SHAKE TABLE TESTS FOR BRIDGE MODEL USING STRUCTUAL RESPONSE CONTROL DEVICES

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ABSTRACT :

This study aims to evaluate the seismic response of bridge model using sliding bearings and dampers. Shake table tests of bridge model and the numerical analyses were performed. The result of shake table tests showed that the superstructure inertia force effectually decreased by sliding bearing and dampers. The simple analytical model could approximately simulate the test results.

KEYWORDS: dampers, sliding bearings, shake table tests, analytical simulation

1. INTRODUCTION

The seismic isolation bridges using high damping bearings such as lead rubber bearings and high damping rubber bearings have been constructed since 1995 Hyogo-ken Nanbu Earthquake. These rubber bearings generally become larger because they have functions to support vertical and horizontal forces and to absorb rotational deformation. The large clearance between deck end and abutment and large expansion joints are generally needed. In recent years, therefore, new type bearing system has been developed. Vertical load and horizontal load are supported by different bearings such as sliding bearing and rubber buffer, respectively. The sliding bearing has the function to support the vertical load and isolates the superstructures from the substructures. Using dampers is one of the methods to disperse the inertia force of superstructure, to dissipate the energy and then to control the response displacement. Various kinds of dampers for seismic response control have been developed. For example, they are viscous, plastic and viscoelastic dampers whose materials are oil, steel, lead, etc. These damping force characteristics are nonlinear and complicated, for example, they depend on loading velocity or loading displacement. They are evaluated and numerically-modeled for dynamic analysis based on cyclic loading tests of device itself. However there are few shake table tests of bridge system using dampers to verify the effectiveness and mathematical modeling.

Based on the above background, shake table tests were conducted to investigate the dynamic behavior of bridge model using sliding bearings and dampers and to verify the mathematical model of dampers based on the comparison of analytical simulation with the test results.

2. DAMPERS TESTED IN THIS STUDY

In this study, shake table tests using two kinds of damper whose characteristics are different are performed. Damper type 1 is oil damper and damper type 2 is Bingham damper. The damping force characteristics of both dampers depend on loading velocity. The damping coefficient is large in low velocity and become low in high velocity. The efficiency of energy absorption is high because large damping force performs even in low loading velocity.

Fig.1a) shows the force-velocity characteristics of damper type 1 used in this study. The damping force is generated by flowing thorough the release valve. The trigger opens the release valve to increase the flow volume when the applied force to the valve increases beyond the switching force, 53kN. Thus, the dependency on loading velocity is represented by bilinear. The damping force is defined in Eqn.2.1. Fig.1a) also shows the result of the cyclic loading tests. The damping coefficient C_1 and C_2 are 4000kN/(m/sec) and 180kN/(m/sec) based on the tests. The stroke of damper is ±120mm.

Fig.1b) shows the characteristics of damper type 2 used in this study and the result of the cyclic loading tests. Bingham plastic fluid is filled in the cylinder of the damper. The fluid doesn't flow until the applied force to the fluid increases beyond a certain level. When the applied force to the fluid is beyond the certain force the damping force increases according to the loading velocity. The damping force is defined in Eqn.2.2 based on the tests. The stroke of damper is ±80mm. In this study, 4 dampers are used because the damper type 2 with smaller damping force and stroke than damper type 1 is used. The each characteristic of 4 dampers is almost the same according to loading tests.

$$F = Cv = \begin{cases} 4000v & (v < 0.013) \\ 53 + 180(v - 0.013) & (v > 0.013) \end{cases} \tag{2.1}$$

$$F = Cv = 23.6v^{0.1} \tag{2.2}$$

where

F : damping force (kN)
C : damping coefficient (kN/(m/sec))
v : loading velocity (m/sec)

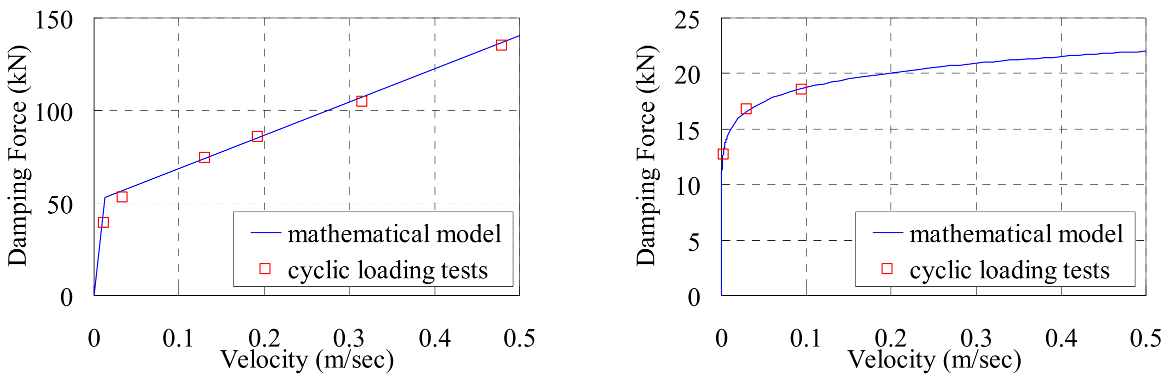


Figure 1 Damping force dependency on loading velocity

3. BRIDGE MODEL AND THE MEASUREMENT

Fig.2 shows the setup of the bridge model on the shake table. The girder is assembled by H-section steel and counterweight and are vertically supported by four sliding bearings which consist of stainless plate and polytetrafluoroethylene (=PTFE) plate. The frictional coefficient depends on the surface pressure and loading velocity. In these tests condition, the frictional coefficient is between 0.1~0.15 depending on applied surface pressure. Each sliding bearing is on the top of steel column which is rigidly connected with shake table. The span and width of girder are 5.71m and 1.43m. The frictional force and vertical load acting on sliding bearings are measured by 3-dimensional load cells which underlie every sliding bearing. The response of girder is measured by the acceleration sensors and optical displacement sensors. The acceleration sensor is settled in the midmost shake table to measure the input acceleration.

The weight is different between the bridge models using damper type1 and damper type 2 because the maximum damping forces and damper stroke are different. The weight of bridge model using damper type 1 is 283kN. The weight of bridge model using damper type 2 is 214kN.

Fig.3a) shows the setup of damper type 1 which is settled parallel with the longitudinal axis between girder and steel column which is rigidly fixed with shake table. The damping force is measured by load cell which is coaxially settled with damper. Fig.3b) shows the setup of damper type 2 which is settled parallel with the longitudinal axis between girder and each steel column supporting the girder. The strain gauges are bonded on each damper rod and the damping forces are measured by converting the strains.

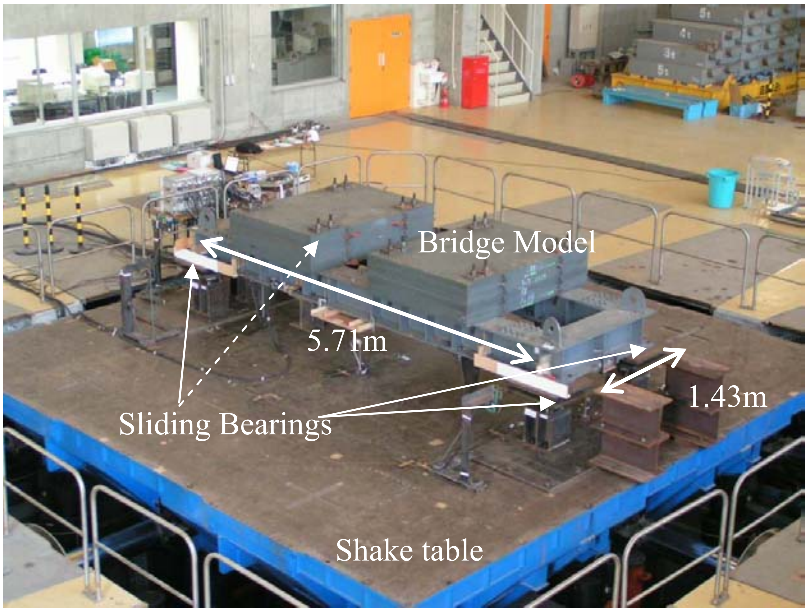
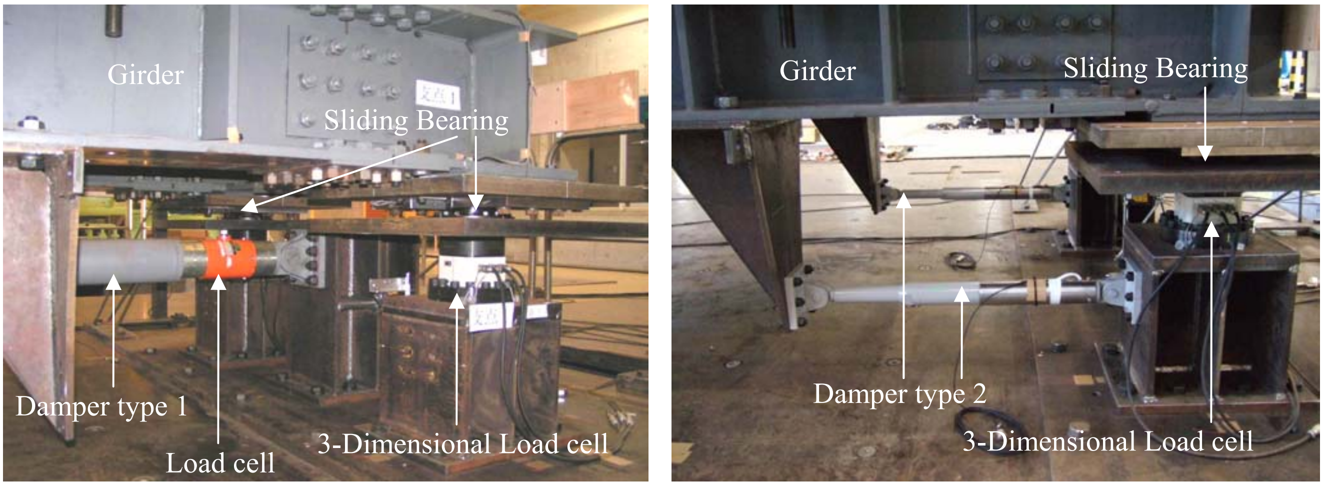


Figure 2 Setup of bridge model



a) Setup of damper type 1

b) Setup of damper type 2

Figure 3 Setup of damper

4. GROUND MOTIONS AND TEST SEQUENCE

Fig.4 shows the input acceleration actually observed at JR Takatori station during the 1995 Hyogo-ken Nanbu Earthquake. NS component of acceleration was inputted parallel with the longitudinal axis. The excitation was not inputted transversally and vertically. Table 1 shows the test cases. Case1~Case3 were performed for bridge model using damper type 1. Case4~Case6 were performed for bridge model using damper type 2. The input amplitude increased gradually in each bridge model because the response of bridge model was unknown before the tests and it was necessary to control the displacement within the damper stroke.

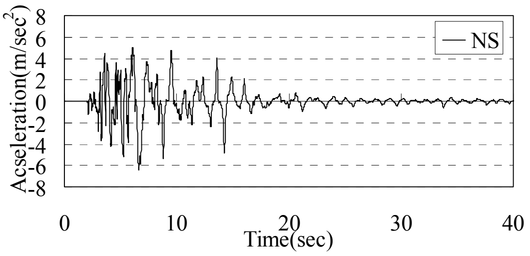


Figure 4 Input acceleration

Table 1 Test cases

	Damper type	Input amplitude
Case1	1	70%
Case2	1	90%
Case3	1	100%
Case4	2	90%
Case5	2	95%
Case6	2	100%

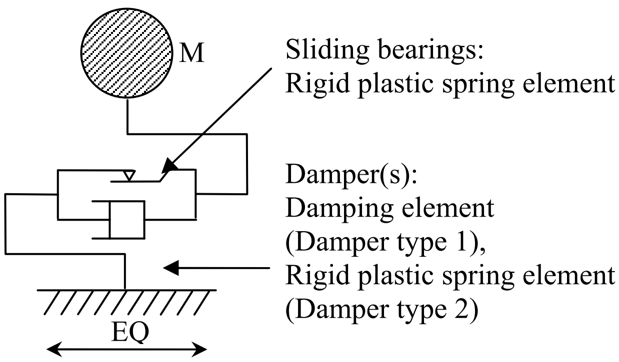


Figure 5 Analytical model

Table 2 Maximum response

	Input Acceleration (m/sec^2)	Girder Acceleration (m/sec^2)	Girder Displacement (mm)	Damping Force (kN)
Case1	4.62	3.92	29.9	68.2
Case2	6.12	4.52	70.2	87.5
Case3	6.95	4.87	92.7	99.4
Case4	6.16	4.89	31.0	71.9
Case5	6.58	5.08	40.8	76.5
Case6	6.99	5.11	55.0	75.8

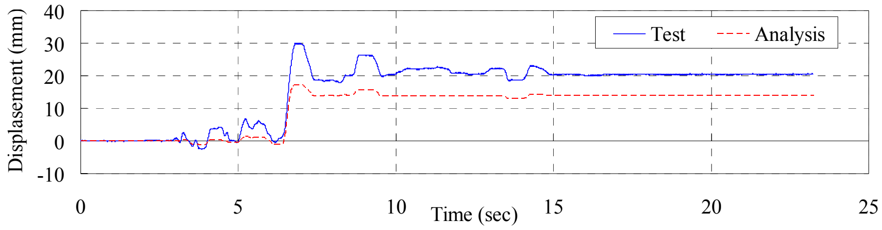
5. DYNAMIC RESPONSE OF BRIDGE MODEL AND ANALYTICAL SIMULATION

Table 2 shows the input acceleration and the maximum responses of the girder acceleration, the girder displacement and the damping force. The damping force in bridge model using damper type 2 is sum of 4 dampers. In both bridge models, the larger input acceleration is, the larger the responses of girder and damper are. However the girder acceleration in every case is reduced than the input acceleration.

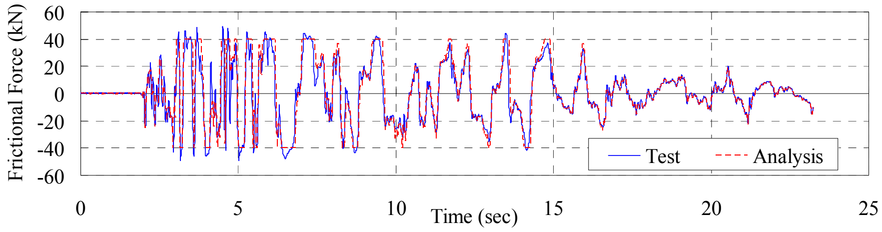
Nonlinear dynamic analyses are performed to simulate the behaviors of the bridge models. The bridge models are idealized with one mass system as shown in Fig.5. The frictional coefficient of sliding bearings depends on the surface pressure and loading velocity. However, in this study, 4 sliding bearings are collectively idealized with simple rigid plastic spring element up to 40kN and 30kN in the bridge model using damper type 1 and type 2, respectively, based on the observed averagely frictional force. The damper type 1 is idealized with the nonlinear damping element represented as Eq.(1). 4 dampers in bridge model using damper type 2 are collectively idealized with simple rigid plastic spring element up to 70kN because of the limitation of used analysis software. The viscous damping of the system is assumed to be 0. The Newmark β method (β=1/4) is used.

The analysis result shows that it is possible to simulate the seismic response of both bridge models approximately. Fig.6~Fig.8 show the comparison of the displacement of girder, the frictional force and damping force for the tests of bridge model using damper type 1 with the analyses. The displacement amplitudes of analyses are smaller than the tests. The larger the input acceleration is, the displacement is simulated more accurately. The residual displacements are not simulated so well in every case. However the frictional forces and damping forces are almost simulated well in every case.

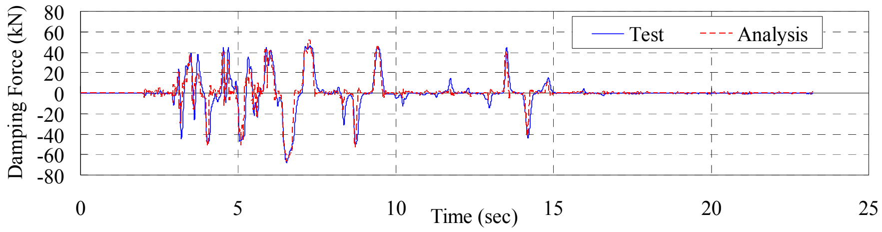
Similarly, Fig.9~Fig.11 show the comparison about bridge model using damper type 2. The displacement amplitudes of analyses are smaller than the tests and the timing to slide is not simulated well. The larger the input acceleration is, the maximum displacement is simulated more accurately. In every case, the bridge model slid small in low loading velocity because the damping force is low. However, because the sliding bearings and dampers are idealized with simple rigid plastic spring elements the dynamic responses are not simulated well for this point.



a) Displacement of girder

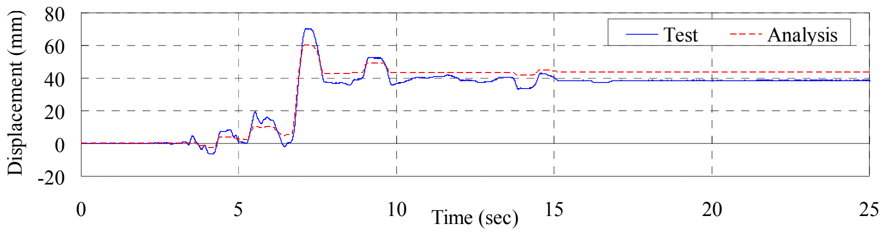


b) Frictional force of sliding bearings

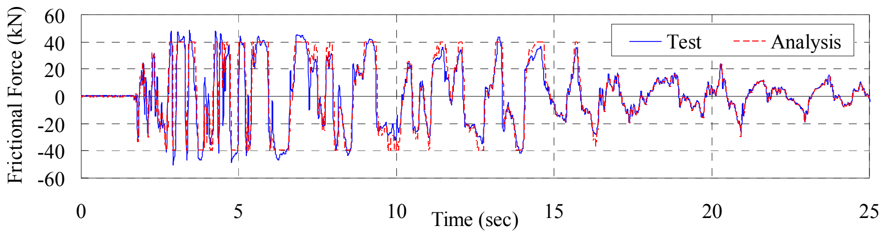


c) Damping force

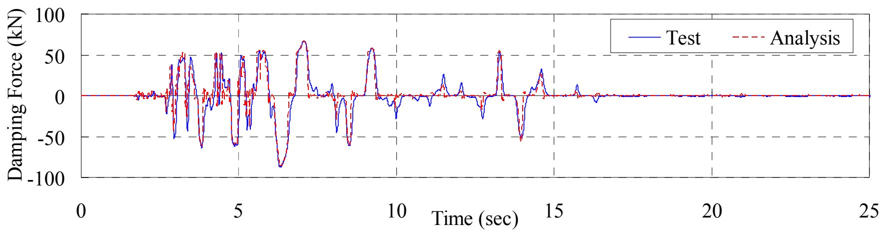
Figure 6 Analytical simulation in Case1 (damper type 1, input amplitude 70%)



a) Displacement of girder

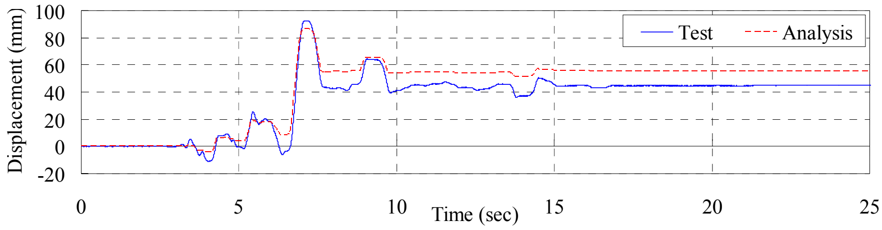


b) Frictional force of sliding bearings

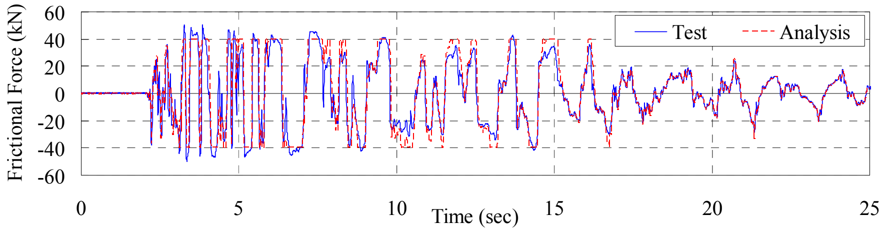


c) Damping force

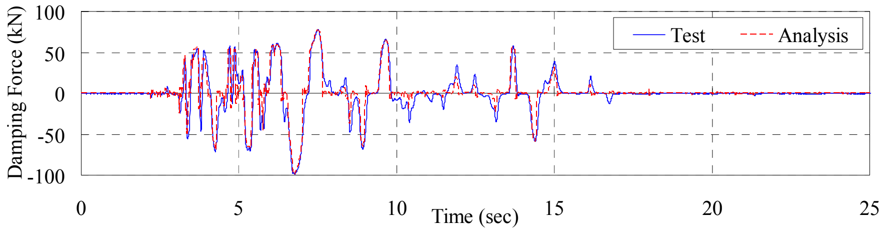
Figure 7 Analytical simulation in Case2 (damper type 1, input amplitude 90%)



a) Displacement of girder

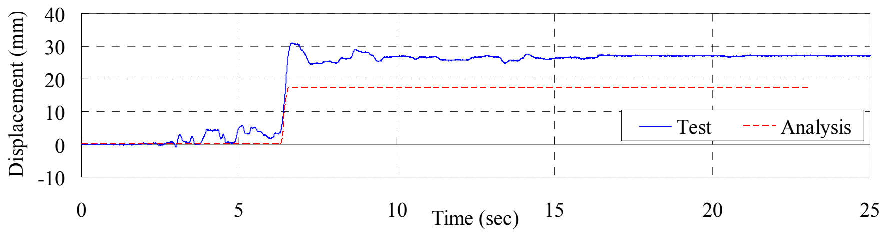


b) Frictional force of sliding bearings

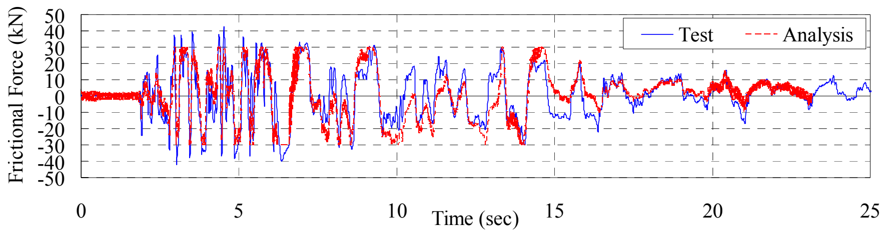


c) Damping force

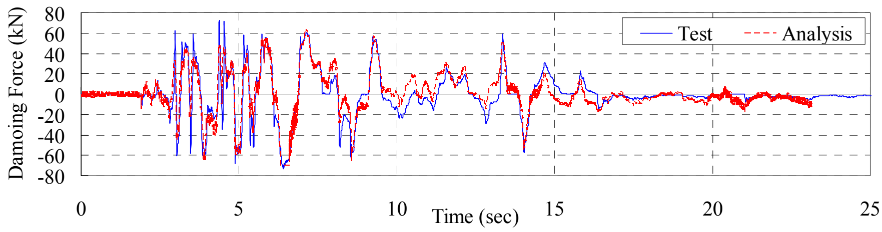
Figure 8 Analytical simulation in Case3 (damper type 1, input amplitude 100%)



a) Displacement of girder

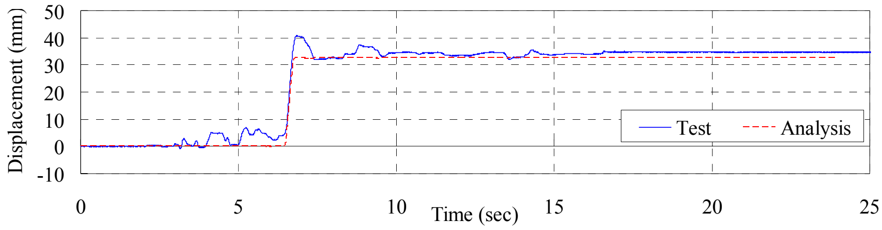


b) Frictional force of sliding bearings

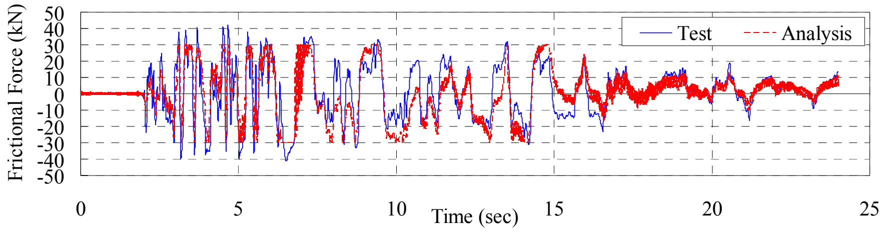


c) Damping force

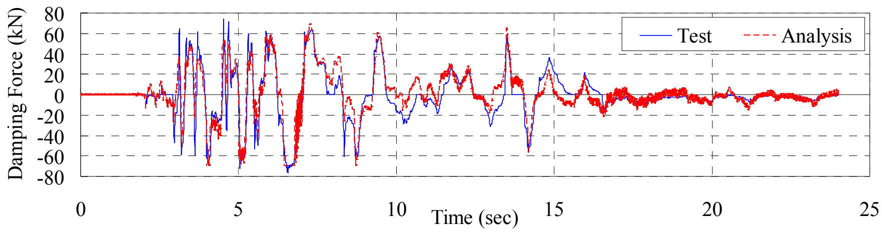
Figure 9 Analytical simulation in Case4 (damper type 2, input amplitude 90%)



a) Displacement of girder

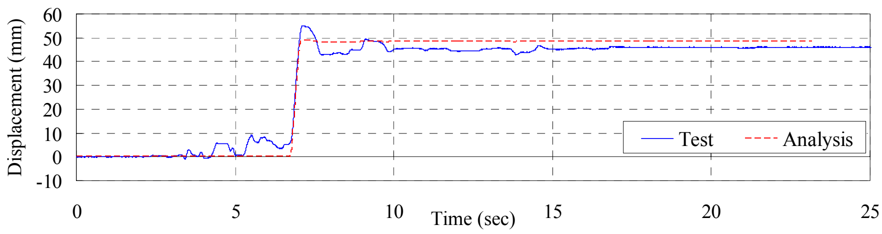


b) Frictional force of sliding bearings

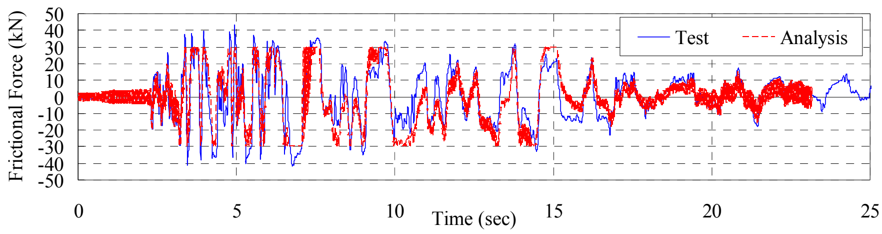


c) Damping force

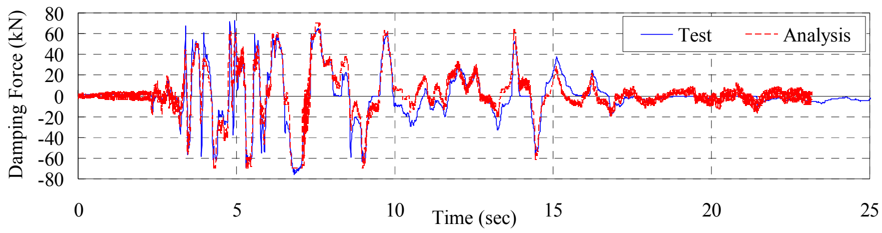
Figure 10 Analytical simulation in Case5 (damper type 2, input amplitude 95%)



a) Displacement of girder



b) Frictional force of sliding bearings



c) Damping force

Figure 11 Analytical simulation in Case6 (damper type 2, input amplitude 100%)

6. ESTIMATION OF THE EFFECT OF DAMPER

To estimate the effect of damper, the shake table tests of the bridge model supported by only sliding bearings without damper were required for comparison the test results of the bridge model with damper. However, their tests without damper were not performed because it was impossible to perform their tests by reason that it is highly possible that the seismic responses exceed the range of bridge model movement. Therefore the analytical simulation without damper was performed instead of the shake table tests. Fig.12 shows the comparison between the test result with damper, analytical simulation with damper and analytical simulation without damper for Case3. The displacement in analysis without damper is about 600mm which is six times the displacement of the test result in Case3. The analysis result shows that the damper plays the important role to control the displacement.

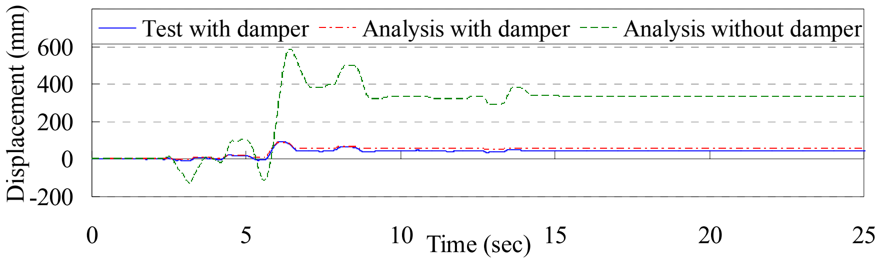


Figure 12 Damping effect for displacement

7. CONCLUSION

To investigate the seismic behavior of bridge model using sliding bearings and dampers, a series of shake table tests and analyses have been conducted. Below are the conclusions determined from the study:
1) The result of shake table tests shows that the dampers surely generated the damping force depending on the dynamic behavior.
2) The result of analytical simulation using simple mass model shows that it is possible to simulate the seismic responses of the each bridge model approximately.
3) The comparison between the test result with damper, analytical simulation with damper and analytical simulation without damper proves that dampers play the important role to control the girder displacement.

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