Seismic Optimization of Concrete Gravity Dams Using a Rubber Damper

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One of the major factors in an economic project of new concrete dams and safety valuation of available dams in seismic areas is the control and dissipation of the induced hydrodynamic pressure induced by dam and reservoir interaction. As one of the main control functions, dissipating the induced hydrodynamic pressure on the upstream face of the dam is considered in the evaluations. In this paper, the effects of a rubber damper as an isolation layer on the dam’s seismic control have been investigated. For optimization of the rubber damper thickness and height, the Monte Carlo probabilistic analysis is used. The ANSYS program on the basis of finite element technique is applied for modeling and analysis. The Pine Flat dam in California, due to components of El Centro, San Fernando and North Ridge earthquake is modeled as a case study to evaluate the effect of upstream isolation layer on seismic control and optimization. The effect of the thickness and height of the rubber damper on reducing the responses is investigated and the optimum thickness and height are selected using sensitivity analysis for safe and economic design. The obtained results show the capability of the rubber damper in the seismic and hydrodynamic control of the sample model.

1. INTRODUCTION

The analyzing of concrete dams due to the presence of interaction effects is a very complex problem. Besides the static pressure of water, the dam is subject to dynamic forces of the reservoir when earthquake ground motion affects the system. In an earthquake, the dam body connected to the ground starts to fluctuate, while the water behind the dam is not directly affected by the seismic motion of the ground because of the low shear resistance of the water. So, the hydrodynamic pressure is only created by dam vibrations in the reservoir which spreads away to the reservoir upstream. Because of the interaction, the interface between the dam and the reservoir is a main boundary where the hydrodynamic forces are applied on the structure of the dam. These forces cause a considerable contribution to evaluate the seismic performance and design of the dam.1–3 During an earthquake, there is a significant relationship between the hydrodynamic pressure and the seismic response of a concrete gravity dam. The resulting stresses may cause a to crack to occur with propagation in the dam over relatively severe seismic phenomena. The direct approach to reduce the response of a concrete dam is to increase its structural damping to a desired high value. However, due to the nature of the dam structure and the concrete material properties, no significant action can be done for the structural damping aspect of response reduction.4 Bayraktar et al. investigated the effect of reservoir length on seismic performance of gravity dams to near-and far-fault ground motions using the finite element method.5 They considered the linear and nonlinear behavior for a concrete body. The obtained results illustrated that the length of reservoir affects the seismic responses, considerably. Also, the induced stress on the dam body is more due to near-fault ground motions in comparison with far-fault ground motions. Wang et al. investigated the effect of near fault and far-fault ground motion on seismic performance of the Koyna gravity dam using the concrete damaged plasticity model for nonlinear analysis. The obtained results showed the importance of the near-fault ground excitations on seismic performance of the model.6

Recently, energy dissipation was used in the structures with application of seismic isolation and protection systems.7 These systems can reduce the seismic responses imposed on the structure during an earthquake. The performance of these systems presents a new design philosophy that focuses on increasing the capacity of energy dissipation in the structures. In other words, the earthquake energy, instead of absorbing and causing failures in structural elements, is absorbed in this system. As one of the modern technologies, the seismic isolation and control systems have been more used in the structural engineering such as structures, bridges and dams, the practical effects of which are proven in several strong earthquakes. It has become a new improved method for earthquake engineering.

Due to the nature of the dam structure and the concrete material properties, there is little that can be done on the structural damping aspect of response reduction. The idea of reducing the hydrodynamic loading on the dam appears to be a promising approach for seismic response reduction of concrete dams, though it is still in the early stages in the field of safety of large dams. The separation interface is placed on the upstream face of dams. One of the first ideas for reducing hydrodynamic pressure on the dam by an air curtain at the upstream side of the dam has been examined by Lombardo et al., Sheinin, and Savinov et al.7–9 As’kov et al.10 and Gellis et al.11 examined the idea of hydrodynamic isolation by laboratory model tests as well as measurements of the dam prototypes equipped with an air curtain.

In recent researches, Zhang et al. using the finite element model, studied air cushion impact to reduce the Jinping dam seismic responses with 305 m height.10 They used the Eulerian-Lagrangian formulation for modeling and analysis. Their obtained results illustrated that applying an air cushion in...