DAMAGE EVALUATION OF CONCRETE STRUCTURES USING ACOUSTIC EMISSION

by

Rafal Anay

Abstract

The deterioration and aging of the infrastructure in the U.S. have become a crucial issue, especially for highway bridges and nuclear power plants. The reliability and safety of existing structures are affected by growing populations and limited resources. This issue has gained significant concern during the last two decades and efforts are being conducted to accelerate the improvement of nondestructive testing (NDT) and structural health monitoring (SHM) methods. Additional information regarding the condition of existing structures and the early detection of damage can aid in reducing overall maintenance costs. The studies presented in this dissertation employ acoustic emission (AE) as a non-destructive evaluation technique, leveraging its extreme sensitivity to mechanical waves generated by damage and progressive deterioration mechanisms within these structures. The objective of the research is to characterize damage conditions of existing structures using a stress wave-based approach including two cases of study: a) detect and identify the extent of microcrack initiation and progression occurring due to different compressive loading levels applied on small scale cement paste specimens using acoustic emission, and b) monitor and evaluate damage growth in a prestressed concrete girder bridge with shear cracks under truck loading and varying load positions.

Three studies were performed in an effort to achieve the objectives and are presented in a series of journal articles as chapters in this dissertation. The first and second studies present a two-part paper which discusses damage mechanisms in cement paste under compression loading based on AE (Part I) and fracture mechanics (Part II). In this study, cement paste specimens having dimension of 38.1 mm x 38.1 mm x 152.4 mm (1.5 in. x 1.5 in. x 6 in.) were cast using Portland cement Type I/II and a water to cement ratio of 0.5, which was then cured for 28 days in lime water. Part I presents and discusses the results from compression tests while monitoring with AE. Active crack growth was detected and classified using amplitude and cumulative signal strength (CSS), and unsupervised pattern recognition was utilized to separate AE data into clusters. Then the source of AE data was verified using micro-CT scanning.

Part II included a three-point bending test conducted on 38.1 mm × 38.1 mm × 152.4 mm (1.5 in. × 1.5 in. × 6 in.) cement paste specimens to measure the fracture toughness property. Also, the compression test of the cement paste prism was simulated using the Abaqus finite element program to determine the stress intensity factor (SIF) along a predefined crack tip at a specific level of loading. The SIF is to be compared with the fracture toughness to define the limit at which a crack grows in an unstable manner. The results of this study show that under the conditions of unstable crack extension (defined in Part I by the AE method), the calculated SIF reached the fracture toughness of cement paste. This verifies the defined damage mechanisms described in part I.

In the third study, AE was utilized to evaluate the condition of a three-span, prestressed concrete girder bridge located in Guadalupe County, New Mexico during a load test. The 15-year-old bridge has inclined cracks in four girders of the exterior spans. Some cracks were injected with epoxy, however, most of the cracks extend beyond the epoxy regions, and some girders have developed new cracks. AE data was collected from sensors attached on three girders toward the obtuse corner of an exterior span under
different levels of load. The results indicated that external girder 1 and interior girder 3 experienced more damage accumulation during load testing than interior girder 2. Additionally, shear strength analysis using modified compression field theory (MCFT) was performed to extrapolate the AE results collected from the test to predict future damage and to decide whether long term monitoring or closure of the bridge is required. The results showed that bridge closure is not necessary.

The outcomes of the studies described in this dissertation demonstrate the potential of using AE as a feasible technique for condition assessment and structural health monitoring through two main points including: a) stress wave-based data acquisition can be used to inform the microscale damage compression model as it relates to the degradation of cement paste, and b) a stress wave based approach may be used to define the level of shear damage in prestressed bridge girders due to applied loading.