Damage estimation of expansion joint by collision between girders

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ABSTRACT

In this paper, we carried out numerical analyses on collision between girders, which consist of the expansion joint, concrete floor slab and steel girder, by using the 3-dimensional finite element method. To be more precise, the damage level of the expansion joint and concrete slab is simulated. From the numerical analyses, the finger part of the expansion joints is lifted up from about 20mm to 200mm depending on the collision velocity. From the result, it is found that the emergency cars are necessary to traverse in low speed when the collision velocity is larger than 2.0m/sec.

1. INTRODUCTION

After the 1995 Hyogoken-Nanbu Earthquake, steel bearings have been replaced by rubber bearings in order to improve earthquake resistance.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 will increase. Therefore, it is expected that frequency of the pounding phenomena will become large, e.g., the pounding between two 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 expansion joints 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 expansion joints. 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.

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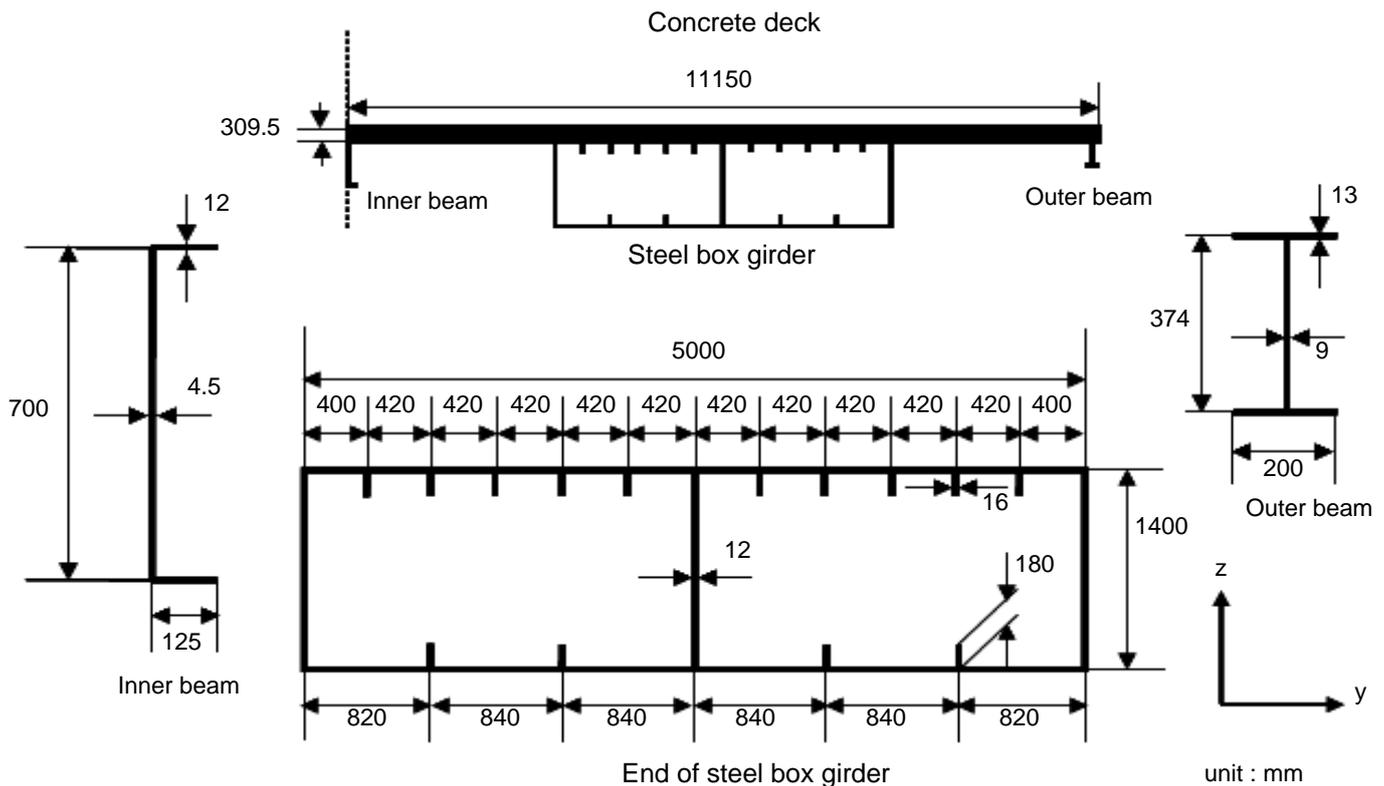
Fig.1 Cross section of the superstructure of the target bridge

W. S. Tseng and J. Penzien first carried out a seismic response analysis considering pounding between girders by using a pounding spring. However, it was modeled by a perfectly plastic collision in their study. Then, K. 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 degree of damage of expansion joints and the girder ends. In addition, natural rubber is installed on the girder ends to protect the girder ends.

2. OUTLINE OF THE NUMERICAL ANALYSIS

2.1 Numerical 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 target bridge. The superstructure consists of the concrete deck, the inner/outer beam and the steel box girder. Fig.2 shows the numerical model and Table 1 shows the material properties of concrete, steel and natural rubber. The analytical model of the superstructure length is set to be 100 (m).

(a) Numerical model of the superstructure

(b) Close up of the girder ends

(c) Close up of the expansion joint
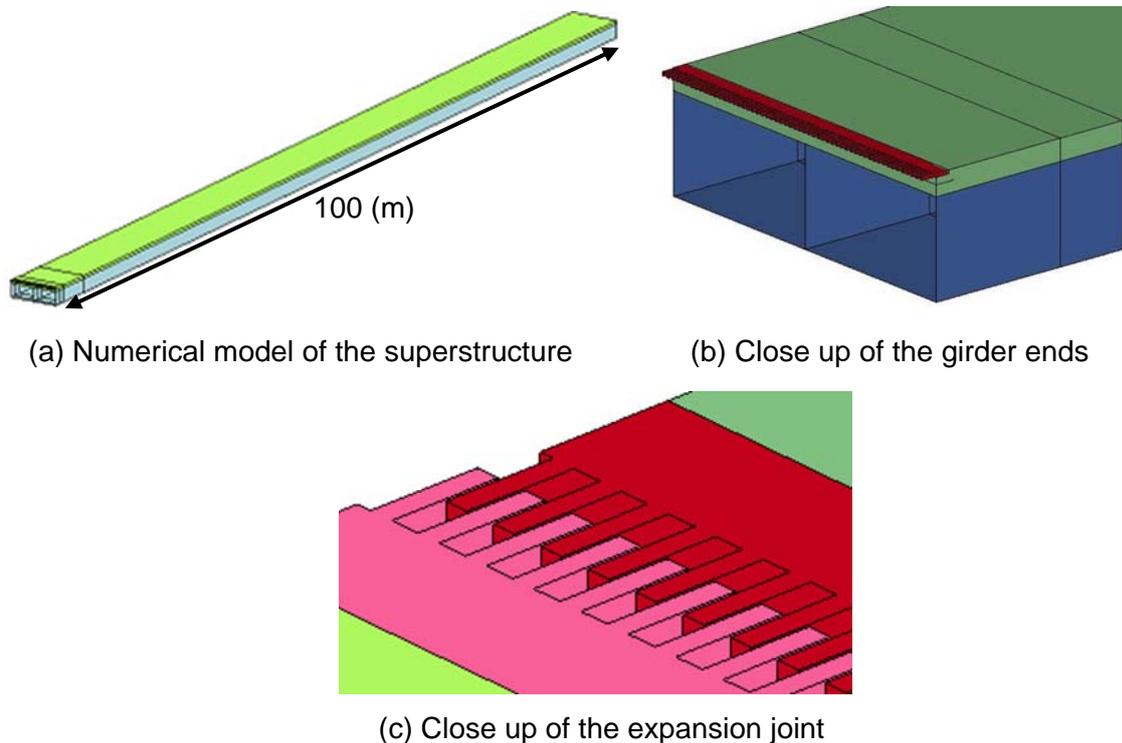
Fig. 2 Numerical model

Table 1 Material properties

	Density	Young's Modulus	Poisson's ratio	Compressive strength	Tensile strength
unit	ton/mm^3	MPa	-	MPa	MPa
Concrete	2.69E-9	2.06E+4	0.2	30	3
Steel	7.85E-9	2.10E+5	0.3	235 (yield stress)	
Rubber	1.03E-9	-	0.495	-	-

The steel box girder is discretized by the 4-nodes shell element. The constitutive law of steel is perfect elasto-plastic considering the von-Mises's yield condition. The yield stress is set to be 235 (MPa). The concrete deck is discretized by the 8-nodes solid element. The stress-strain curve of the concrete is shown in Fig.3. In this study, the collision occurs only in the bridge axis direction. Natural rubber is discretized by the 8-nodes solid element. The constitutive law is Ogden-rubber model. Fig.3 also 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 1.5 times of the dead load reaction (10200 kN) divided by the

(a) Concrete
(b) Natural rubber

Fig. 3 Stress-strain curve

(a) No natural rubber (case 1)

(b) With natural rubber (case 2)
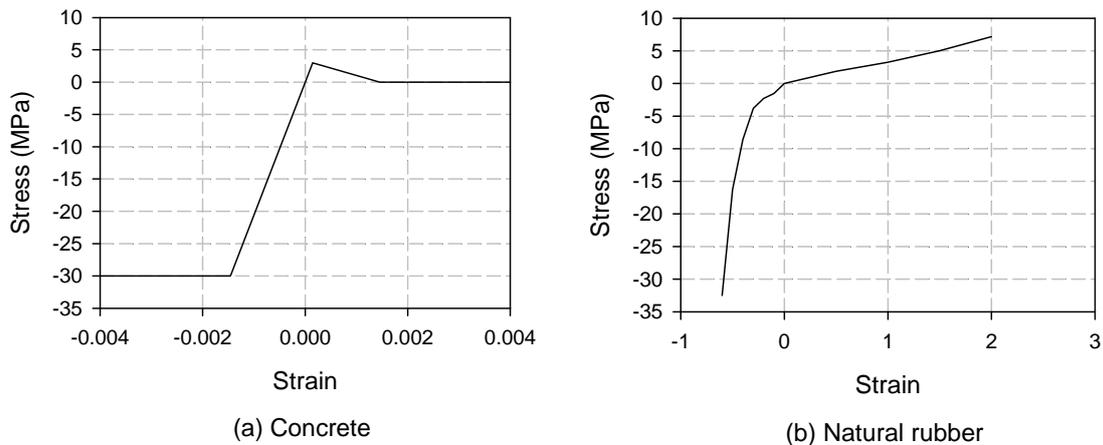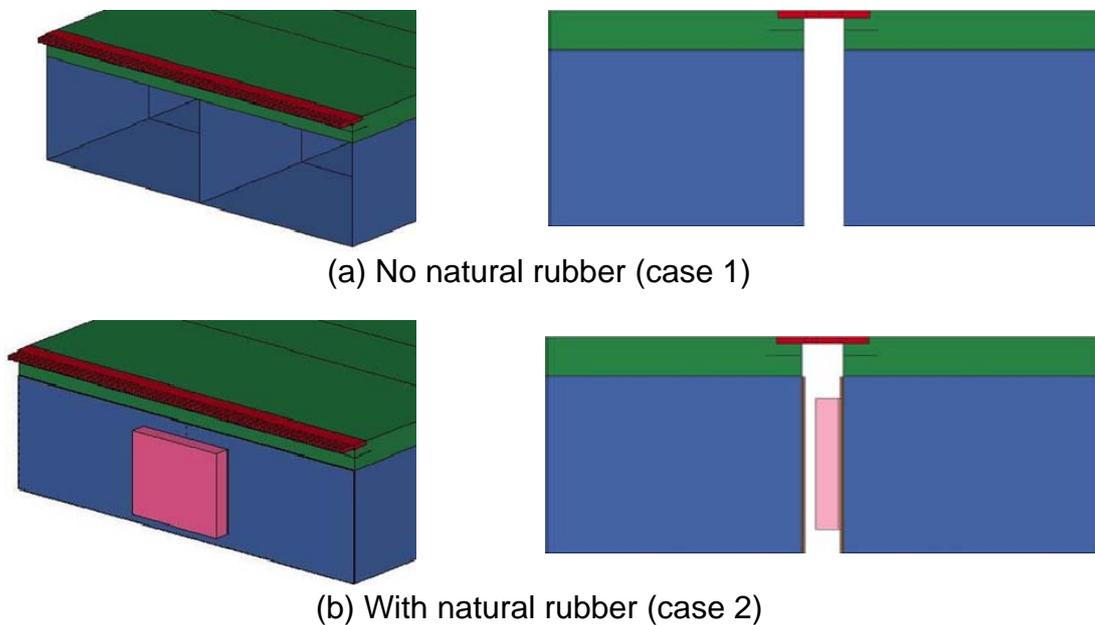
Fig. 4 Analytical cases

allowable compression stress of natural rubber (12N/mm^2). The sectional area is 1.28E+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 analytical cases. 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. As previously mentioned, the thickness of the natural rubber is set to be 200(mm). This is because natural rubber touches the other girder end before the collision between the expansion joints. The initial velocity is set to be 0.5, 1.0, 1.5, 2.0

(a) No natural rubber (case 1)   (b) With natural rubber (case 2)

Fig. 5 Damage situation of the expansion joints
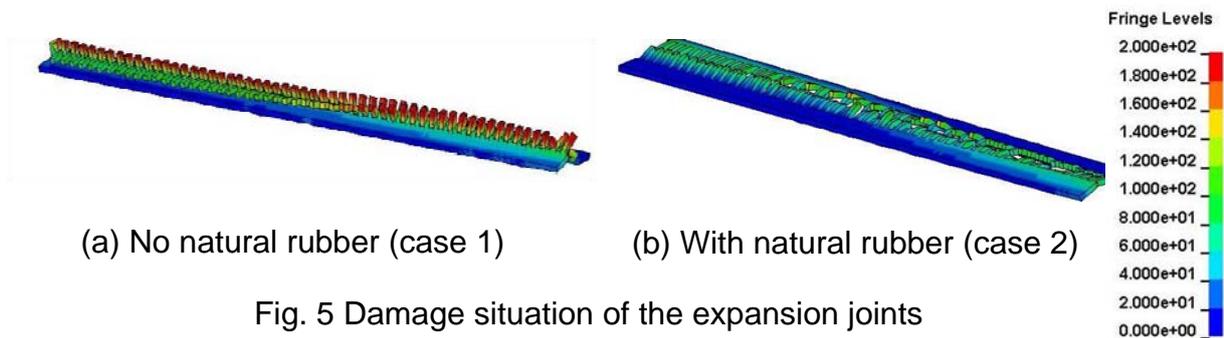
(a) collision velocity 2.0 (m/s)   (b) collision velocity 2.5 (m/s)
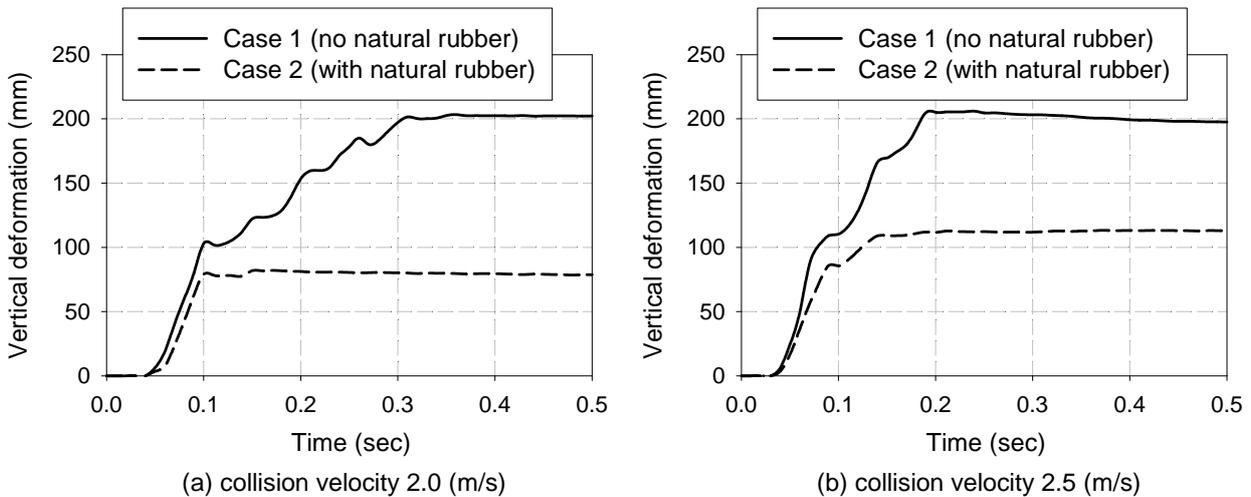
Fig. 6 Time history of the vertical deformation of the expansion joints

and 2.5 (m/s). This is because a collision may generally occur at a velocity of from 1.0 (m/s) to 2.0 (m/s) for the actual bridges during a severe earthquake.

3. Analytical results

3.1 Damage situation of the expansion joints

Fig.5 shows the damage situation of the expansion joints at the collision velocity of 2.0 (m/s). Fig. 6 shows the time history of the vertical deformation of the expansion joints at the collision velocities of 2.0 and 2.5 (m/s).   In this study, the vertical deformation is defined as the front edge location of the finger part of the expansion joint. It is found from the Fig.6 that the deformation is almost same in an early stage. In the Case 2, the collision of expansion joints starts when the natural rubber deforms at only 10 (mm). So, the velocities of the superstructure at the time of impact of the expansion joints are almost same in two cases. After the elapse of a certain period of time, the relative displacement between expansion joints cannot change due to the natural rubber in the Case 2. So, the vertical deformation can be reduced by the existence of the natural rubber.

(a) No natural rubber (case 1)   (b) With natural rubber (case 2)
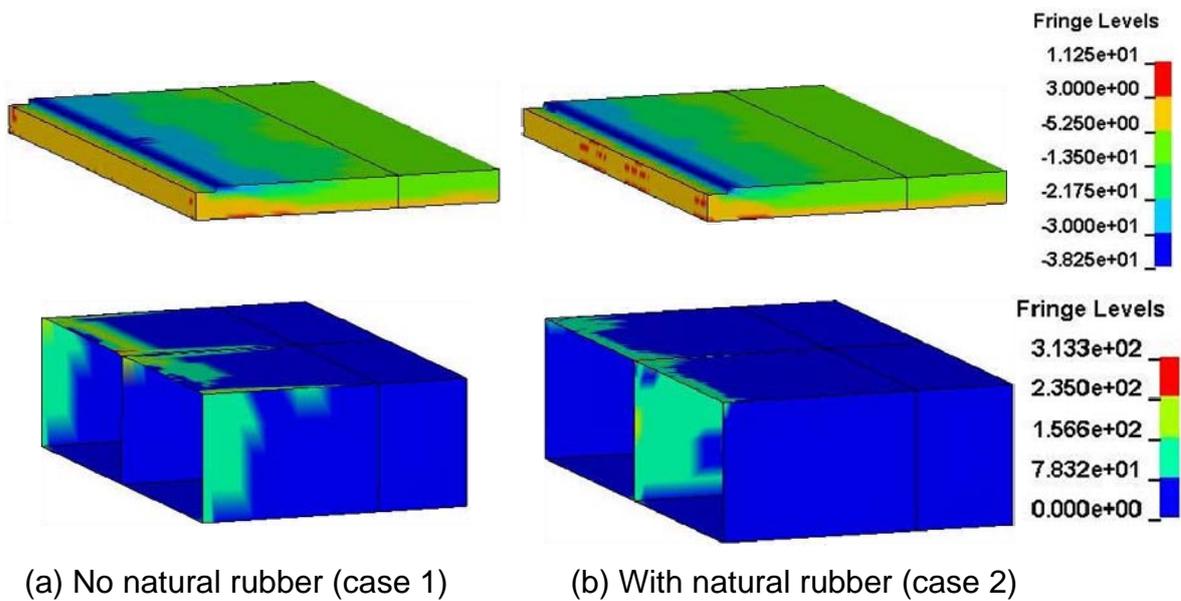
Fig. 7 Stress contour figure of the concrete slab and steel box girder

3.2 Damage situation of the concrete slab and the steel box girder

Fig.7 shows the stress contour of the concrete slab and the steel box girder at the collision velocity of 2.0 (m/s). In the case of the concrete slab, Fig.7 shows the maximum normal stress in the bridge axis direction. On the other hand, in the case of the steel box girder, Fig.7 shows the maximum von Mises stress. As previously mentioned, although the superstructure collides with the natural rubber first in the Case 2, the natural rubber cannot reduce the velocity of the superstructure drastically. The velocities of the superstructure at the time of impact of the expansion joints are almost same. Therefore, there is not much difference between the stress contour figure of Case 1 and Case 2. As for the von Mises stress of the steel box girder, the red part indicates the area where the steel has yielded. So, the steel has yielded at the middle of the upper edge of the box in the Case1.

3.3 The confirmation of trafficability

Fig. 8 shows the allowable vertical gap (Abe, 2004). This figure indicates that if a vehicle drives at the speed of 40km/h, a vehicle can climb over the 75mm-vertical gap. In other word, if there is the 100mm-vertical gap on the road surface, we have to reduce a vehicle's speed less than 30km per hour. Table 2 shows the maximum available velocity for traffic. In the case that the collision velocity is 1.5(m/s), the vertical gap is 47.7(mm). So, the vehicle can pass by the gap at
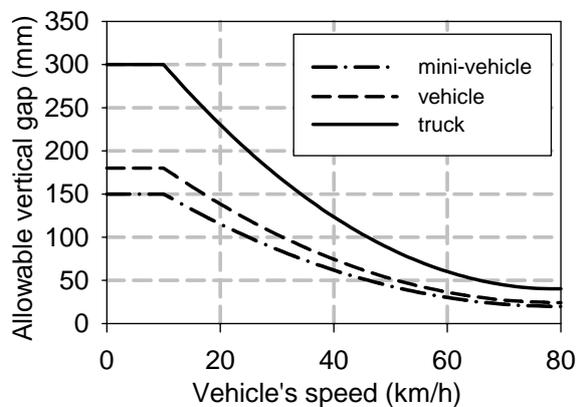
Fig. 8 Allowabl vertical gap

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Table 2 Maximum available speed for traffic

collision velocity	thickness of rubber	vertical gap	mini vehicle	vehicle	truck
m/s	mm	mm	km/h	km/h	km/h
1.5	0	47.7	51	56	72
2.0	0	202.29	impassable	impassable	24
	200	78.65	32	38	52
2.5	0	197.56	impassable	impassable	25
	200	112.74	20	27	42

the speed of 56 (km/h). If the collision velocity is larger than 2.0 (m/s), it is found that the emergency cars are necessary to traverse in low speed in the case that the natural rubber is not installed. Although the collision velocity cannot be reduced by the natural rubber, the degree of damage of expansion joint can be small when the natural rubber is installed. So, the trafficability is secured even if a large earthquake is generated.

4. CONCLUSIONS

In this study, in this study, the damage analyses of the real size girder ends due to the collision are conducted by the general-purpose dynamic finite element program LS-DYNA to clear the damage situation. The following remarks can be made as conclusions of this research.

(1)The vertical deformation of the expansion joint is almost same just after the collision regardless of the presence of the natural rubber. After the elapse of a certain period of time, the relative displacement between expansion joints cannot change due to the natural rubber. So, the vertical deformation can be decreased drastically by the existence of the natural rubber.

(2)There is not much difference between the stress contours of the concrete slab regardless of the presence of the natural rubber.

(3) If the collision velocity is larger than 2.0 (m/s), the emergency cars are necessary to traverse in low speed in the case that the natural rubber is not installed. The degree of damage of expansion joint can be small when the natural rubber is installed. So, the trafficability is secured even if a large earthquake is generated.

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)

Abe, M., Fujino, Y., Yoshida, J., Zhu, Ping. 2004. Evaluation of pounding countermeasures and ser-viceability for elevated bridges with 3D modeling, Journal of Civil Engineering, No.773/I-69, pp.47-61 (in Japanese)