学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Seismic response control of coupled structures using passive negative stiffness connection
(パッシブ負剛性接続を使用した連結構造物の地震応答制御)

Coupled vibration control (CVC) is a promising method formed by linking two or more adjacent buildings with a connecting mechanism to reduce the response under dynamic excitations such as earthquakes. A spring and/or a damping element as vibration controllers connecting a mainframe and a subframe represent a typical passive CVC system. Over the last years, a number of control techniques have been proposed for the structural protection of CVC systems against earthquakes. The control techniques include passive, active, and semiactive control strategies. Various vibration control devices, primarily energy dissipators, have been proposed and practically applied to reduce the CVC systems' seismic response. Negative stiffness, which exerts an opposing restoring force when the displacement increases, is considered a potential vibration control technique for structures. In the past decades, rapid progress has been made in researching and developing negative stiffness devices (NSDs) incorporated into individual buildings. However, research on the incorporation of NSDs into CVC structures is very limited and remains challenging, despite the increasing applications of coupled building control. There has been limited research on assessing the seismic control effectiveness of a passive or active negative stiffness as a connecting controller for CVC systems.

This thesis explores the behavior and control efficiency of a passive NSD (PNSD) to improve the seismic resistance of coupled buildings. PNSD as a connecting element is installed between the mainframe and subframe, forming the CVC system. This work highlights four objectives to accomplish the aim: (1) to investigate the behavior of PNSD as the vibration control device and optimal tuning of the CVC structures; (2) to examine the linear and nonlinear numerical response of adjacent single degree of freedom (SDOF) structures connected by PNSD; (3) to figure out the control performance of PNSD on multi degrees of freedom (MDOF) CVC systems; (4) to validate the analytical and numerical investigation of the effective control technique of PNSD on CVC system through experiments. In this dissertation, the optimal parameters to effectively reduce the seismic response of the CVC systems were established. The numerical investigation of the CVC system incorporated with PNSD was verified with the experimental data. The thesis is organized as follows:

Chapter I introduces the background and review of existing work in vibration control strategies of CVC systems using PNSD.

Chapter II performs an analytical investigation of a linear two degrees of freedom (2DOF) vibrating system model representing a simplified coupled vibration-controlled building for determining the basic characteristics of PNSD on adjacent structures. Based on the transfer function (TF) of the model's relative displacement and absolute acceleration, the peak amplitude was investigated for the CVC system. For optimal tuning of the displacement TF for the mainframe, the optimal stiffness ratio and

optimal viscous damping coefficient were calculated against various values of stiffness ratio (α) and mass ratio (μ). For comparison, a reference viscous damping coefficient for the connecting element that minimizes the peak amplitude of the displacement TF for the mainframe without the connecting spring element was numerically obtained. The analysis found that adopting negative stiffness in the connection elements enabled optimal tuning of the TF for the mainframe, even if it was impossible to achieve by positive or zero stiffness.

Chapter III inspects linear and nonlinear seismic response analyses of 2DOF CVC systems linked by PNSD for determining the dynamic characteristics and seismic response of adjacent structures. Four groups of numerical models having linear characteristics were used, i.e., SDOF mainframe models, SDOF subframe models, 2DOF CVC models with PNSD and damper as the connecting elements (CVC-SD), and 2DOF CVC models with damper as the connecting element (CVC-D). Three natural periods for the state of the mainframe alone were set, and six combinations of α and μ were selected such that each group consisted of 18 cases of models. The optimization was done using the mainframe displacement TF as a control target. As a result, a sufficient control effect was achieved for the mainframe response. In addition, a nonlinear earthquake response simulation was conducted using the CVC-SD, CVC-D, and SDOF-mainframe models. The averaged displacement ratios showed a control effect on the mainframe of the CVC-SD model.

Chapter IV discusses a study on the numerical investigation of the seismic controlled motion for multi-story coupled structures linked by negative stiffness connection. The analysis included the MDOF mainframe model and MDOF subframe model of equal heights with substantially different structural properties connected by vibration controller(s) subjected to various earthquake motions. The study indicated that the reduction in the structural response of the CVC system subjected to input motions depends on the setting of the connecting elements. Significant control performance of the negative stiffness as connecting vibration controller of coupled models was achieved.

Chapter V addresses shaking table tests carried out for obtaining the earthquake response of connected building models using a prototyped PNSD to study the vibration control effects experimentally. The CVC model used in this experiment was of one mass system of mainframe and one mass system of a subframe. The CVC systems were examined by shaking table tests with/without the prototyped PNSD, subjected to sinusoidal and simulated earthquake waves. The result shows that PNSD exhibits negative stiffness over a displacement range. A reduction in the displacement response of the coupled structures occurred upon incorporating PNSD.

Chapter VI concludes the thesis and discusses the scope of future work. The results of the evaluations show that adopting PNSD in CVC structures can extend the range of optimal tuning conditions. The effective control performance of PNSD as a vibration controller of adjacent structures was understood. Evidently, the results show that PNSD can be considered as one of the potential vibration controllers for adjacent structures. Lastly, some directions for future work are listed.