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Optimal sensor placements for system identification of concrete arch dams

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Abstract. This paper investigates the optimal sensor placements and capabilities of this procedure for dynamic characteristics identification of arch dams. For this purpose, a prototype arch dam is constructed in laboratory conditions. Berke arch dam located on the Ceyhan River in city of Osmaniye is one of the highest arch dam constructed in Turkey is selected for field verification. The ambient vibration tests are conducted using initial candidate sensor locations at the beginning of the study. Enhanced Frequency Domain Decomposition and Stochastic Subspace Identification methods are used to extract experimental dynamic characteristics. Then, measurements are repeated according to optimal sensor locations of the dams. These locations are specified using the Effective Independence Method. To determine the optimal sensor locations, the target mode shape matrices which are obtained from ambient vibration tests of the selected dam with a large number of accelerometers are used. The dynamic characteristics obtained from each ambient vibrations tests are compared with each other. It is concluded that the dynamic characteristics obtained from initial measurements and those obtained from a limited number of sensors are compatible with each other. This situation indicates that optimal sensor placements determined by the Effective Independence Method are useful for dynamic characteristics identification of arch dams.

Keywords: arch dams; dynamic characteristics; effective independence method; modal testing; optimal sensor placement

1. Introduction

Arch dams are one of the most important civil engineering structures and have strategical, financial importance due to their contribution to the economy, energy generation, retaining a large quantity of water, and flood control. Arch dams can be subjected to several dynamic and static loads such as earthquakes, water pressure, and blast during their service life. Also, the structural behavior of these structures may change with time due to material degradation, corrosion, damages, and other factors. These loads and deteriorations may cause loss of structural integrity and destructive effects in dams. If the structural integrity of dams is not well monitored and operated, it may cause severe economic losses and, more importantly, may endanger public safety. For these reasons, the safety of arch dams should be monitored and maintained periodically with experimental methods.

Structural health monitoring is a prediction process for operational safety and damage detection of all types of engineering structures in operational conditions (Abdulkarem *et al.* 2020). In this process, the structural behaviors are monitored periodically with experimental methods (Abdel and Abdo 2014). It can also be used for condition assessments of structures against sudden events such as natural disasters (e.g., earthquakes) and man-made hazards (e.g., blasts and impacts) (Fu *et al.* 2020). The structural behaviors of engineering structures are identified according to dynamic characteristics such as mode shapes, natural frequencies, and damping ratios. In the structural health monitoring, the changes in the dynamic characteristics are evaluated for damage detection, because the dynamic characteristics depend on the mass and rigidity of the structures (Farrar and Doebling 1997, Farrar and Jauregui 1998, Altunişik *et al.* 2015, Altunişik *et al.* 2018a).

The dynamic characteristics can be obtained by modal analyses of the finite element (FE) model based on various parameters such as material properties, cross-sections of the structural element, and boundary conditions, in the design stage before construction. However, the parameters are not generally constant due to some reasons such as faulty workmanship, material degradation, corrosion, damages, fatigue, etc. In this case, the existing dynamic characteristics of the structures are different from the FE model results. Therefore, the dynamic characteristics of structures should be determined by non-destructive experimental methods as well as analytical methods (Günaydın *et al.* 2017, Altunişik *et al.* 2018b). The non-destructive experimental methods reflect the in-situ existing dynamic characteristics of structures because the methods are applied directly to the structures

The operational modal analysis method is a widely preferred non-destructive method to identify the experimental dynamic characteristics of structures. In this method, the sensitive sensors are placed on the nodal points which are selected according to the FE model. Accumulated

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