# Factors Leading to a Model Predicting the Compressive Strength of Concrete by Means of Its Sound-Transmission Properties


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## Purpose of the Research

The purpose of this research is twofold: 1. Design and fabricate a test stand for use in these laboratory experiments and 2. determine if any of several independent variables have the ability to predict the compressive strength of concrete. The independent variables that we will test all arise from the acoustic signature produced from the impact of a hammer on a standard, concrete test cylinder.

## Importance

This research is important for two reasons. First, the equipment required for this type of test is less costly and generally more widely available than the standard hydraulic ram now used for testing concrete samples. Second, if this method works on standard concrete test cylinders, it may be possible to transfer this technology to in-place, impact-echo testing of concrete.

## Related Prior Work

In 1948, Ernst Schmidt developed what became known as the *Swiss Hammer* for testing the strength of concrete (Malhotra, 1976). This device works on the principle as explained by Kolek (1958): “When concrete is struck by a hammer, the degree of rebound is an indicator of the hardness of the concrete”. The device was tested extensively in Switzerland. These tests established a correlation between compressive strength and rebound number. Other researchers soon found several factors that could effect the relationship between strength and rebound number (Kolek, 1958). This resulted in the observation that tests of this type are only effective when correlations are made using the identical concrete and forming methods as employed in the structure to be tested.

Another method that gained wide interest is Pulse Velocity measurement. This process basically measures the velocity of a propagated acoustic wave through concrete. Early tests found that while the method was effective at locating faults in concrete, it was not very useful in determining compressive strength (Sturrup et al. 1984).

According to Carino (1994), "The ultimate objective is the development of a technique which is reliable, simple to use and inexpensive. Despite many years of research, there is no method that satisfies all of these criteria. Exploratory research should be designed so that the performance of a prospective test method is evaluated over a wide range of conditions. To avoid drawing faulty conclusions about the suitability of a new method, a statistically-based screening test program should be used to permit valid conclusions to be drawn about the effects of different factors …" Our work is a first step toward such a result.

**Methods and Procedures**

- Design and fabricate the test stand.
- Prepare seven concrete test cylinders from one batch of concrete.
- Test one of the seven cylinders approximately every four days as they mature over the standard 28-day curing cycle.
- Place each standard concrete cylinder on the test stand.
- Secure an Acoustic Information Retrieval System (AIRS) sensor to the cylinder, generate a controlled, repeatable sound by the impact of a steel object on the concrete cylinder.
- Digitally record the acoustic signal produced by the impact.
- Repeat this test for a total of 5 replications for each cylinder.
- Obtain measured values for the following independent variables: event duration, peak amplitude, minimum RMS power, maximum RMS power, average RMS power and number of peaks.
- Destructively test the cylinders to determine their compressive strength.
- Perform a multiple regression analysis to determine if there is any significant treatment effect on the dependent variable, compressive strength, due to any of the independent variables. Construct a predictive model that will predict the compressive strength based upon a significant set of independent variables.

**Main Results**

**Test Stand**

A test stand was designed, fabricated and used to collect data for the study. Although it is heavy and difficult to move, it is excellent for laboratory use.

The sensor consists of a microphone, stethoscope head and connective tubing. These components are all enclosed in a steel electrical box. A spring steel clamp is attached to the box opposite the stethoscope head.

*Figure 1. Acoustic Sensor*

The test stand is designed to hold a standard six-inch diameter concrete test cylinder. The cylinder is placed into the test stand. Once a steel C clamp is firmly attached to the cylinder, the acoustic sensor is secured to the C clamp.

*Figure 2. Test Assembly*

The microphone lead is now attached to the acoustic sensor and the microphone input port on the computer. The hammer is set to the desired height and the pin removed. The impact of the hammer on the concrete is recorded digitally using a program called Cool Edit 2000.

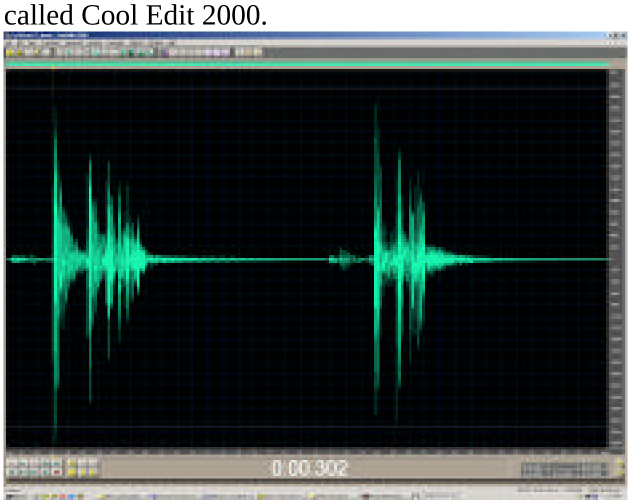

*Figure 3. Two Typical Impact Waveforms as Displayed on Cool Edit 2000*

## The Data

All observed values for the independent variables are calculated within Cool Edit 2000. The variables are: Event Duration, Maximum-Minimum Sample Value, Peak Amplitude, Minimum-Maximum RMS Power, Average RMS Power and Total RMS Power.

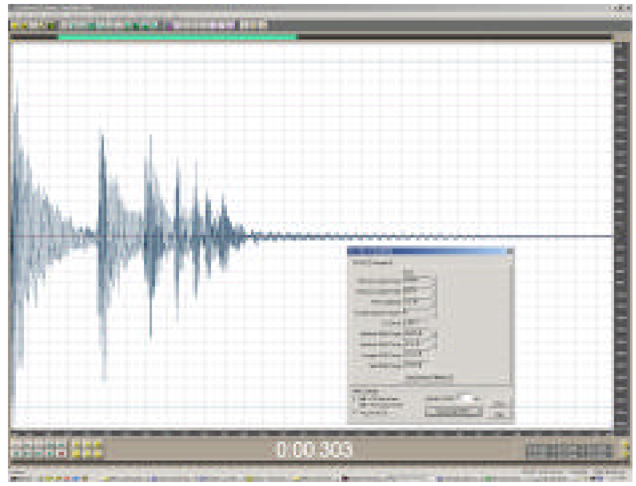

*Figure 4. Cool Edit 2000 Observed Waveform Statistics*

The dependent variable is Compressive Strength. This observation is measured on a standard hydraulic press designed for this purpose. This measurement is done according to ASTM standards.

## Analysis

The statistical analysis resulted in the following:

- Four of the eight independent variables are statistically significant at the .01 level. These are: Minimum RMS Power, Frequency, Minimum Sample and Peak Amplitude. The predictive model constructed from these four variables had an R-Square of .80.
- A satisfactory predictive model was created using the four significant independent variables and a constant. The resulting equation is: Compressive Strength = 16948 + 156.55 Min RMS Power – 3.086 Frequency + 0.1918 Min Sample + 953.3 Peak Amplitude + Error. This model has an overall significance better than 0.0000000035.

## Status of the Effort

The results of the current study pave the way for our next experiments. In the next project we will test the compressive strength of five concrete cylinders per day for 30 days. The test will consist of recording five impact events per cylinder and then immediately destructively testing the cylinders on a hydraulic press to measure the compressive strength