those made of rubber, be installed at the girder ends in addition to devices which prevent girders from falling off. However, it has not clarified how much impact force is produced during a collision.

W. S. Tseng and J. Penzien first carried out a seismic response analysis considering pounding girders by using a pounding spring. However, it was modeled by a perfectly plastic collision in their study. Then, K.

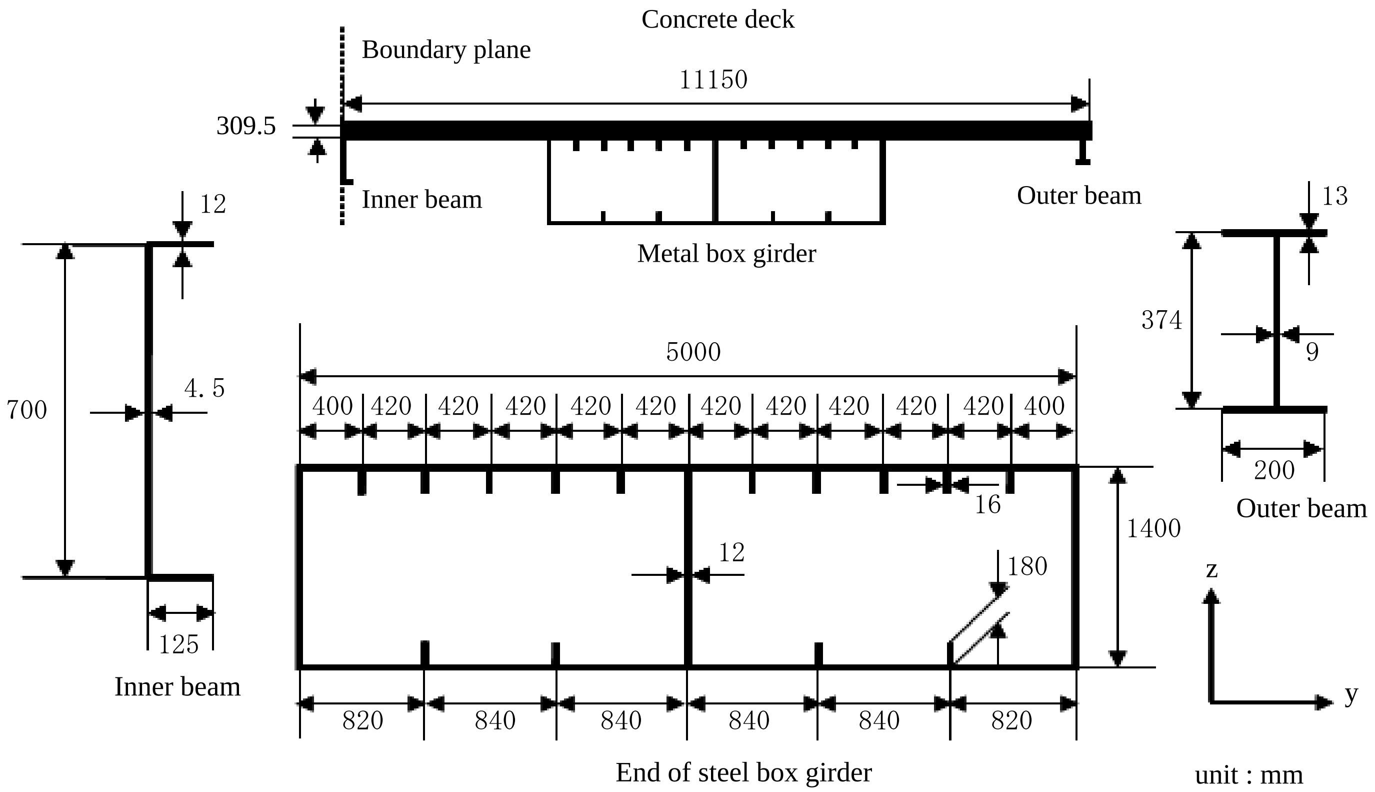


Fig.1 Cross section of the superstructure of the subject bridge

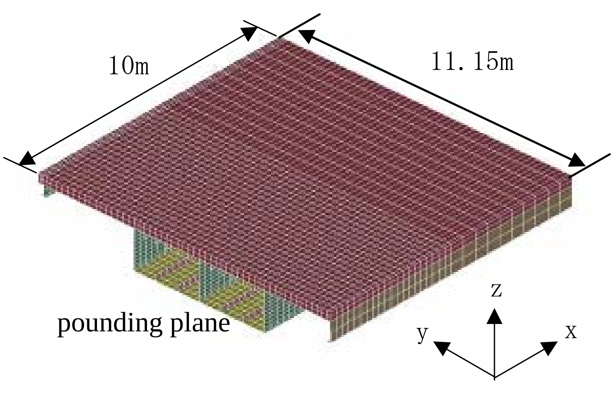


Fig.2 Finite element discretization

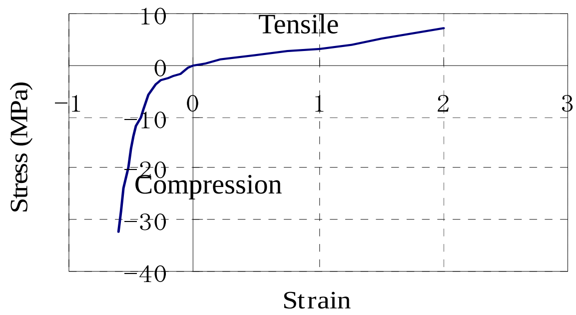


Fig.3 Stress-Strain curve

Kawashima and J. Penzien took into consideration a perfect elastic collision for the pounding spring model. It was found that the analytical results given by the pounding spring model were in good agreement with the results of the shaking table test. The analysis by using the pounding spring cannot simulate the damage of girder ends.

In this paper, numerical analyses on pounding of steel girders by the 3-dimensional finite element method were conducted in order to investigate the damage of the girder ends. In addition, natural rubber is installed on the girder ends to protect the girder ends. Moreover, the installation site of the natural rubber is change in order to examine the difference of the damage area.

Table.2.1 Material properties

	Mass density	Young's modulus	Poisson's ratio
Unit	N･sec^2/mm^4	MPa	-
Concrete	2.50E-08	2.50E+04	0.15
Steel	7.85E-08	2.10E+05	0.3
Natural rubber	1.03E-09	-	0.495

Table.2.2 Analytical cases

Case	Natural rubber block	Total nodes	Total elements
1	None	16368	14040
2	Installed (One block)	35218	30256
3	Installed (Two blocks)	33132	28536
4	Installed (Eleven blocks)	195280	140888

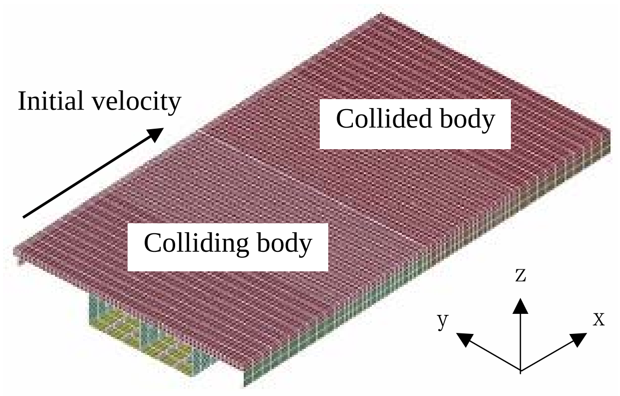


Fig.4 Overall view of the model

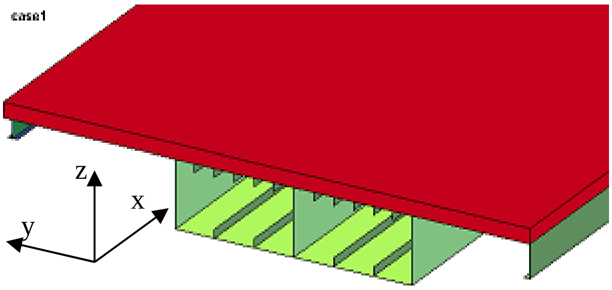


Fig.5 Analytical model (Case 1)

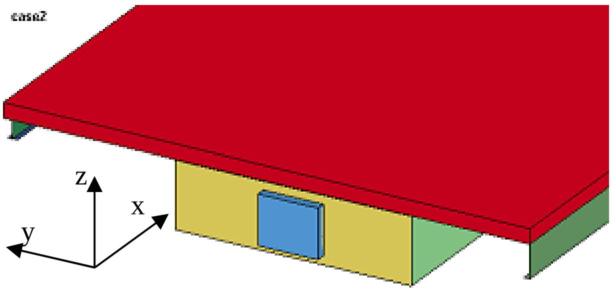


Fig.6 Analytical model (Case 2)

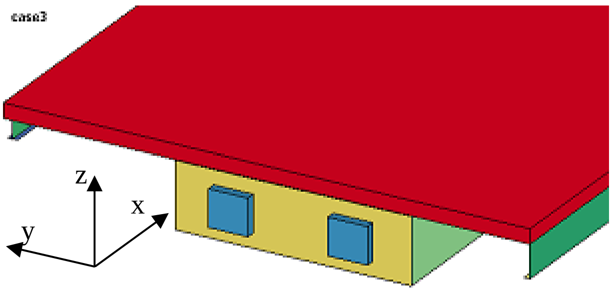


Fig.7 Analytical model (Case 3)

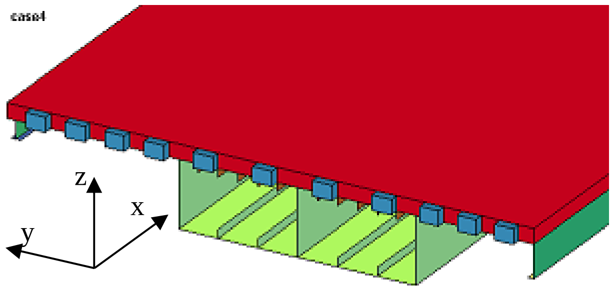


Fig.8 Analytical model (Case 4)

2. OUTLINE OF THE NUMERICAL ANALYSIS

2.1 Analytical model

In this paper, the numerical analyses were carried out by using the general-purpose finite element method code, called LS-DYNA, which is specialized for dynamic structural crush analyses. Fig.1 shows the cross section of the superstructure of the subject bridge. The superstructure consists of the concrete deck the inner/outer beam and the steel box girder. Fig.2 shows the finite element discretization and Table 2.1 shows the material properties of the concrete, steel and natural rubber. The analytical model of the bridge length is set to be 10 (m). The density of the material is set to be 10 times as the general value. The expansion device is not considered in this analysis.

The inner/outer beam and the steel box girder are discretized by the 4-nodes shell element. The constitutive law is perfect elasto-plastic considering the von-Mises's yield condition. The yield stress is set to be 370 (MPa). The concrete deck is discretized by the 8-nodes solid element. The constitutive law is elastic. This is because the damage of the concrete slab is not investigated in this study and the calculation time is shortened. The contact condition between the concrete deck and the upper flange is fixed. In this study, the collision occurs only in the horizontal direction. Natural rubber is discretized by the 8-nodes solid element. The constitutive law is Ogden-rubber model. Fig.3 shows the stress-strain curve of the natural rubber by a single axis compression/tensile test. The sectional area of the natural rubber block where the impact force is applied is obtained by the Japanese Specification of Highway Bridges. The required sectional area is obtained from 1.5times of the dead load reaction (10200 kN) divided by the allowable compression stress of the natural rubber (12N/mm^2). The sectional area is set to be 1.28*10^6 (mm^2). The specification has no detail prescript regarding the thickness of shock absorbing rubbers. So, the thickness of the natural rubber is set to be 200 (mm) tentatively.

2.2 Analytical cases

Fig.4 shows the overall view of the analytical model. In this analysis, the superstructure model to which the initial velocity is applied is named the colliding body, and the superstructure model resting before the collision is named the collided body, respectively. The colliding body crashes head-on into the collided body and the collision occurs once. Table 2.2 shows the analytical cases. Figs 5-8 show the contact surface of the analytical model. Case 1 indicates the usual condition without the shock absorber. Case 2 indicates that one natural rubber block was installed in front of the steel box girder. Case 3 indicates that two natural rubber blocks were installed. Case 4 indicates that 11 natural rubber blocks were installed in front of the concrete slab. The thickness of the natural rubber and the total volume of the natural

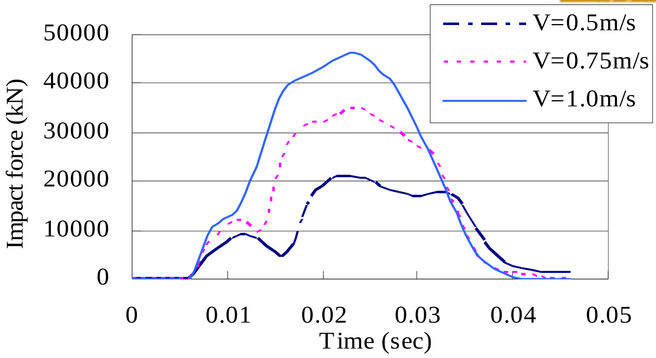
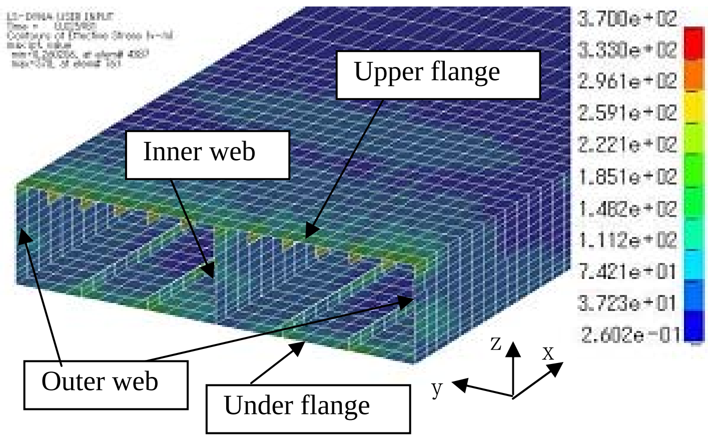
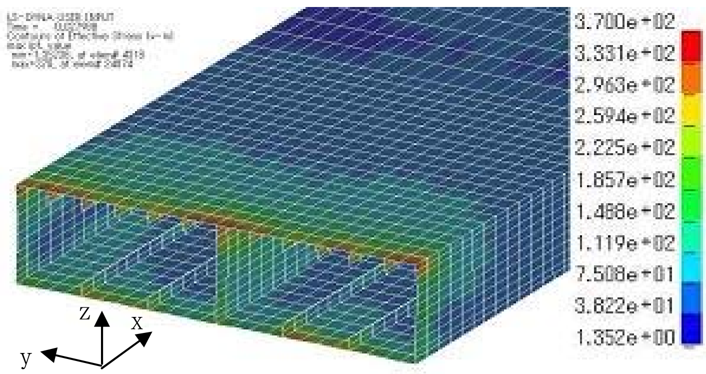


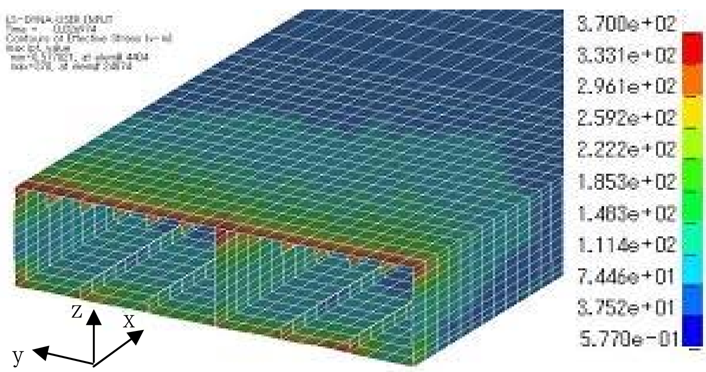
Fig.9 Time history of the impact force (Case 1)



(a) Initial velocity 0.5 m/s (0.026sec)



(b) Initial velocity 0.75 m/s (0.028sec)



(c) Initial velocity 1.0 m/s (0.027sec)

Fig.10 Stress distribution (Case 1)

rubber are the same between Case 2, Case 3 and Case 4. The natural rubber is installed on the collided body. The initial velocity is set to be 0.5, 0.75 and 1.0 (m/sec). This is because a collision may generally occur at a velocity of 1.0 (m/s) for the actual bridges during a severe earthquake.

3. ANALYTICAL RESULTS

3.1 Results and Discussion (Case 1)

Fig.9 shows the time history of the impact force in the Case 1. The maximum impact force is 20925kN (v = 0.5m/s), 34673kN (v = 0.75m/s) and 46205 kN (v = 1.0m/s), respectively. These values exceed the weight of the superstructure (10200kN). In all cases, it is found that the maximum impact force decreases around the time of 0.01 sec. This is because some parts of the girder end yield and the resistance force is decreased temporary. Fig.10 shows the stress distribution at the time of the maximum impact force. In the case of the initial velocity of 0.5m/s, only the stiffeners yielded (the red part of the figure). In the case of the initial velocity of 0.75 m/s, a part of the flange and the web yielded. Moreover, in the case of the initial velocity of 1.0 m/s, the yield area spread widely and 80% area of the upper flange yielded.

3.2 Results and Discussion (Case 2)

Fig.11 shows the time history of the impact force. The maximum impact force is 3235kN (v = 0.5m/s), 4971kN (v = 0.75m/s) and 6160 kN (v = 1.0m/s), respectively. The maximum impact force decreased by about 80% compared to Case 1. In the cases of the initial velocity of 0.75 m/s and 1.0 m/s, it is found that the maximum impact force decreases around the time of 0.01 sec same as in the Case 1. The reason why the impact force decreases is that the stiffness of the web element loses. Fig.12 shows the stress distribution at the time of the maximum impact force. The maximum impact force is reduced compared to the one in the Case 1. However, the impact force propagates only the web elements. So, the web elements yield in the initial velocity of 0.75m/s

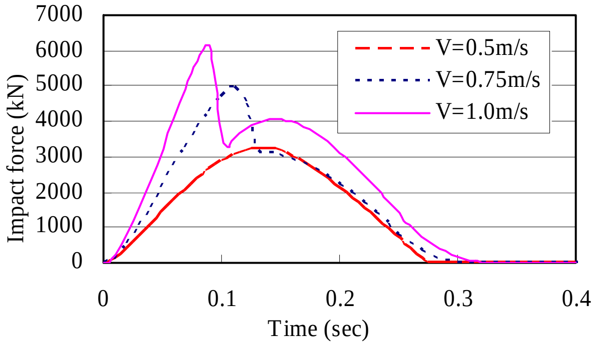
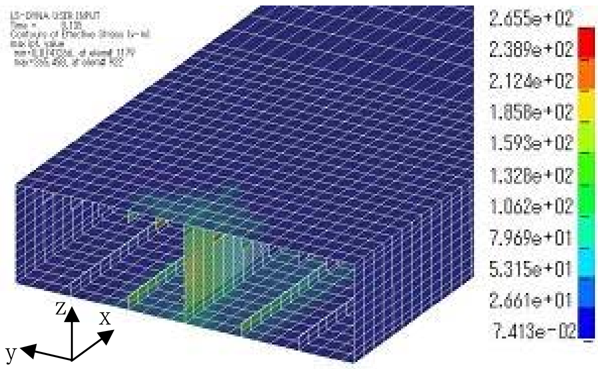
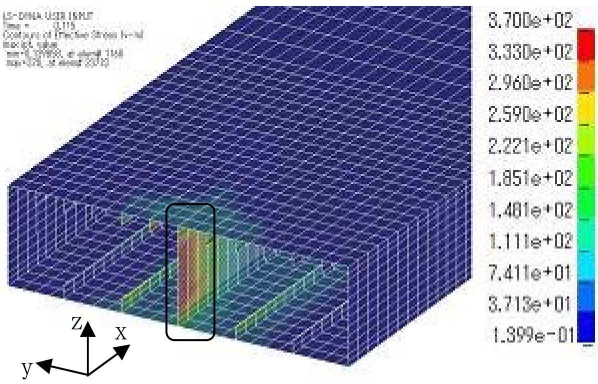


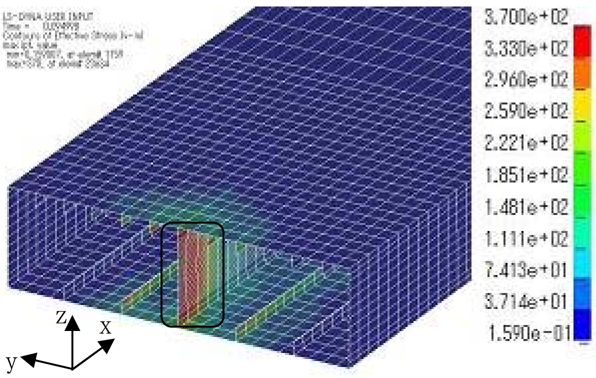
Fig.11 Time history of the impact force (Case 2)



(a) Initial velocity 0.5m/s (0.135sec)



(b) Initial velocity 0.75m/s (0.11sec)



(c) Initial velocity 1.0m/s (0.09sec)

Fig.12 Stress distribution (Case 2)

and 1.0m/s.

3.3 Results and Discussion (Case 3)

In this case, two blocks of natural rubber are installed in order to prevent the steel box girder from yielding locally. Fig.13 shows the time history of the impact force. Compared to Case 2, the maximum impact force decreased by about 30%. Fig.14 shows the stress distribution. Even if the initial velocity is 1.0m/s, only the stiffeners yielded (the red part of the figure). So, there is no damage in the steel box girder.

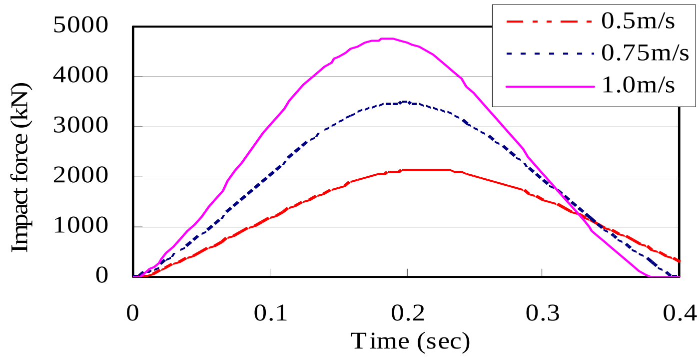
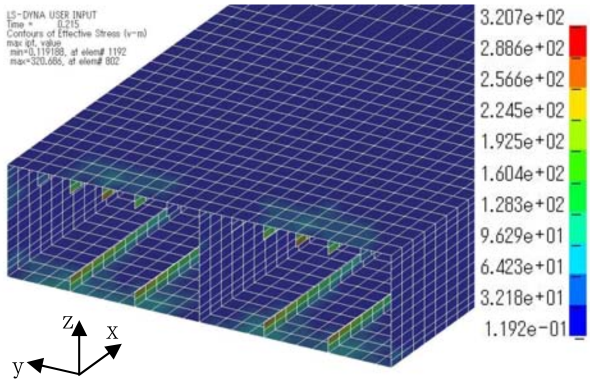
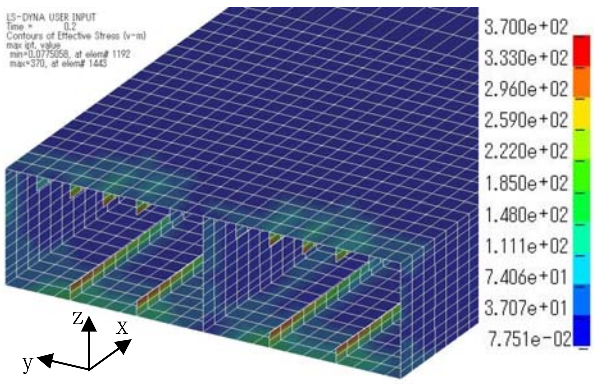


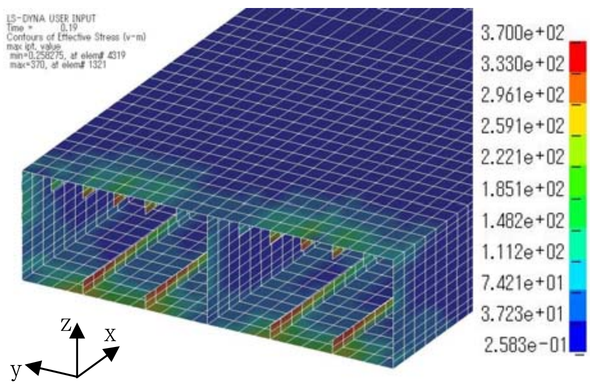
Fig.13 Time history of the impact force (Case 3)



(a) Initial velocity 0.5m/s (0.215sec)



(b) Initial velocity 0.75m/s (0.20sec)



(c) Initial velocity 1.0m/s (0.19sec)

Fig.14 Stress distribution (Case 3)

3.4 Results and Discussion (Case 4)

In this case, 11 blocks of natural rubber are installed on the concrete slab because the stiffness of the concrete slab is larger than the one of the steel girder. Table 3.1 shows the maximum impact force and Fig.15 shows the stress distribution. As for the maximum impact force, the result of Case 4 is a little larger than the one of Case 2 and Case 3. However, as for the stress distribution, the result of Case 4 is much smaller than the one of Case 2 and Case 3. Even if the initial velocity is 1.0m/sec, the steel girder and the concrete damage have no damage. So, from the perspective of the damage control, it is thought that installation of the rubber at the concrete floor slab end is much better.

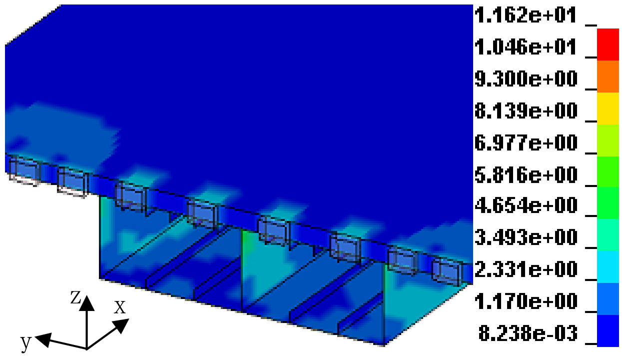
4. CONCLUDING REMARKS

In this paper, numerical analyses on pounding of steel girders by the 3-dimensional finite element method were conducted in order to investigate the damage of the girder ends. In addition, natural rubber is installed on the girder ends to protect the girder ends. The results obtained from the analyses can be summarized as follows:

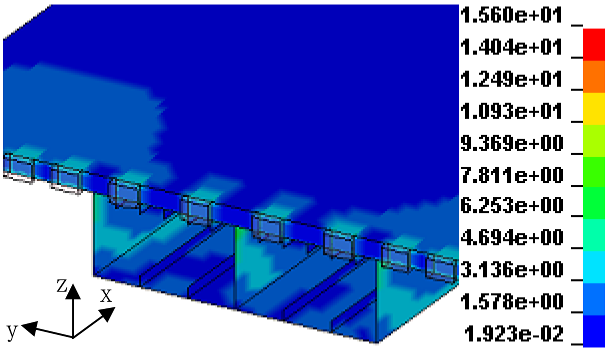
(1)It is found that the maximum impact force decreased by about 80% when the natural rubber was installed at the girder ends and the damaged area also lessened. Therefore, the installation of the shock absorber is very

Table 3.1 Maximum impact force (unit: kN)

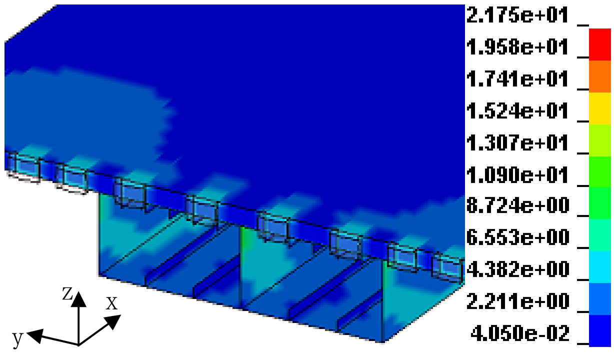
	Case 1	Case 2	Case 3	Case 4
v=0.50m/s	20295	3235	2134	3594
v=0.75m/s	34673	4971	3461	5985
v=1.00m/s	46025	6160	6160	8403



(a) Initial velocity 0.5m/s (0.18sec)



(b) Initial velocity 0.75m/s (0.17sec)



(c) Initial velocity 1.0m/s (0.16sec)

useful to prevent the girder ends from yielding.

(2)It is found that the installation site is very important to protect the steel box girder ends. The site is determined just as the impulsive force doesn't propagate locally.

(3)From the perspective of the damage control, it is thought that installation of the rubber at the concrete floor slab end is much better.

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REFERENCES

W. S. Tseng and J. Penzien: Analytical Investigations of the Seismic Response of Long Multi-span Highway Bridges, Report No. EERC 73-12, Earthquake Engineering Research Center, University of California, Berkeley, 1973.

K. Kawashima and J. Penzien: Theoretical and Experimental Dynamic Behavior of a Model Bridge Structure, Earthquake Engineering and Structural Dynamics, Jul. 1979, pp.129-145.

Japan Road Association: Specification of Highway Bridges, Part V, Seismic Design, 2002 (in Japanese)