Optimized real-time hybrid experimental framework for testing HDR dampers

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1. Introduction

In hybrid experimentation, the structure to be tested is split into one or more experimental and computational substructures with actuators providing the interface between them. Thus, hybrid simulation provides information of the entire structure without the need of testing the whole system.

This work presents the implementation of a real-time hybrid (RTH) experimental system for testing HDR dampers using a novel computational algorithm which requires a minimal computational hardware, and the evaluation of its results by comparison with those obtained with a conventional pseudo-dynamic (PsD) test.

2. Real-time background

Real-time hybrid simulation (RTHS) follows the same principle of pseudo-dynamic test (PsDT). However, the main difference is that in real-time test, the input excitation is imposed in a high-rate in such a way that it simulates the actual earthquake motion in real-time.

The test starts when the earthquake record is input into the numerical substructure at time *i*, following, the displacements at time *i+1* are calculated numerically using a direct step-by-step integration strategy and imposed into the experimental substructure through actuators. The restoring forces due to these displacements are measured and feed back to the computational substructure. Finally, the velocities and accelerations are calculated in the numerical substructure and the loop is repeated until the whole earthquake record is processed. Therefore, the test will last the total duration of the input motion.

In a displacement-controlled real-time test, the signals have to be imposed from the numerical to the experimental substructure continuously. However, in the actual test due to the inherent delay in the response of the actuator and the delay in the data transfer between the computational hardware the control signal is not properly achieved in real-time. Thus, sophisticated control and extremely fast communication among all components of the test are required then, these aspects are major issues to be enhanced in real time experimentation.

In parallel with the methods to compensate the delay of the actuator, several computational architectures and control schemes have been developed.

Most of the displacement-controlled approaches are based in the extrapolation and interpolation of the actuator displacements; in this work, a different approach characterized by the velocity-based loading was adopted and programmed with a novel control algorithm, which allows flexibility to assign more time to complete critical steps depending on the complexity of the test, and at the same time by optimizing the computational resources consisted of a single host computer and a single digital signal processor (DSP).

3. Control algorithm

Figure 1 schematically shows the experimental framework.

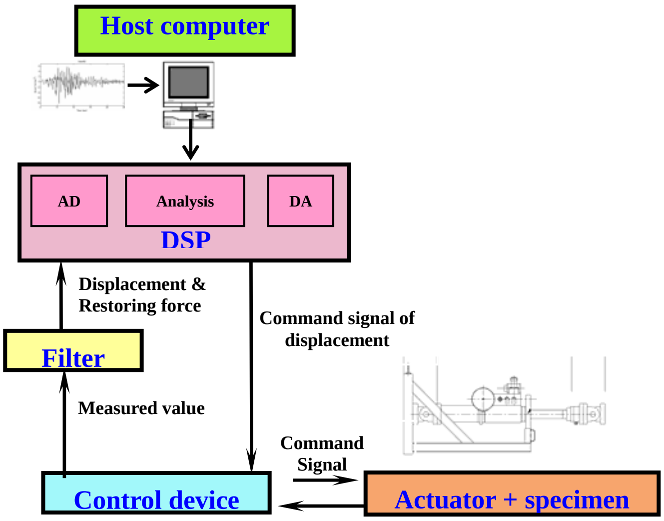

Fig 1. Experimental framework

The signal displacements are imposed continuously to the actuator each millisecond (ms) to achieve smooth motion. The integration time step, Δt, was set equal to 0.01 sec (10ms). Considering these conditions, the calculations in one time integration step were divided in 10 sub steps (each millisecond) as follows (figure 2):

1st ms: The target displacement, $\hat{d}_{i+1}$, is calculated and the signal is imposed to the actuator.

2th-9th ms: In parallel with the sending of partial signals, the program waits for the achievement of the target displacement by the actuator. Even in the case the target displacement is not achieved during this time, the actuator keeps moving until the desired position at the velocity of the current step. The reading of the displacement and restoring forces is done until the 9th ms. Thus, the obtained displacement is close the target one.

10th ms: The final calculation of the displacement, velocity and acceleration vectors is performed while the actuator keeps moving with the velocity imposed in the 1st ms.

4. Analytical substructure

The structure analyzed was the Higashi Kobe Bridge

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(Fig. 3) modeled as a 3DOF (Fig. 4) including the HDR damper between the tower 2 and the girder.

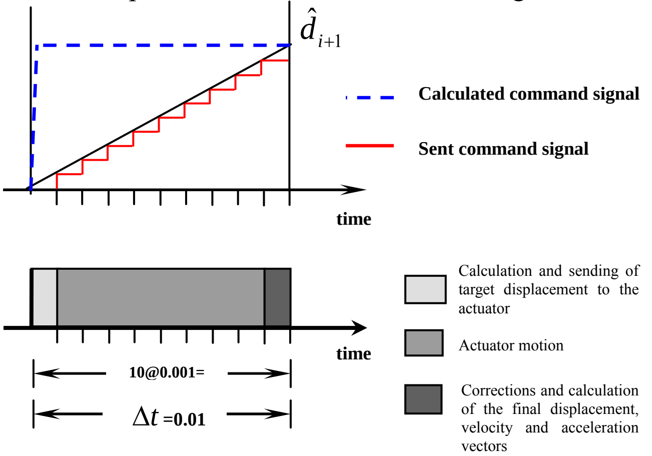

Fig 2. Control concept

The equation of motion, solved by the Operator Splitting Method (OSM) is:

$$Ma + R_N(d,v) + R_E(d,v) = F \qquad \ldots (1)$$

Where $\boldsymbol{d}$ is the vector of nodal displacements, $\boldsymbol{v}$ the vector of nodal velocities, $\boldsymbol{a}$ the vector of nodal accelerations, $\boldsymbol{R_N}$ is the restoring force of the numerical substructure and $\boldsymbol{R_E}$ is the restoring force of the experimental substructure. The reaction force increment between predictor and corrector displacements is assumed related linearly to the difference of two displacements by a linear stiffness.

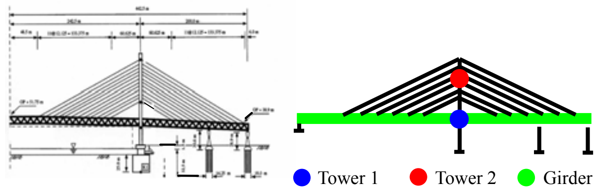

Fig 3. Geometry of the bridge and its idealization

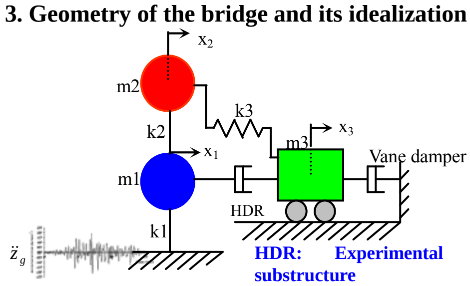

Fig 4. Analytical model

5. Experimental substructure

The experimental substructure consisted of a, properly scaled, 15cm x 15 cm specimen of a HDR damper (one layer, thickness = 30mm, K_1=3300 KN/m) subjected to the Nihonkai Chubu Earthquake, amplitude 50%.

6. Results.

A comparison of the response obtained with the RT system developed and that computed by a PsD test is shown in figure 5. Figure 6 shows the corresponding comparison of the hysteresis loop.

Finally to verify the stability of the system, the energy balance is shown in figure 7.

7. Conclusions.

1. A real-time experimental hybrid test for testing HDR dampers was implemented using a velocity-based control programmed with a novel control algorithm, which allowed the optimization of the available equipment.

2. The performance of the system was verified by testing an HDR damper specimen. The results were compared with those obtained from a conventional PsD test, showing close agreement between them.

3. The energy balance was calculated verifying the stability of the system.

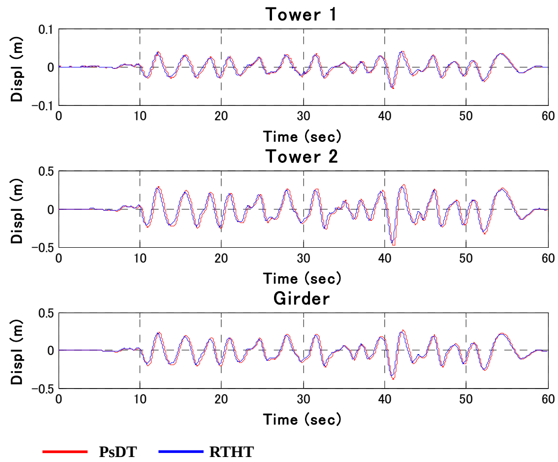

Fig 5. Displacement response

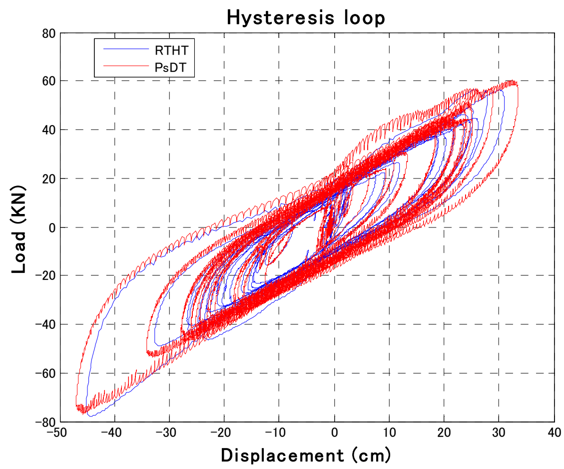

Fig 6. Specimen hysteresis loop

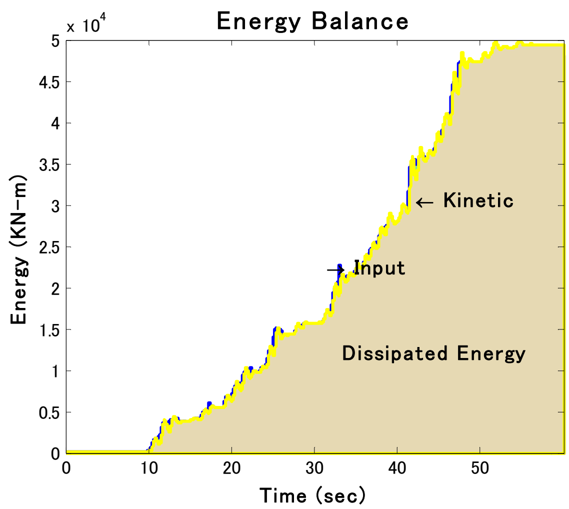

Fig 7. Energy balance of the substructured system