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# Artificial Neural Network Model using Ultrasonic Test Results to Predict Compressive Stress in Concrete

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**Abstract.** This study focused on modeling the behavior of the compressive stress using the average strain and ultrasonic test results in concrete cubes as input parameters. Optimum feed-forward backpropagation artificial neural network (ANN) models were used to compare four types of concrete mixtures with varying water cement ratio (WC), as ordinary concrete (ORC) and concrete with short steel fiber-reinforcement (FRC). Four types of mixtures for the concrete cubes are: ORC WC40, ORC WC60, FRC WC40, and FRC WC60. The concrete specimens used for training and testing the data came from sixteen (16) concrete cubes having size of 150mm x 150mm x 150mm. Each cube specimen contains eighteen (18) datasets. Ultrasonic t est with pitch-catch conFiguration was conducted at each loading state to record linear and nonlinear test response with multiple step loads in the experiment. Prior to ANN modeling, statistical Spearman's rank correlation was used to reduce the input parameters in the ANN model. In general, different types of concrete produced similar top five input parameters that had high correlation to compressive stress. These are average strain (ε), fundamental harmonic amplitude (A1), 2nd harmonic amplitude (A2), 3rd harmonic amplitude (A3), and peak to peak amplitude (PPA). Twenty eight ANN models were trained, validated and tested for each WC40 and WC60 mixtures. Optimum model was chosen for each WC model having the least mean square error, the highest Pearson correlation coefficient, and the soundness of the behavior for the input parameters in relation to the compressive stress of concrete. Optimum ANN model showed that increasing WC produced delayed response to stress at the initial stages, followed by abrupt response after 40%. This is due to the presence of more voids for high water cement ratio that activates Contact Acoustic Nonlinearity (CAN) at the latter stage of loading path. In addition, FRC showed slow response to stress than the ORC. This indicates the resistance of short steel fiber that significantly produce delayed stress increase against the loading path.

**Keywords:** Artificial Neural Network, Linear Ultrasonic Test, Nonlinear Ultrasonic Test, Concrete, Fiber-reinforced concrete

## 1. Introduction

In today's infrastructure development, structural health monitoring is crucial in assessing existing bridges against man-made and natural disasters. Accurate assessment after an event in preparation for repair, rehabilitation, or retrofitting is the common problem. Most of the existing structures are made out of complex material known as concrete. Concrete can be assessed in many ways where factors to be considered in the test are cost, time, idle period during assessment, and degree of uncertainty. Development of this accurate assessment can be made with rapid assessment using non-destructive

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testing. Non-destructive test in concrete is complex due to its inhomogeneous ingredients and its particle sizes which experiences clapping of cracks and friction present inside the material. In this paper, ultrasonic test was used as a non-destructive assessment in concrete under uniaxial compressive test in concrete cubes. This ultrasonic test method is divided into two tests, linear and nonlinear.

From references, there were numerous linear ultrasonic testing procedures in concrete. Past researches use combination of linear ultrasonic test using ultrasonic pulse velocity and rebound hammer to test on site strength of concrete (Breysse 2012). Another example is the combination of ultrasonic pulse velocity and ultrasonic pulse amplitude to predict the compressive strength of concrete (Liang and Wu 2002). Researchers use combinations to improve the prediction of the behavior of concrete. But still, ultrasonic pulse velocity is limited due to its insensitivity to the changes in load (Daponte *et al.* 1995). Previous researches also used air-coupled impact echo, infrared, and sounding through chain drag method as a non-destructive method to test concrete (Oh *et al.* 2013).

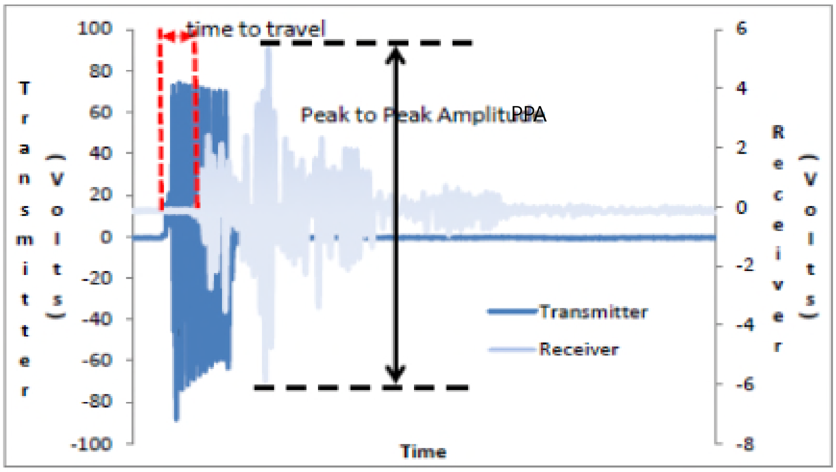


Fig.1. Linear ultrasonic test using UPV and PPA in time-domain recorded from the transmitter and receiver

In linear ultrasonic testing, the received waveform shares the same amplitude as that of the transmitted waveform. Thus, no harmonics is generated during linear ultrasonic testing. An illustration of this is the ultrasonic pulse velocity test (ASTM C597) wherein time of wave traveling a particular distance are the parameters measured during testing as shown in Eq.(1). This parameter is shown in Fig. 1 where the time to travel of the longitudinal wave from transmitter to receiver is used to compute the ultrasonic pulse velocity. It is worth noting that in this test, it is not essential to measure the wave amplitude. In other study, it was observed that cracks of size greater than 100mm are the only ones detected by longitudinal ultrasonic pulses (Komlos *et al.* 1996). Further study claimed that cracks are undetectable especially if it is filled up with fluids.

In relation to Fig.1, Peak to Peak Amplitude (PPA) of the received waveform was also used as a measurement in damage detection. Peak to peak amplitude can be taken from the time domain spectra. Peak to peak amplitude is the vertical distance from the highest point of the wave form to the lowest point of the waveform. In other study, PPA has also been one of the significant parameters in estimating the residual strength of concrete (Shah *et al.* 2008) (Shah *et al.* 2012).

$$\text{UPV} = \text{distance of transmitter to receiver / time to travel} \tag{1}$$

For the aforementioned methods, nonlinear ultrasonic provides to be promising due to its sensitivity in damage and micro- crack detection. Nonlinear ultrasonic waves proved to be sensitively interacting with contact-type defects (Yim *et al.* 2012) (Shah *et al.* 2010a). This includes the opening/closing of