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Identification of Zero Effect State in Corroded RCC Structures Using Guided Waves and Embedded Piezoelectric Wafer Transducers (PWT)

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Abstract

Reinforced cement concrete (RCC) structures are prone to damages such as corrosion of reinforcement, surface cracking, debonding and the like. The corrosion process results in two effects, namely, reduction in the diameter of rebar and debonding at the steel/concrete interface. Several researchers have worked to establish a correlation between intrinsic damage features and guide wave signal characteristics. However, the work till date is focused mainly on identifying the individual damage phenomenon, and few researchers have attempted to correlate the combined effect of these damage parameters. Therefore, it is an impending task to study the combined influence of corrosion and debonding on wave characteristics and to establish methods to distinguish and correctly quantify the damage level. A three-dimensional finite element model of a RCC beam is developed in the Abaqus software by using an explicit method in order to study wave propagation in an RCC beam after including the two effects of corrosion. The implicit and explicit models are co-executed using standard-explicit co-simulation. It is observed that the reduction in diameter would result in the diminishing of the guided wave amplitude, whereas debonding results in an increase in the guided wave amplitude. It is found that these two complimentary effects on wave features result in a signal that has the same wave features as undamaged rebar that is surrounded by concrete, which could be termed as the zero effect state.

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1. Introduction

Concrete is a widely used material in the infrastructure industry due to its easy availability, high compressive strength-to-density ratio, ability to form into the required shape, and its lower cost when compared to its metal counterparts. In order to increase the tensile strength of concrete, reinforcing bars (rebars) are embedded in it. Reinforced concrete structures are prone to damages such as surface cracking of concrete; corrosion of steel; debonding of steel due to various factors such as weathering, chemical attack, overloading, aging, and the like. Concrete acts as a natural protector against the corrosion of rebars by serving as an alkaline medium. However, ingress of chloride ions over extended periods of time neutralizes the cathodic protection, and the reinforcing bars corrode. In this process, the pore solution serves as electrolyte, and the rebar acts as a mixed electrode, that is, a part of the bar acts as a cathode, whereas another part acts as an anode, leading to pitting corrosion[1]. Eventually, rust begins to form, which can lead to another kind of damage, namely, debonding of steel and concrete at the interface. Hence, prior diagnosis of apparently healthy concrete would help in taking preventive action, which would reduce the maintenance cost and improve the safety and reliability of Reinforced cement concrete (RCC) structures.

Several researchers have studied corrosion by attaching ultrasonic transducers to the ends of the rebar [2][3][4]. However, such a method is not field deployable because the ends of rebars may not be available for the attaching of the transducers. Embedded smart aggregates have been used as transducers to monitor the strength of early age concrete, detect impact location [5], and monitor cracks in concrete [6]. An embedded smart aggregate can capture the early ingress of chloride ions and, therefore, can detect the onset of the corrosion process. However, the passive film that protects the embedded sensor may get damaged during the corrosion process due to which the smart aggregate becomes unusable [7]. Due to their durability, sensors that are bonded on the surface of the rebar prove to be more effective than smart aggregates in monitoring the corrosion. Piezoelectric wafer transducers (PWT) sensors, which can be attached to the surface of the rebar, promise to be better a alternative.

Researchers have tried to correlate the level of corrosion in rebars in RCC beams by using differential time of flight measurements [8][9]. In a typical reinforced concrete structure, more than one rebar is embedded in concrete. In previous studies by researchers[10], it has been observed that the presence of damage in a nearby bar affects the received signal of the rebar under examination; therefore, locating the damage becomes more complicated. Recently advanced techniques such as principal component analysis[11], genetic algorithms, neural networks [12], simulated annealing, and particle swarm optimization[13] have been applied in damage diagnosis.

Although various kinds of damages have been extensively studied individually, the combined effect of these damages has not been studied much. Based on the studies on damages of corrosion and debonding it can be established that these two effects have complementary effects on wave characteristics [2][14]. In the present study, it is shown that the combination of a reduction in the diameter of rebar due to corrosion and separation of rebars and concrete due to debonding may conceal the damage. Hence, further studies are required to investigate the influence of corrosion on wave characteristics in reinforced concrete structures, and to establish methods to distinguish and correctly quantify the level of damage. To meet this objective, a three-dimensional finite element model of an RCC beam is developed using an explicit method in Abaqus software in order to study guided wave propagation that is generated by embedded PWT. Corrosion in rebar is simulated by reducing the diameter of the rebar, and debonding is simulated by untying the concrete and the rebar. The dynamic-implicit method is used to simulate piezoelectric material. The implicit and explicit models are co-executed using standard-explicit co-simulation. The two complementary effects of corrosion and disbond on wave features, which results in a zero effect state, are studied in detail.