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SEISMIC PERFORMANCE ESTIMATION OF MODULAR BRIDGE EXPANSION JOINTS SYSTEM

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ABSTRACT

In order to evaluate the seismic performance of the rail-type expansion joint known for its large expansion allowance and remarkable durability, this study conducts seismic response analysis and seismic simulation test. The bridge selected for the seismic response analysis is a cable stayed bridge with main span length of 1,000 m. Three artificial earthquakes were generated with respect to the design response spectra of the Korean Standards (KS), AASHTO LRFD and Eurocode, and applied to the selected bridge. The seismic simulation tests reproduced the artificial earthquakes using dynamic hydraulic actuators in the longitudinal and transverse directions. The test results verified the durability and safety of the expansion joint in view of its seismic behavior since abnormal behavior or failure of the expansion joint was not observed when the artificial earthquake waves were applied in the longitudinal direction, transverse direction and both directions.

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In order to evaluate the seismic performance of the rail-type expansion joint known for its large expansion allowance and remarkable durability, this study conducts seismic response analysis and seismic simulation test. The bridge selected for the seismic response analysis is a cable stayed bridge with main span length of 1,000 m. Three artificial earthquakes were generated with respect to the design response spectra of the Korean Standards (KS), AASHTO LRFD and Eurocode, and applied to the selected bridge. The seismic simulation tests reproduced the artificial earthquakes using dynamic hydraulic actuators in the longitudinal and transverse directions. The test results verified the durability and safety of the expansion joint in view of its seismic behavior since abnormal behavior or failure of the expansion joint was not observed when the artificial earthquake waves were applied in the longitudinal direction, transverse direction and both directions.

Introduction

Expansion joints are devices designed to allow the heat-induced expansion of the bridge, to allow horizontal movements due to live loads as well as the drying shrinkage and creep of concrete, to accommodate movement and rotation of the bridge superstructure caused by unexpected displacements like support settlement or earthquake so as to contribute to the functions and structural stability of the bridge and secure riding comfort and reliable waterproofing of irregularities by supporting the wheels monolithically with the road surface.

The performance requirements related to the expansion joints are being strengthened according to the recent lengthening of the bridges. Therefore, optimized test methods are necessary for the seismic and fatigue behaviors of the expansion joint in order to secure durability against earthquake and wind loads. Especially, need it to clarify experimentally the behavioral simulation performance of the device under the earthquake input to achieve smooth behavior of the expansion joint installed in the bridge subjected to a seismic event.

Accordingly, this study intends to clarify experimentally the performance and simulation test of the rail-type expansion joint fitted to the regulations of the Korean Standards (KS), AASHTO LRFD and Eurocode to secure the durability [1,2,3].

Generation of Artificial Earthquake Waves

Fig. 1 plots the response spectra specified in the design codes of Korea, USA and Europe for the seismic response analysis. Compliance is done with the Korea Bridge Design Code (2010)

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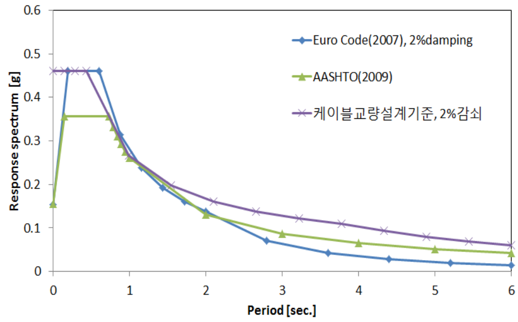
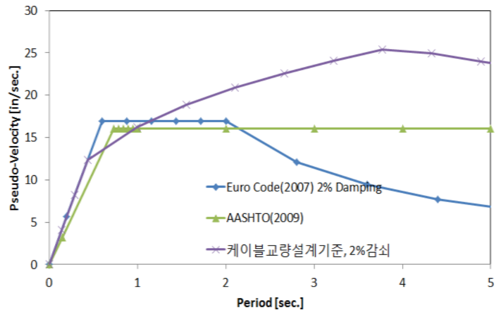
for the Korean design code [1]. The design ground acceleration (a_g) for the generation of the artificial earthquakes having similar size to the Korean design earthquake is set to 0.154g for Europe and 0.156g for USA.



(a) Acceleration response spectra



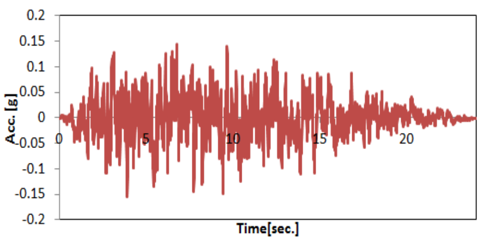
(b) Velocity response spectra

Figure 1. Response spectra according to the design code of each country.

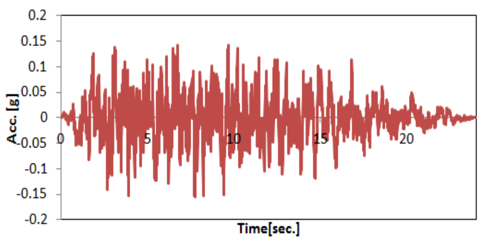
The artificial earthquakes were generated to be compatible with the design response spectra proposed in the Korea Bridge Design Code [1], Eurocode [2] and AASHTO LRFD [3] using the SIMQKE program [4]. SIMQKE is a program that has been developed using the random vibration theory and generates artificial earthquakes by superposing irregular sinusoidal functions with various frequencies. Based on the random vibration theory which states that all periodic functions can be expressed as series of sinusoidal functions, the periodic function can be expressed as follows:

$$X(T) = \sum A_n \sin(\omega_n T + \emptyset_n) \tag{1}$$

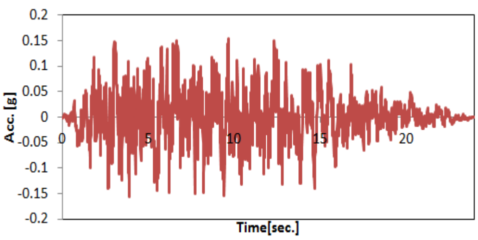
where A_n, ω_n, $\emptyset_n$ are respectively the amplitude, frequency and phase angle of the n-th sinusoidal function. Since the motion generated by Eq. 1 is a steady-state motion, the motion is multiplied by an envelope function so as to endow it with characteristics similar to the design earthquake. In this study, a trapezoidal envelope function was applied. Three artificial earthquakes were generated by varying the occurrence time of the peak response (Fig. 2). The duration of the artificial earthquake waves is 24 seconds with time interval of 0.01 second.



(a) KS (Design Code of Cable-supported Bridges)



(b) Eurocode [2]



(c) AASHTO LRFD [3]

Figure 2. Generated artificial earthquakes compatible with the design code of each country.

Finite Element Analysis

The bridge selected in this study is a cable stayed bridge, which is a representative long-span bridge (Fig. 3). The bridge is modeled using the finite element analysis software MIDAS. Each connection and node has 6 degrees-of-freedom and the structural mass is modeled by means of concentrated mass having minimum 3 motions. The stiffening girder and the pylons are modeled by beam elements, and cable elements are used for the stay cables. The free vibration analysis was conducted up to the 400th mode. Considering the characteristics of the cable-supported steel bridge, a structural damping ratio of 2% was applied.

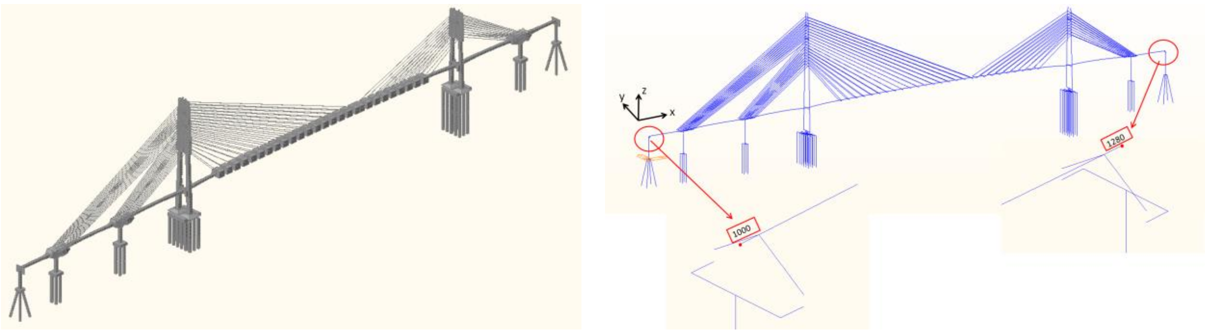


Figure 3. Analysis model of the selected bridge.

Analysis was performed until 40 seconds to verify the effects posterior to the application of each artificial earthquake. As shown in Fig. 3, analysis of the displacement according to time was carried out for the longitudinal and transverse directions at the expansion joints. Table 1 arranges the earthquake load combinations used in the analysis. The orthogonal seismic forces of the Korea Bridge Design Code are applied. Table 3 summarizes the results of the seismic response analysis using the artificial earthquakes of each design code in terms of the displacement in the longitudinal and transversal directions.

Table 1. Load combinations (Korea Bridge Design Code, 2008).

Load combination	**Longitudinal elastic support force**	**Transverse elastic support force**
Load Combination 1	1.0	0.3
Load Combination 2	0.3	1.0

Table 2. Results of loading by artificial earthquake waves according to each design code (node 1000).

		Longitudinal direction		**Transverse direction**	
		0.3X+Y	X+0.3Y	0.3X+Y	X+0.3Y
KS	Max	52.5	168.5	246.5	73.3
	Min	-48.4	-159.3	-227.7	-66.4
Eurocode	Max	38.0	123.2	297.4	84.6
	Min	-37.2	-120.2	-269.6	-79.8
AASHTO	Max	53.6	171.1	277.0	82.4

	Min	-51.5	-169.2	-250.9	-73.5

Test Method and Results

There are still no regulations related to the performance evaluation test of the expansion joint for securing the durability against earthquake. Accordingly, test is performed by measuring the changes in the expansion displacement and behavioral pattern by reproducing the displacement pattern of the expansion joint obtained from seismic response analysis for each KS, Eurocode and AASHTO on a real expansion joint using dynamic actuators in the longitudinal and transversal directions. Fig. 4 shows a view of the seismic simulation test of the expansion joint. Table 3 summarizes the peak displacement and peak load according to the test variables.

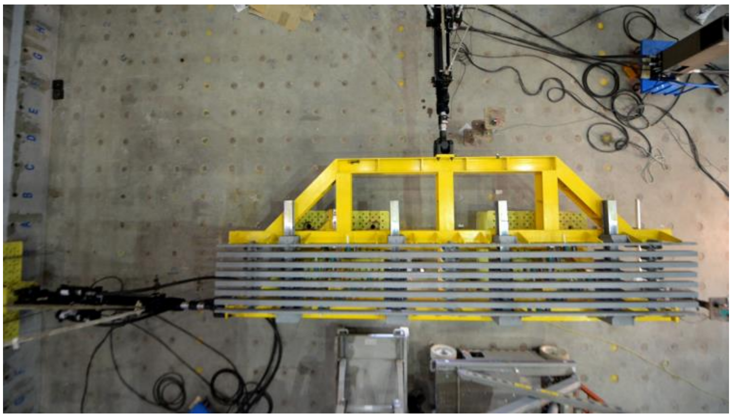
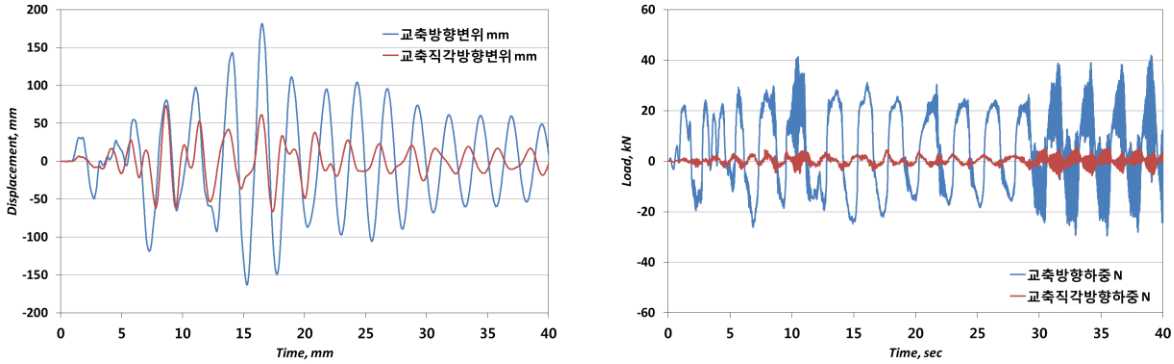


Figure 4. Seismic simulation test of expansion joint.

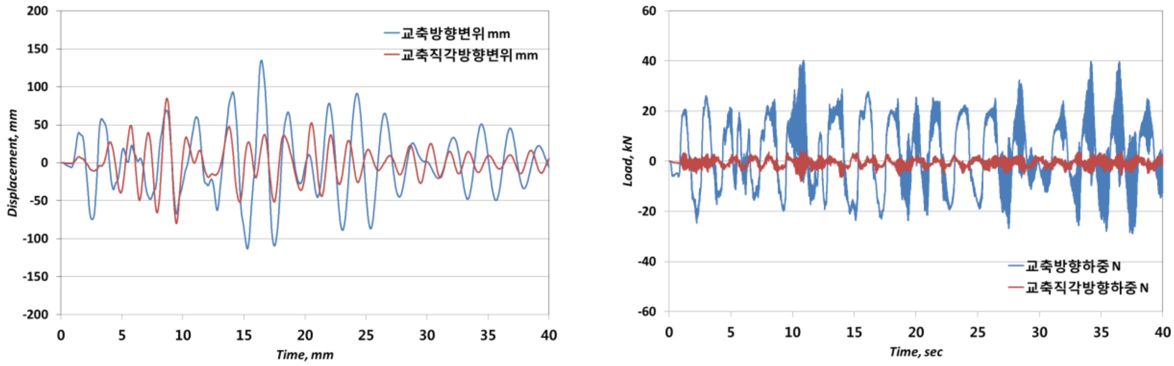
Table 3. Peak displacement and peak load of expansion joint.

	Longitudinal direction		**Transverse direction**	
	Peak displ. (mm)	Peak load (kN)	Peak displ. (mm)	Peak load (kN)
KS	337.0	41.96	136.3	5.48
Eurocode	244.0	40.30	159.8	4.15
AASHTO	353.4	36.93	151.3	5.81

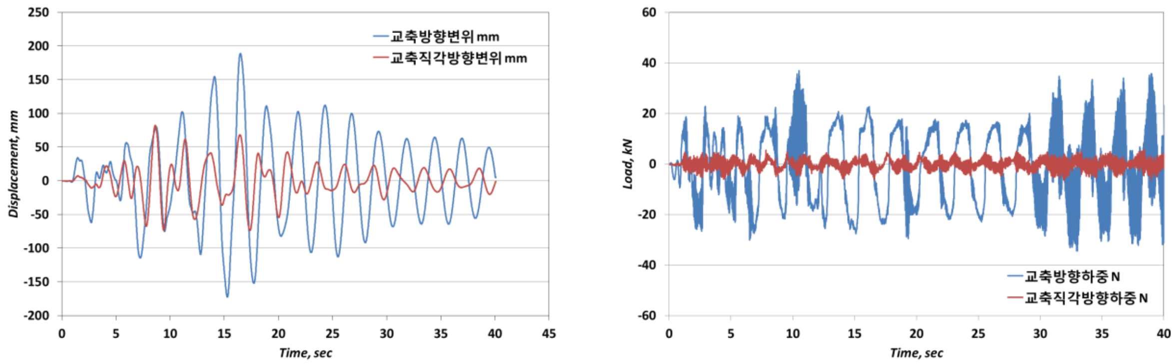
Fig. 5 plots the time histories of the displacement and load obtained by applying the artificial earthquakes in the longitudinal and transverse direction of the selected bridge. As shown in Fig. 5, the expansion joint exhibits smooth behavioral pattern under the application of the artificial earthquakes corresponding to each code. The load acting in the expansion joint during its operation remains below approximately 40 kN (longitudinal direction), which indicates that the expansion joint secures sufficient durability against earthquake. In addition, after completion of the seismic durability evaluation test, a visual inspection could not find any defect or anomalies in the components of the expansion joint. Accordingly, in view of the test results using artificial earthquakes corresponding to the seismic design codes of Korea, USA and Europe, the expansion joint satisfied each design code.



(a) KS



(b) Eurocode



(c) AASHTO LRFD

Figure 5. Time histories of displacement and load according to each design code.

Conclusions

This study evaluated the seismic behavioral characteristics of the expansion joint for the evaluation of its performance to secure the seismic durability. Study was conducted on the performance evaluation method of the expansion joint relative to the corresponding responses. The expansion joint exhibited smooth behavioral pattern under the application of artificial earthquakes fitted to the design codes of Korea, Europe and USA. The corresponding load acting on the expansion joint remained small with values below 40 kN. This indicated that the expansion joint secured sufficient movement capacity against earthquake without damaging the bridge. Future study shall focus on the development of optimized performance evaluation methods in order to secure the durability against earthquake and wind loads according to the lengthening of the bridges.

Acknowledgments

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