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Tuned mass damper system of high-rise intake towers optimized by improved harmony search algorithm

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ABSTRACT

The seismic safety and proper functioning of intake towers in a major earthquake are very crucial to the whole hydraulic project, since the controlled release of the reservoir could help to prevent catastrophic failure of a dam after an earthquake by reducing the water pressure. In this study, the tuned mass damper (TMD) system was introduced into the seismic design of high-rise intake towers. The installation of TMD can effectively dissipate the seismic energy acting on the intake tower and thus overcome the whiplash effect of the hoist room. The 3D finite element model of the intake tower was simplified into a 2D MDOF model. Improved harmony search (IHS) algorithm was used to determine the optimal parameters for the TMD systems using Matlab, and the robustness of the TMD systems was investigated. The simulation elements of the TMD system were incorporated into ADINA to simulate and evaluate the effect of the TMD system on the dynamic displacement and stress responses of various key points of the intake tower to different seismic excitations.

1. Introduction

The seismic safety and proper functioning of intake towers during and immediately after an earthquake are crucial to the whole hydraulic project. In the traditional hydraulic structural design, the essence of seismic design is to improve seismic capacity by strengthening structural stiffness and mass distribution [1]. The research on the vibration resisting system may provide new insights into how to proactively reduce the seismic responses of the hydraulic structures [2,3]. High-rise intake towers are particularly susceptible to the whiplash effect under earthquakes, resulting in damage to the hoist room atop the intake tower, opening failures of the spillway gates and even dams overtopping. The use of TMDs has the potential to mitigate the whiplash effect and improve the seismic capacity of the intake towers, contributing to its safety and serviceability during and after an earthquake.

TMDs have been shown to be effective and reliable in civil engineering practice [4,5]. Much research effort has been devoted to the optimization of TMD parameter mass, stiffness and damping based on simplified models, with the aim of reducing structural vibration. Den Hartog developed closed form equations of optimum parameters for undamped single degree of freedom (SDOF) main system subjected to harmonic excitations [6]. Later, Warburton derived expressions for optimum parameters for undamped SDOF main systems subjected to harmonic and white noise excitations [7]. Sadek et al. presented the optimum parameters of TMDs for multi-degree of freedom (MDOF) structures [8]. Rana and Soong designed a TMD for a SDOF structure and a certain vibration mode of a MDOF by numerical optimization, and investigated the controlling of multiple structural vibration modes using multi-TMDs [9]. Bakre and Jangid derived equations of optimum parameters for TMD attached to a SDOF main system for various excitation and objective function, such as dynamic displacement, velocity and base shear force [10]. In addition, many intelligent algorithms such as the genetic algorithm [11–15], bionic algorithm [16,17], particle swarm optimization [18,19] and harmony search (HS) algorithm [20–23] have been proposed for the optimization of TMD parameters. Previous studies on the application of TMD in high-rise civil buildings provide important theoretical and practical insights into the seismic design of high-rise hydraulic structures. However, the hydraulic structural pattern and foundation geological condition are very complex and various thereby making it difficult to simplify them into SDOF, MDOF or multi-storied structures. And, instant of a fix-based structure, the interactions of the hydraulic structures with foundation and reservoir also have to be considered in design and optimization of a vibration control system.

In this study, the TMD system was introduced into the seismic design of high-rise intake towers. The TMDs installed in the hoist room can effectively dissipate the seismic energy acting on the

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intake tower and thus reduce the whiplash effect of the hoist room. This could effectively reduce the dynamic response of the hoist room and the intake tower to earthquakes without affecting their normal functions. A 3D finite element model of the intake tower considering the interactions of the structure with foundation and reservoir was established and simplified into a 2D MDOF model. Improved harmony search (IHS) algorithm was used to determine the optimal parameters of the TMD systems using Matlab software, and the robustness of the TMD systems was also investigated. Finally, the simulation elements of the TMD system were incorporated into ADINA to simulate and evaluate the effect of the TMD system on the dynamic displacement and stress responses of various key points of the intake tower to different seismic excitations.

2. 3D finite element model

A typical high-rise intake tower of a hydropower station in China was selected as the test case [24]. It is an underwater freestanding structure, where the height of the main tower and hoist room is 85.0 and 19.5 m, the size of the cross section is 15.0 × 10.3 m, and the thickness of the tower is 2.2–2.9 m, respectively (Fig. 1). The normal storage water level is 900.0 m. The foundation is moderately and weakly weathered sandstone and mudstone.

A finite element model considering the interactions of the main tower with the hoist room, foundation and reservoir was established (Fig. 3), where the structure of the intake tower (including water inlet, gate groove, breast wall and backfill concrete) is shown in Fig. 2, the hoist room was simulated by the separated reinforced concreted model, the equipment was considered as added masses; the reservoir surface was constrained as a free surface boundary and the tail and side areas were constrained as a fluid-infinite boundary. The element types and material parameters are shown in Table 1. The dynamic elastic modulus of concrete was increased by 30%. The Rayleigh damping was used in the dynamic analysis,

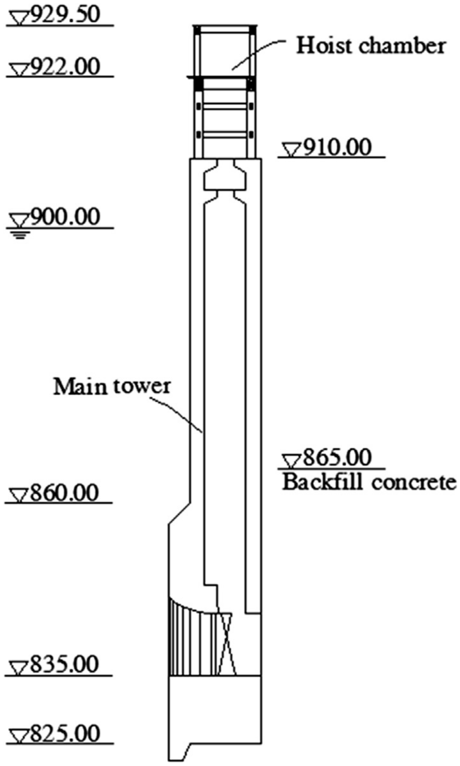

Fig. 1. Typical cross section of the intake tower.

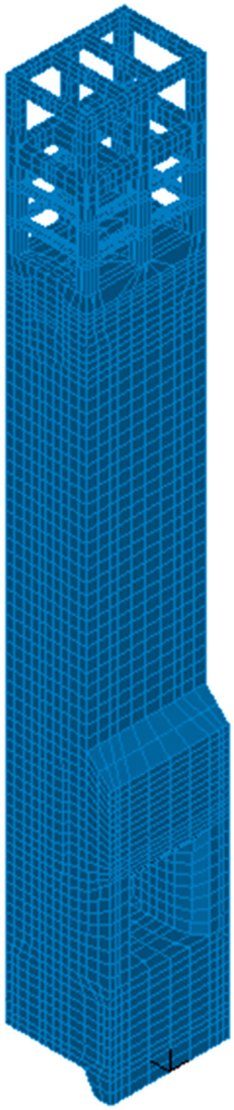

Fig. 2. Finite element model of the intake tower.

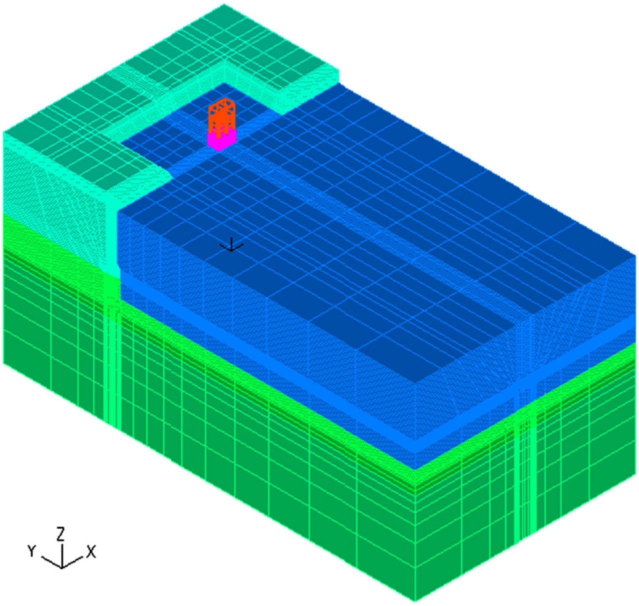

Fig. 3. The whole finite element mesh.