Seismic Control of Continuous Bridges Using Variable Radius Friction Pendulum Systems and Viscous Fluid Dampers

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This paper investigates the performance of a variable radius friction pendulum system (VRFPS) with supplementary damping using viscous fluid dampers (VFD) to control the seismic response of bridges. A VRFPS is similar to a frictional pendulum system (FPS), but the curvature of the sliding surface is varied, and it becomes the function of the sliding displacement. The bridge is seismically isolated with a VRFPS between the superstructure and the pier, and a VFD is added between the abutment and superstructure. Effectiveness of the proposed system is studied for a three-span continuous bridge isolated with a VRFPS and VFD hybrid system. The performance of a proposed system is compared to a corresponding performance of a hybrid system consisting of a conventional FPS with a VFD. The results of the numerical simulation showed that supplementary damping reduces the seismic response of the isolated bridge. Further, a hybrid system consisting of a VRFPS and a VFD is found to be more effective than a FPS and a VFD hybrid system for seismic control of bridges.

1. INTRODUCTION

Bridges are susceptible to damage when subjected to major earthquakes. The damage to the bridge structure occurs primarily in the piers, which results in the collapse of the bridge super structure. In recent years, seismic isolation devices such as rubber bearings or sliding bearings have been used to improve the seismic response and to reduce the damage of bridges for both new and retrofitting applications. These devices are placed between the superstructure and pier. The friction pendulum system (FPS) proposed by Zayas et al.[1] is recognized as an effective isolation device to reduce the seismic effects of buildings and bridges. In this system the sliding and restoring mechanisms are integrated in one unit in which the sliding surface takes a spherical shape.[2] However, the restoring stiffness, which is proportional to the curvature of the sliding surface will inevitably introduce a constant isolation frequency to the isolated structure.[3] This frequency remains constant during the earthquake ground motion due to the spherical sliding surface. A resonant problem may occur when the structure resting on the FPS is subjected to near-fault earthquake ground motions characterized by low frequency and high intensity. In one of the approaches, to overcome this problem, a sliding surface with variable frequency has been suggested.[2–4] In this system, the shape of the sliding surface of the FPS is made non-spherical by varying the curvature of the sliding surface with isolator displacement. These isolators are found to be effective in reducing the forces transferred to the structure at all intensities of excitations without showing any resonance problems. However, the sliding surface of these isolators is flatter than the FPS system. This induces large sliding displacement for low frequency and high intensity earthquakes, resulting in expensive loss of space for a seismic gap. In another approach, to overcome the resonance problem, various additional seismic control devices such as passive viscous fluid dampers[5,6] and active or semi-active variable stiffness or variable damping devices have been augmented[7–11] to the FPS or rubber bearings. Although, the active or semi-active devices by varying the properties like stiffness or viscosity are found to be more effective compared to passive devices, such systems are relatively complex since they require special hardware, sensors, and constant maintenance. On the other hand, passive devices are easy to maintain since they do not require any additional power and sophisticated equipment. Several analytical and experimental studies carried out on isolated buildings and bridges demonstrated a reduction in bearing displacement when additional passive damping devices are added to the FPS or rubber bearings. However, the major drawback of passive dampers with the FPS is their inability to adjust the parameters during the earthquake in response to seismic excitations. To overcome this problem, a FPS with a variable frequency is proposed in the present study instead of a FPS with a constant frequency. In the case of a variable frequency FPS, the frequency varies in response to seismic excitation due to the geometry of the isolator without the need of any external power. A new isolator known as a variable radius friction pendulum system (VRFPS) is proposed, and its effectiveness is investigated when additional passive damping using a viscous fluid damper (VFD) is added. A VRFPS isolator is used to overcome the resonance problem of the FPS associated with near-fault characteristics, and an additional passive damping device is used to reduce the sliding displacement of the isolator. Krishnamoorthy[12] studied the effectiveness of the VRFPS with a VFD for seismic isolation of space-frame structures. In this study, the effectiveness of the proposed isolator with a VFD is investigated to control the seismic response of a continuous bridge. The mechanical behaviour of a VRFPS is similar to that of a FPS. The difference between the VRFPS and a FPS is that the radius of the curvature is constant in the case of a FPS whereas it varies with the sliding displacement in the case of the VRFPS. For the pro-