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CFRP composite retrofitting effect on the dynamic characteristics of arch dams

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ABSTRACT

The purpose of this study is to investigate the effect of retrofitting dynamic characteristics of a damaged laboratory arch dam model, subsequently repaired with high-strength structural mortar and strengthened with composite carbon fiber reinforced polymer. This study constructed in laboratory conditions is a prototype arch dam–reservoir–foundation model. Five test cases of ambient vibration on the arch dam model illustrate the changes in dynamic characteristics: natural frequency, mode shape, and damping ratio, before and after retrofitting. The ambient vibration tests collected data from the dam body during vibrations by natural excitations which provided small impacts and response signals from sensitivity accelerometers placed at crest points. Enhanced Frequency Domain Decomposition Method in the frequency domain extracts the experimental dynamic characteristics. At the end of the study, experimentally identified dynamic characteristics obtained from all test cases have been compared with each other. Apparently, after the retrofitting, the natural frequencies of the dam body increased considerably, demonstrating that the retrofitting, including repairing and strengthening is very effective on the flashback of initial dynamic characteristics.

1. Introduction

Arch dams, constructed for many crucial functions, serve humans through flood control, hydroelectric power, navigation, and provision of drinking water, irrigation, and industrial needs. Consequently, these structures require sophisticated engineering for design and construction to avoid risks from of a dam's failure and ensuing damage. Despite the fact that dam failures are rare, a number of factors including age, construction deficiencies, inadequate maintenance and weather or seismic events contribute to the possibility of a dam's failure [29,39]. In addition, the deterioration of dam materials resulting in loss of strength, stiffness, and other physical properties of concrete may increase possibility of failure. Therefore, structural deterioration or damage requires repair or strengthening to avoid threats to the reliability of the dams.

Concrete is an inexpensive, strong, durable and primary construction material usually used in arch dams, but many of dams exhibit deterioration, which means loss of mechanical and physical properties such as strength and stiffness [6]. The deteriorations result from reasons such as poor workmanship, construction and design errors, freezing and thawing, shrinkage, accidental loadings and chemical reactions, all requiring repairs to avoid catastrophic damage. Consequently the issue becomes the appropriate method to repair damaged concrete from among those used in the past.

Beside the classic methods such as cement and epoxy mortar injections, new and innovative materials such as fiber reinforced polymers (FRPs) have had wide use to repair and strengthen due to benefits and advantages such as high strength, rapid and easy application, low weight, corrosion resistance and durability [26,12,8]. Three types of FRP materials are general choices for structural retrofitting (repairing and strengthening): glass fiber reinforced polymer (GFRP), carbon fiber reinforced polymer (CFRP) and aramid fiber reinforced polymer (AFRP). These materials have application in reinforced and prestressed concrete, masonry, timber and steel structures by adhesive bonding to surfaces of structural members. Many researchers emphasized that retrofitting with FRP materials increase the

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nonlinear response capacity, rigidity, load-carrying capacity, energy absorption, strength and environmental resistance, and reduce the seismic vulnerability and maximum displacement values [22,40,37,23,4,13,7,28,34,20,16,30].

To decide the necessity of repairing and/or strengthening, the structural performance of arch dams should be checked. Dynamic characteristics such as natural frequencies, mode shapes, and damping ratios are the key parameters for monitoring integrity during service life. Widely accepted is the notion that the cracks or damage change stiffness, damping, mass and boundary conditions which directly affect dynamic characteristics [38]. An ambient vibration test is one popular inspection method to determine dynamic characteristics [11,17].

In the literature, many studies consider finite element analysis, experimental measurements, model updating, damage assessment, and dynamics analysis of arch dams. Loh and Wu [24] determined the dynamic characteristics of the Fei-Tsui arch dam using finite element analysis and experimental measurement tests. Ziyad [47] conducted the finite element analysis and experimental measurements on the Morrow Point arch dam to determine the dam–water interaction effect and water's compressibility. Valliappan et al. [44] presented the nonlinear seismic response of arch dams. Proulx et al. [35] showed the effects of water level on the dynamic behavior of arch dams. Darbre and Proulx [14] preferred continuous ambient vibration monitoring studies related to the Mauvoisin arch dam. Barpi and Valente [9] conducted fuzzy parameters analysis of time dependent fracture on models of concrete dams. Oliveira and Faria [31] studied the numerical simulation of failure scenarios of concrete dams reproduced experimentally on reduced scale models. Akköse et al. [1] investigated the effects of the reservoir's water level on nonlinear dynamic responses of arch dams. Mirzaei et al. [27] performed a seismic response analysis of a double curvature arch dam using nonlinear static analysis similar to the capacity spectrum method. Bayraktar et al. [10] demonstrated the finite element model's updating effects on nonlinear seismic response of arch dam–reservoir–foundation systems. Oliveira et al. [32] studied damage identification in a concrete dam by fitting measured modal parameters. Alembagheri and Ghaemian [2] explored damage assessment of a concrete arch dam through nonlinear incremental dynamic analysis. Wang et al. [45] analyzed earthquake damage to arch dams by considering dam–water–foundation interaction. Türker et al. [42] showed the effectiveness of the model updating method for damage detection on a laboratory model of an arch dam. Apparently, from the literature, studies of damaged dams and their retrofitting (repairing and strengthening) using new and innovative materials such as FRP composites, are sufficient. The current study seeks to contribute to relieve the deficit.

In this paper, it is aimed to investigate the effect of retrofitting on dynamic characteristics of a damaged arch dam, subsequently repaired with high-strength structural mortar and strengthened with composite carbon fiber reinforced polymer. Five test cases of ambient vibration are performed on the dam model to illustrate the changes in dynamic characteristics before and after retrofitting.

2. Laboratory arch dam model

This study selects for experimentation the laboratory model of a Type-1 arch dam, one of five types of arch dams suggested at the

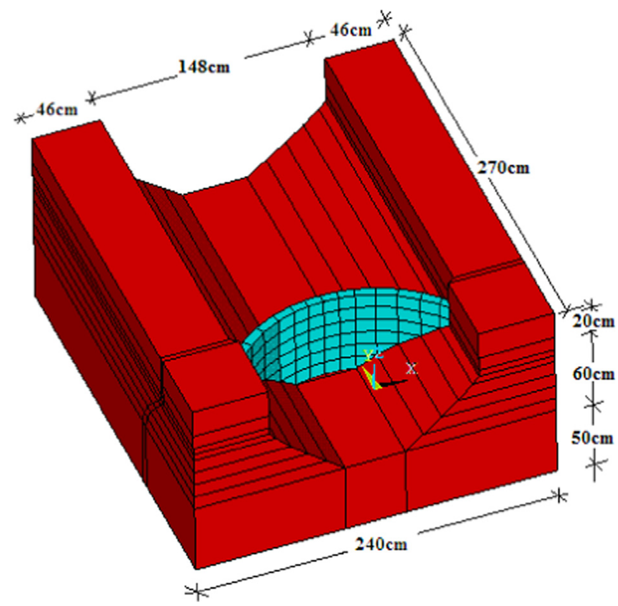

Fig. 2. Type-1 arch dam–reservoir–foundation system and its dimensions.

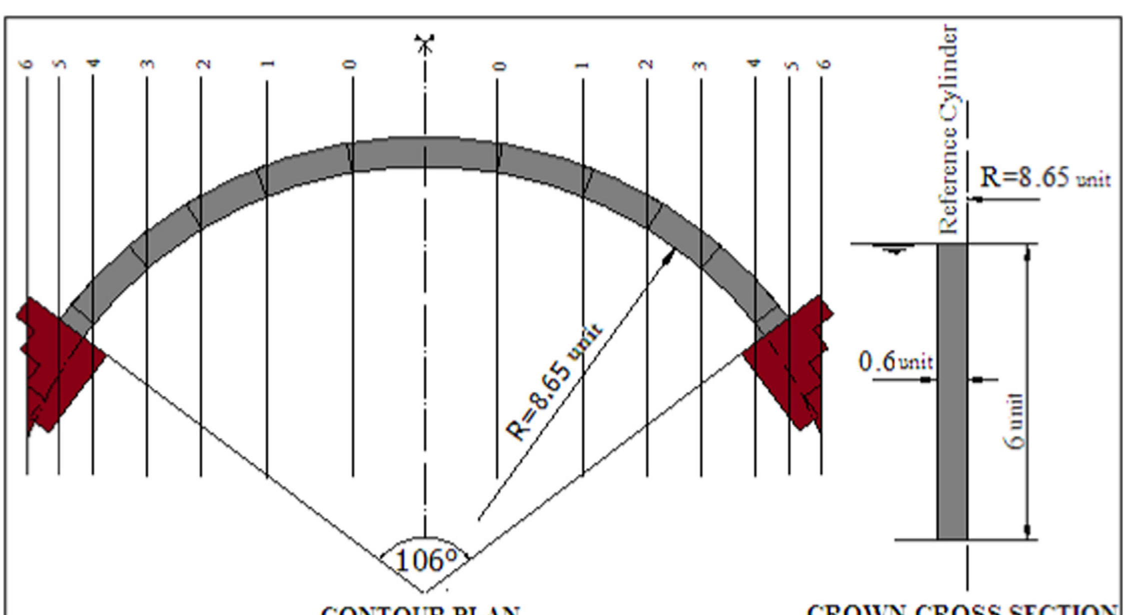

Fig. 1. Geometrical properties of the Type-1 arch dam.