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A Case Study on the Effect of Damaged Expansion Joint for Safety Assessment of Highway Bridges

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Abstract : In this study, the variations of transformed impact factors and load carrying capacity of highway bridges measured from the state of expansion joint are evaluated. the field loading tests were performed on the highway bridge with damaged expansion joint to investigate the variation of the load carrying capacity. From the field loading tests in case that damaged expansion joint exist or do not exist, the static displacements and dynamic displacements were measured, and TIF were calculated, respectively. dynamic test is performed in order to estimate dynamic displacement and TIF according to the level of damage of expansion joint. From the results of TIF, the load carrying capacity of highway bridges with damaged expansion joint were estimated.

Key words: expansion joint, load carrying capacity, transformed impact factor, dynamic test

1. Introduction

Load carrying capacity of the current highway bridge has been evaluated by using some response ratio, i.e., the ratio of the tested values to theoretical values, the damage factor, and TIF(transformed impact factor). Among these factors, the transformed impact factor tends to be obtained from the external appearance of the bridge structure, such as the state of the expansion joint, even though it really depends on the variation of vehicle speeds.

In this study, the variations of transformed impact factors and load carrying capacity of the highway bridges measured from the state of the expansion joint are evaluated.

2. Evaluation Methods of Load Carrying Capacity for Highway Bridges

In the maintenance of the bridge, evaluation load carrying capacity properly is crucial especially for the aged highway bridges. In general, evaluation methods of load carrying capacity for highway bridges have been developed from two different theories considering aging index of the bridges : strength design method and allowable stress design method.

2.1 TIF (Transformed Impact Factor)

In general, the responses of the aged bridges induced by the live loads are increased by loosing composite action, coarse slab surface and damaged expansion joint. TIF is used to indicate damaged level of the aged bridges.

$$\mathrm{TIF} = \frac{\sigma_{MD}}{\sigma_{MS}} - 1 \qquad (1)\ [1],\ [5]$$

where, σ_{MD} : Dynamic maximum stress (displacement)
σ_{MS} : Static maximum stress (displacement)

2.2 Evaluating method of load carrying capacity by strength design

Evaluation of load carrying capacity by strength design is expressed as following equations.

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$$P_n = P_L \times RF \quad (2)$$

$$RF = \frac{P_n}{P_L} = \frac{\varnothing D_F R_n - \gamma_D D_n}{\gamma_L L_n} \times \frac{1}{K} \quad (3)[2]$$

where, P_n : Load carrying capacity

RF : Load carrying capacity ratio

R_n : Presumption nominal strength by actual-strength of nothing damaged section

D_n : Moment by dead load

L_n : Moment by design live load

D_F : Damage factor

K : Corrective factor of load carrying capacity

$$K = K_s(1 + i_M) \quad (4)[2]$$

where, K_s : Response ratio(tested stress or tested displacement/calculated stress or calculated displacement)

i_M :Tested impact factor

Φ, γ_D, γ_L : Safety parameter for resistance and load($\Phi = 0.85$, $\gamma_D = 1.3$, $\gamma_L = 2.15$)[3]

2.3 Evaluating method of load carrying capacity by allowable stress design

The evaluation of load carrying capacity is drastically improved by including damage factor acquired from actual resisting strength for damaged structure and real response ratio measured from the loading test, and is shown as following equations [2].

$$P_n = P_L \times RF \quad (5)$$

$$RF = \frac{P_n}{P_L} = \frac{\sigma_a D_F - \sigma_d}{\sigma_l} \times \frac{1}{K} \quad (6)$$

where, P_n : Load carrying capacity

RF : Load carrying capacity load ratio

P_L : Design live load

σ_a : Allowable stress of material

σ_d : Stress by dead load

σ_l : Stress by design live load

D_F : Damage factor

K : Corrective factor of load carrying capacity

Table 1. Graded list of load carrying capacity[4].

	RF	P_n	Counterplan
Good	RF≥1.0	P_n≥24	Periodical observation
Common	0.75≤RF<1.0	18≤P_n<24	Repair
Poor	0.57≤RF<0.75	13.5≤P_n<18	Repair, Reinforcement
Very poor	RF<0.57	P_n<13.5	Reconstruction

2.4 Grade of load carrying capacity

Table 1 shows the summary of evaluating factors of load carrying capacity.

3. Loading Test by using Actual moving Vehicle Load

3.1 Measuring System

In this study, dynamic test is performed in order to estimate dynamic displacement and TIF according to the level of damage of expansion joint. During the test, traffic was totally blocked. Vehicle speed of 5 km/h is assumed as a pseudo static state. History of dynamic displacement is recorded by varying the vehicle speed from 10 km/h to 70 km/h with 10 km/h interval. Fig. 1 shows the flow chart

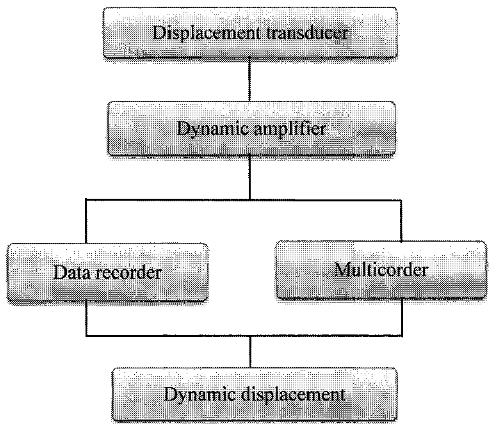

Fig. 1. Measuring system.

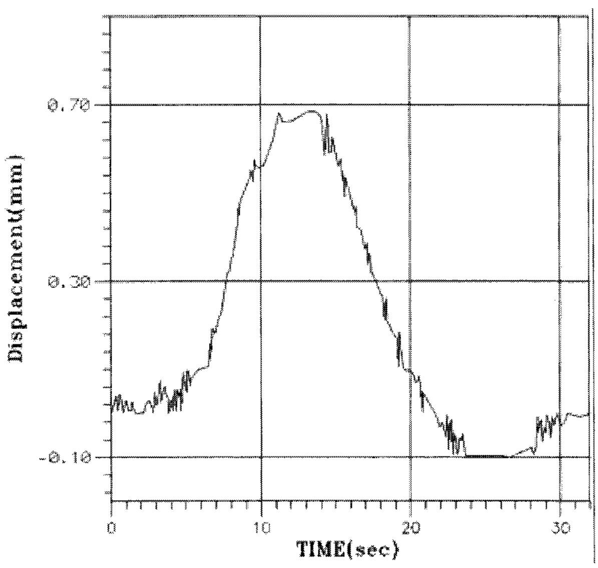

Fig. 2. The relations between time and displacement (north-bound lane, 5 km/hr).

of measuring system for dynamic test.

3.2 Results and considerations of dynamic test

Dynamic test was performed under two conditions. In the first condition called as northbound lane, the expansion joint affects the bridge response. In the other condition called as southbound lane, the expansion joint cannot cause any effect of the bridge response. Measured history of the dynamic displacement is shown in Fig. 2~Fig. 13, and maximum displacement and TIF are shown in Table 2~Table 3.

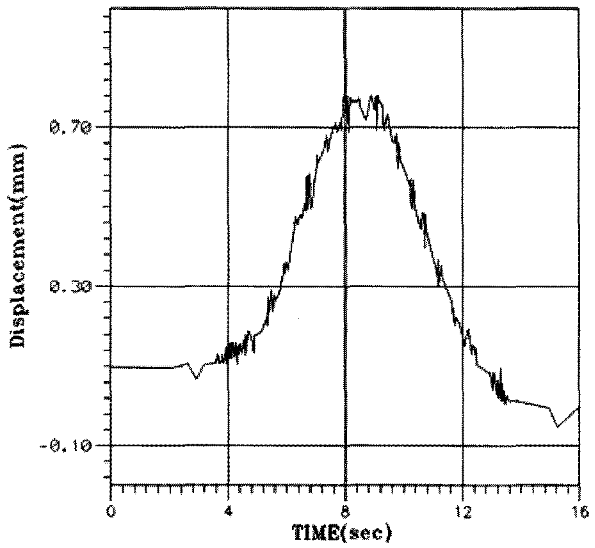

Fig. 3. The relations between time and displacement (northbound lane, 10 km/hr).

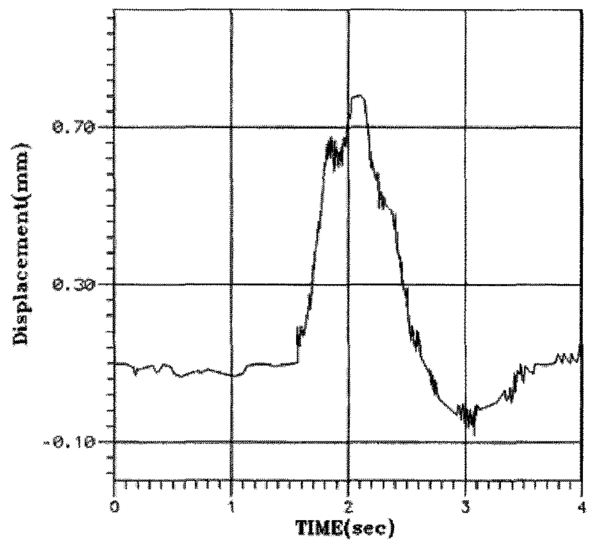

Fig. 4. The relations between time and displacement (northbound lane-1, 60 km/hr).

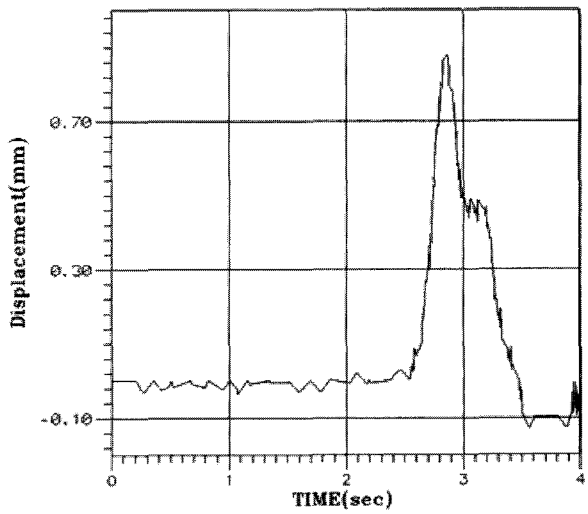

Fig. 5. The relations between time and displacement (northbound lane-2, 60 km/hr).

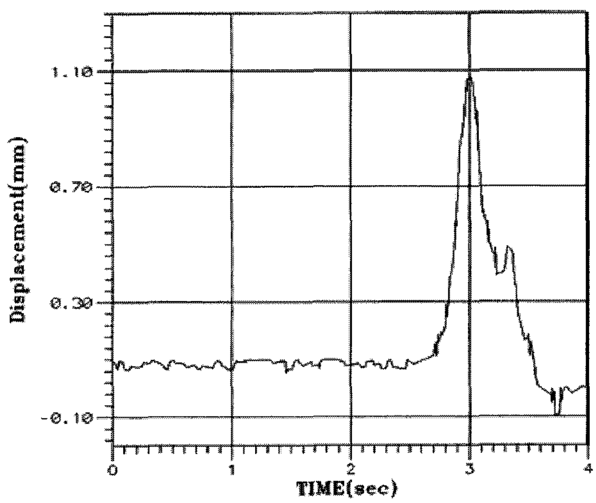

Fig. 6. The relations between time and displacement (northbound lane-1, 70 km/hr).

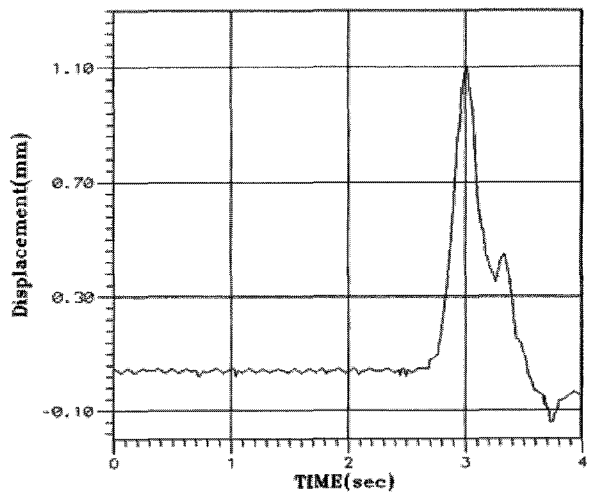

Fig. 7. The relations between time and displacement (northbound lane-2, 70 km/hr).

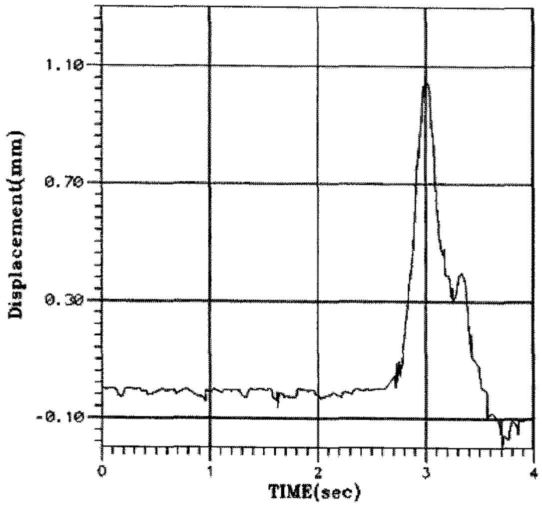

Fig. 8. The relations between time and displacement (north-bound lane-3, 70 km/hr).

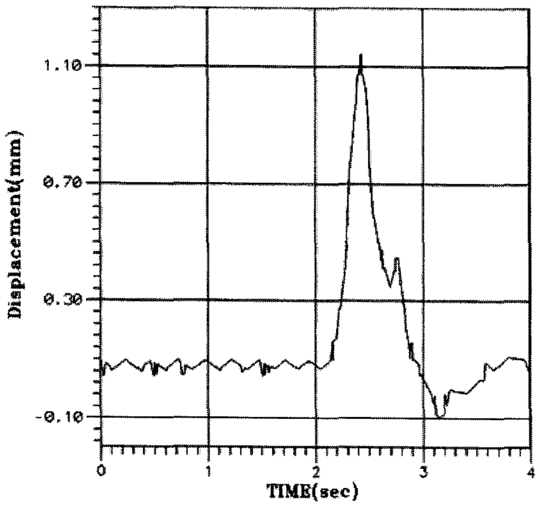

Fig. 9. The relations between time and displacement (north-bound lane-4, 70 km/hr).

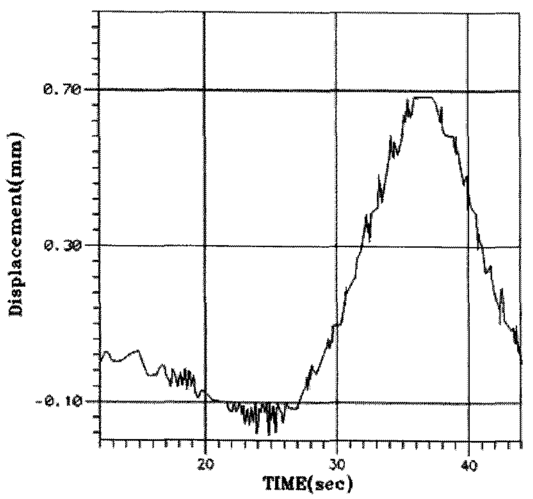

Fig. 10. The relations between time and displacement (south-bound lane, 5 km/hr).

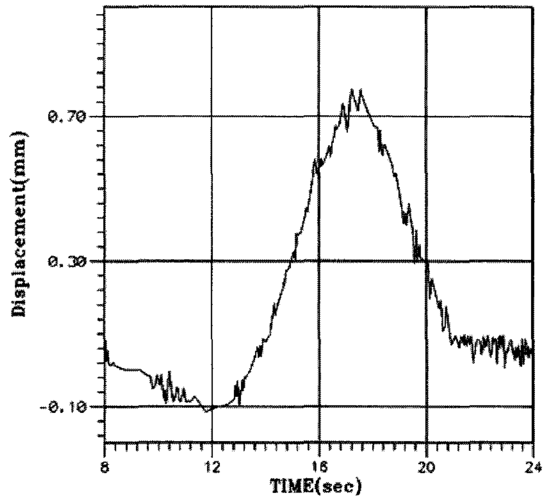

Fig. 11. The relations between time and displacement (south-bound lane, 10 km/hr).

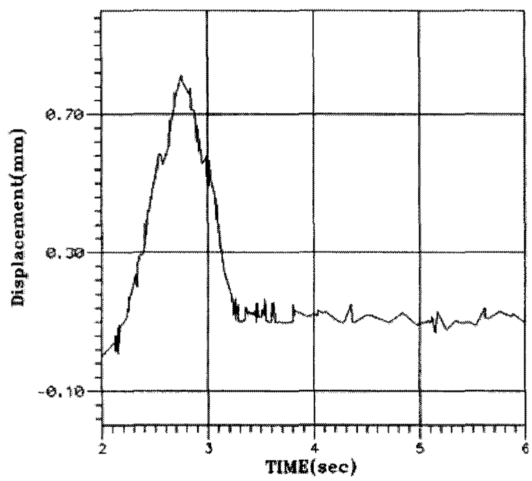

Fig. 12. The relations between time and displacement (south-bound lane, 60 km/hr).

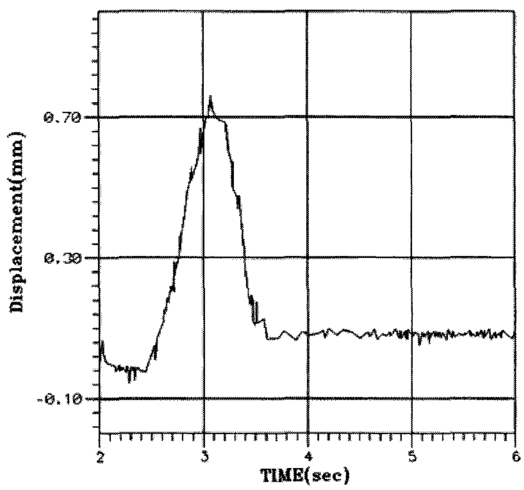

Fig. 13. The relations between time and displacement (south-bound lane 70 km/hr).

As shown in Fig. 2~Fig. 13 and Table 2~Table 3, maximum displacement for southbound lane is 0.684~0.846 mm and corresponding maximum TIF is 0.237. For northbound lane, the results of the speed ranges of 10~60 km/h are exactly the same as the results of southbound lane. However, in case of the vehicle speed of 70 km/h, maximum displacement and corresponding TIF is increased up to 1.172 mm and 0.713, respectively. This result indicate that the huge impact load is occurred when the vehicle moves fast to the highway bridge due to the different levels between paved slab and expansion joint.

3.3 Analysis of the evaluation of capacity load

Results of capacity loads for both conditions by using evaluation methods mentioned in chapter 2~3.2 are summarized in Table 4~Table 5.

As shown in Table 3, the load carrying capacity for southbound lane, in which the expansion joint is not change the response of the bridge, is about DB-18.4~DB-24.4, which is not related to the vehicle speeds.

However, the load carrying capacity for northbound lane, in which the expansion joint can affect the response of the bridge, is matched with the results of southbound lane, except the load carrying capacity of 70 km/h is DB-12.6~DB-16.7 which is slightly low comparing to other cases,

Table 2. Maximum displacement and TIF of objective highway bridge(Northbound lane).

Velocity (km/hr)	Northbound lane	
	Displacement(mm)	TIF
5	0.684	0.000
10	0.781	0.142
60	0.814	0.190
	0.879	0.285
70	1.107	0.618
	1.123	0.642
	1.074	0.570
	1.172	0.713

Table 3. Maximum displacement and TIF of objective highway bridge(southbound lane).

Velocity (km/hr)	Southbound lane	
	Displacement(mm)	TIF
5	0.684	0.000
10	0.781	0.142
60	0.846	0.237
70	0.781	0.142

Table 4. Results of carrying capacity load (allowable stress Design).

Velocity (km/hr)	Allowable stress Design			
	Northbound lane		Southbound lane	
	RF	P_n	RF	P_n
10~60	1.016	18.4	1.016	18.4
70	0.695	12.6	1.016	18.4

Table 5. Results of carrying capacity load (strength Design).

Velocity (km/hr)	Strength Design			
	Northbound lane		Southbound lane	
	RF	P_n	RF	P_n
10~60	1.349	24.4	1.349	24.4
70	0.923	16.7	1.349	24.4

4. Conclusion

In this study, the influences of expansion joint for evaluating load carrying capacity in performing safety estimation for the highway bridge are examined. Variation of displacement of the highway bridge during dynamic test is measured. TIF is calculated according to damage level of expansion joint, and nominal load carrying capacity is analyzed. As a result, below 60 km/h of the vehicle speed, displacement of the bridge is independent to the existence of the expansion joint.

However, in case of vehicle speed of 70 km/h, displacement of the bridge is drastically increased due to the influence of the expansion joint. Consequently, expansion joint can cause some damage as well as reduce nominal load carrying capacity for the highway bridge for certain speed of the vehicle, such as 70 km/h in this study. This result indicate that the huge impact load is occurred when the vehicle moves fast to the highway bridge due to the different levels between paved slab and expansion joint.

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