Automation in Construction 81 (2017) 196–209

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Porosity- and reliability-based evaluation of concrete-face rock dam compaction quality

Peng Lv, Xiaoling Wang*, Zhen Liu, Jia Yu, Minghui Liu

State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China

ARTICLE INFO

Keywords:
Concrete-faced rockfill dam
Compaction quality
Porosity
Reliability
Artificial neural network
Elitist genetic algorithm

ABSTRACT

Compaction quality evaluation of concrete-faced rockfill dams (CFRDs) is a complex nonlinear process. Conventional evaluation methods depend on random spot tests, and porosity is considered as the main evaluation index. However, reliability of results is neglected in existing studies. Considering compaction parameters, material properties and their variability characteristics, an evaluation approach of CFRD compaction quality based on porosity and reliability is proposed. Reliability analysis is introduced to measure the variability in highly variable factors and calculate the porosity- and reliability-based index. Porosities of the entire work area are predicted using an elitist genetic algorithm-based artificial neural network, which are consistent with the measured values with an error < 5%. Data used in this study are based on the results from the real-time monitoring system for construction quality and spot tests accumulated during construction. The applicability of the proposed approach is demonstrated by an illustrative case study in China.

1. Introduction

Recent advances in soil and rock engineering have led to significant progress in design and construction [1] of concrete-faced rockfill dams (CFRDs) [2]. High compaction quality that is commonly improved by vibratory rollers [3] is necessary to ensure the performance and safety of a CFRD [4]. The porosity is an important index when evaluating the compaction quality, which is directly related to compaction parameters and material properties. However, the conventional method of using random spot tests has specific limitations in obtaining porosities: (1) spot tests are conducted at limited locations; thus, the quality of the entire work area in construction cannot be reflected [5], (2) spot tests are time-consuming and may influence the progress of construction, and (3) the measured values are limited because spot tests cannot consider the uncertainty when detecting porosities and ensure the reliability of compaction quality. Because of these limitations, the results by conventional evaluation method are not adequately reliable for controlling compaction quality. Present researches studied the mapping between compaction parameters and porosity, realizing rapid compaction quality assessment of the entire work area. However, few studied the effect of material properties and their variability on the porosity, which are inherent to quality evaluation. In particular, when variability is considerable, evaluating compaction quality by a single index of porosity is limited, as reliability of compaction quality cannot be reflected. Generally, reliability is defined as “the probability that an item will operate without failure for a stated period of time under specified conditions” [6]. In this study, reliability is defined as the ability to ensure compaction quality at some point with a specific porosity. Reliability helps in reflecting variability in the compaction system and measuring the variability of highly random factors, that makes compaction quality evaluation more reasonable and rigorous [7]. In the process of evaluating reliability of the porosity, porosity factors with high variability are considered as random variables. The reliability results are obtained based on the probability theory and statistical method.

The necessity of compaction quality control (QC) has been well illustrated [8]. Conventionally, the effectiveness of compaction QC is verified through sand-replacement method, nuclear-density tool, and speedy-moisture tester. Ilori et al. employed an elastic seismic P-wave method of survey to evaluate the compaction quality of subgrade [9]. However, the point-test methods are time-consuming and hardly reflect the overall quality of the constructed pavement. The intelligent compaction (IC) technology recently has been developed to estimate compaction quality continuously in real time. Commuri et al. [10] and Beainy et al. [4] designed an intelligent asphalt compaction analyzer (IACA) based on a neural network to estimate the density of asphalt in real time considering the entire frequency spectrum of roller vibrations. Tan et al. [11] provided a framework for QC of asphalt-pavement compaction using fiber Bragg grating (FBG) sensing technology. This QC method is based on the principle of FBG sensing technology and

* Corresponding author.
E-mail address: wangxl@tju.edu.cn (X. Wang).

http://dx.doi.org/10.1016/j.autcon.2017.06.019
Received 15 December 2015; Received in revised form 12 May 2017; Accepted 11 June 2017
Available online 21 June 2017
0926-5805/

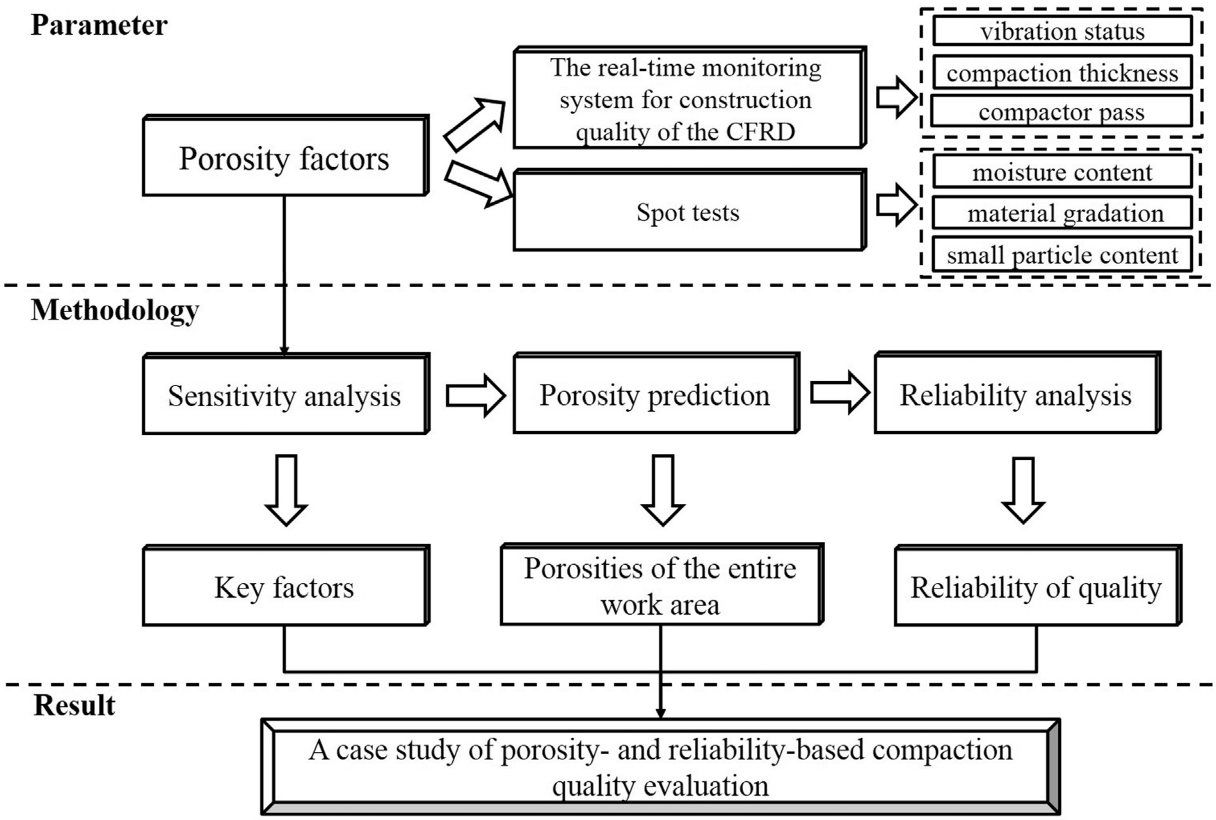

Fig. 1. Research framework.

hypothetical relationship between material performance and deformation property. Xu and Chang [12] proposed a framework for IC construction and an in-situ test control using IC technology and employed it in an engineering project, wherein a computer-aided data-analysis method was developed and the univariate statistics, geostatistical semi-variograms, and compaction curve were studied. However, the aforementioned studies are not completely applicable to dam-compaction QC, because dam construction requires different compaction parameters, compaction indices, and construction techniques as opposed to road construction. Zhong et al. [13] proposed a real-time compaction-quality monitoring system for dam construction, which has helped in further studying the evaluating techniques of compaction quality for dams. Liu et al. [14] employed a compaction value (CV) as a real-time monitoring index to determine the compaction quality of a dam and proposed a CV-based assessment method to estimate the compaction quality of earth-rock dam. The CV is strongly correlated with the compaction parameters, compactness of the gravel-mixed cohesive soil, and dry density of rockfill dam materials. In the aforementioned studies, the compactor and compacted area are assumed to form a coupled system, and the performance of a compactor is analyzed by observing its vibratory response. There is a demand for developing additional equipment installed on a compactor. Mathematical and statistical methods provide a more convenient alternative. Liu et al. [15] developed a quality-inspection process that helps monitor the compaction operations of earth-rock dam construction in real time and establish a multiple-regression model to predict the compaction quality using independent variable data obtained from a real-time quality-monitoring system. In this study, an artificial neural network (ANN) based on the elitist genetic algorithm (EGA) [16] is proposed to evaluate the compaction quality of entire work area of a CFRD. In the proposed model, compaction parameters and material characteristic parameters are considered as inputs, and an ANN model is developed to predict the porosities of undetected points located on the work area. The EGA is used to optimize the architecture of the ANN model.

Most studies mainly focused on the relationship between compaction quality and quality factors; however, the reliability was largely ignored when evaluating the project quality. The most common applications of reliability theory are in the fields of slope stability [17], offshore structures [18], and stability of anchored sheet-pile wall [19]. Tao and Tam [20] proposed a system-reliability optimization (SRO) model based on system reliability theory. As part of the reliability theory that deals specifically with the reliability analysis of systems with several components, the system reliability theory has become one of the well-developed methodologies in electronic engineering, with high potential for application in construction management. Afolayan and Nwaiwu [21] employed a first-order reliability method to assess the suitability of lateritic soil as landfill-liner material based on existing models developed using laboratory and field data. During construction of a dam, the problems involved in effectively controlling the project risk and enhancing the quality of project performance should be paid more attention. In this study, the reliability theory is introduced to evaluate the compaction quality of a dam to analyze the influence of variability in porosity factors.

The objective of this study is to propose a porosity- and reliability-based method to evaluate the compaction quality, which can help in predicting the porosities of the entire work area and provide an index that reflects the reliability of compaction quality. First, based on a real-time monitoring system for monitoring the construction quality of CFRDs, the compaction parameters (i.e., vibration status, compaction pass, and compacted thickness) are obtained during construction. Subsequently, considering the material-characteristic parameters and their variations, a porosity- and reliability-based evaluation method is proposed. The method includes two main parts: 1) porosity prediction of the entire work area using an EGA-based ANN model, and 2) reliability analysis in the process of evaluating the compaction quality. A case study is conducted on a CFRD of a pumped-storage power station located in China. Key factors affecting the porosity are analyzed based on the sensitivity analysis. The proposed method not only helps