別紙様式８(Attached Form 8)

研　究　主　論　文　抄　録 Abstract of Thesis

論文題目 Title of Thesis　英文 English
Seismic Response Control for Highway Bridge and Transmission Tower-Line System using Viscous Dampers
和文 Japanese
粘性ダンパー用いた道路橋および送電鉄塔の地震時応答制御

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主論文要旨 Summary of Thesis
《本文》《Body text》

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Highway Bridges

For arch bridges designed mainly for gravity and service loads, excessive deformation and pounding effect on the abutments can occur and lead to severe damage or even collapse during strong earthquakes. The 1995 Hyogo-ken Nanbu earthquake has triggered the studies about seismic design of highway bridges dramatically. The retrofitting strategies and seismic performance upgrading methods for existing and new design bridges have been extensively proposed. In this sense the innovation of supplemental devices such as energy dissipation devices take important place for the earthquake-resistant bridge structures.

The highway arch bridge structure investigated herein is a conventional two-hinged arch bridge consisting of RC deck slab. The length is 90 m. The seismic design specification used in the design of this bridge is 1980's that does not include regulation of dynamic analysis due to design earthquake ground motions. Therefore the pounding effect on the abutments is likely to occur during severe earthquake ground motions such as Level 2 Type II earthquakes. To prevent the possible damage, the NVDs are proposed to constraint and control the displacement responses.

The three-dimensional finite element model constituted on TDAPIII has been analyzed through dynamic response analysis using Newmark-β direct integration method. Original bridge structure has available distance of 10 cm between the deck and the abutment. However, the maximum displacement value exceeds 10 cm under Kobe-ns, Kobe-ew and Takatori-ns earthquakes resulting pounding effect on abutments. For the evaluation of proper NVD coefficient, iterative method which makes use of SDOF system idealized for fundamental behavior of the structure has been proposed as an alternative method to energy equivalent method. Idealized SDOF system which is employed for each fundamental mode of the structure is composed of mass, stiffness, inherent damping and NVD. For a given target displacement response, the equation of motion is iterated until maximum displacement response reaches the target displacement value while the NVD coefficient increases gradually.

The bridge has been investigated for the aim of controlling the seismic responses along both longitudinal and transversal directions. Throughout the longitudinal direction, the bridge has two fundamental modes. Thus two SDOF systems were constituted to represent the structural behavior along corresponding direction. Since the available distance is 10 cm between the deck and the abutment as mentioned earlier, the target displacements were assigned equal to and less than 10 cm such as 10 cm, 8 cm, 6 cm and 4 cm. The results of dynamic analysis showed that the displacement responses of the bridge installed with NVDs due to longitudinal excitations have been suppressed up to 71%. Also the maximum displacement responses have been reduced to 10 cm, preventing pounding effect on the abutments. In addition the NVDs have satisfying efficacy on the mitigation of axial force responses. The reduction rate up to 57.9% has been observed after installation of NVDs. As to transversal direction, first step was to change the structural boundary conditions on finite element model to find out sufficient NVD coefficient. The bridge structure is originally fixed to translations and rotations along transverse direction. However, to run the analyses and figure out the efficiency of NVDs for controlling the transversal responses, the boundary condition has been changed from fixed to free along corresponding direction. The target displacement was assumed 10 cm as well. After NVD installation, the displacement responses for controlled bridge have been reduced up to 79.9%.

However, it has been observed that the displacement responses at the midspan exceeded the target displacement due to Kobe-ns, Kobe-ew, Takatori-ew and Duzce-ns earthquakes. This arises from the distance between the damper location and the response measured. Nevertheless the results are satisfying in terms of reduction rate in displacement responses when compare to uncontrolled structure. The uncontrolled bridge is not under harmful situation during severe transversal excitations in terms of buckled members. The axial load change of important components of the bridge, however, clarifies the NVD efficiency by the reduction rates on axial load demand of the structure.

In addition to detailed analysis of the arch bridge structure, the iterative method has also been examined to girder bridges in order to confirm its feasibility. The girder bridges investigated have four and five span, respectively. The piers are fixed to the deck in both bridges. The lead rubber bearings at the abutments are able to move along longitudinal direction only. Since the important structural behavior of girder bridges is along longitudinal direction, two-dimensional finite element modeling is sufficient. The structural behavior along longitudinal direction was idealized by SDOF system introducing the fundamental mode characteristics into it and the NVD coefficients required by each girder bridge have been obtained by means of analysis of SDOF systems. The girder bridges installed with NVDs at the abutments have validated the adequacy of iterative method withdrawing the displacement responses of uncontrolled structures to target displacement values. In addition, the SDOF idealization has been confirmed as sufficient and useful approach for simple representation of the structure in terms of fundamental modal behavior. The iterative method is an accurate and fast approach to find out NVD coefficient using idealized SDOF system and to keep the structural responses in the desired values.

Transmission Tower-Line System

The failure of a transmission tower due to devastating loadings can easily propagate along the lines and eventually leads to substantial economic losses. In the recent earthquakes, the collapse of the transmission towers due to seismic loadings has been experienced. This thesis investigates the seismic behavior of tower structures and proposes retrofitting procedure by means of NVDs. Since the viscous damper force depends on the relative velocity between the damper ends, viscous damper installation to lattice towers is an innovative solution in terms of suppressing responses induced by vibrations as well as providing aesthetic design.

The finite element modeling for transmission lines has been investigated in the first step to clarify the line effect on the structural behavior of transmission towers. The lines have no effect for the behavior of tower along out-of-plane direction. However, as to in-plane direction, among the four schemes analyzed, cable element modeling has been found the most accurate model considering identical fundamental frequencies between long and short span systems for the lines than the model that neglects the lines and the model that includes the lines as mass with springs attached to tower arms. The coupled transmission tower-line system is composed of three towers which are identical and at the same elevation and two-span lines. In order to observe the effect of span length on the tower behavior before and after installation of NVDs, the long and short span models of which span lengths are 350 m and 50 m, respectively, have been examined. The target displacements were assumed as the half of the maximum displacement response of top of the uncontrolled tower during Kobe-ns earthquake that induces maximum response among all earthquakes. The SDOF systems have been constituted for fundamental modes of the tower along both out-of-plane and in-plane directions. The location of the NVDs has been determined according to the fundamental mode shapes of the tower where the bending tendency is high. The three towers of the coupled system under examination have been installed with NVDs. Four installation schemes were analyzed through the seismic response analysis. All the cases supply significant reduction rate in the responses of axial load of the main legs and displacement of the tower top. As to long-span model, the target displacement response has not been achieved in terms of 50% reduction for out-of-plane direction, whereas a slight exceedance than target displacement has been obtained along in-plane direction. Reduction rates are lower in short-span model since the tower itself of the short-span model has already less displacement values that are almost same to target displacement values. Briefly, the target displacements have not been reached because of large line effect on the modal behavior of the tower. The compressive loads on the main legs have been reduced significantly after installation of NVDs.

The buckled members of uncontrolled tower have been healed by means of NVDs. The efficacy of NVDs is more remarkable in long-span model than short-span model. It is worthwhile to note that whatever the span length is the compressive loads on legs along out-of-plane direction have been reduced to an almost constant value since the line effect is negligible along corresponding direction. The reduction rate is up to 51.1% for in-plane direction of long-span model. Compressive loads are in allowable range in short-span model even for uncontrolled tower. The installation of NVDs, however, has been examined to observe the effect of NVDs. The reduction rates of compressive loads are less than that of long-span model. The NVDs are effective to reduce structural responses during severe earthquake motions as shown in **Table 5.1** and **5.2** for all damper installation schemes. Case 3 in which the four NVDs were installed to the both sides of the tower as two-pair replacing with the steel members, however, is the superior installation scheme among others since the largest reduction in the responses have been obtained. Furthermore, the NVDs are more effective in the reduction of seismic responses of the long-span model than those of the short-span model. This means that the NVDs on the tower can effectively mitigate and control the seismic responses of the tower due to lines. The iterative method has been validated in transmission tower application.