Vibration Analysis of a Concrete Slab Floor Using Piezoelectric Accelerometers

Warren Sims, Dr. Sally Pardue
Mechanical Engineering Undergraduate Research

Introduction

Why is Analyzing Floor Vibrations Important?

Analyzing and interpreting floor vibration responses experienced daily throughout a building could serve as a major asset by monitoring the well-being of the inhabitants, predicting the number of occupants, and acting as an additional unintrusive security measure. One approach to this analysis, which was the focus of this study, involves the utilization of accelerometers in conjunction with oscilloscopes in order to both visually and numerically evaluate the vibrational responses produced by various forms of impact.

What is an Accelerometer?

An accelerometer is a device that measures the vibration, or acceleration of motion of a structure. The force caused by vibration or a change in motion (acceleration) causes the mass to “squeeze” the piezoelectric material which produces an electrical charge that is proportional to the force exerted. [1] (Figure 3)

What is an Oscilloscope?

An oscilloscope, formerly known as an oscillograph is an instrument that graphically displays electrical signals and shows how those signals change over time. It measures these signals by connecting with a sensor, which is a device that creates an electrical signal in response to a physical stimuli like motion, sound, light, and heat. [2] (Figure 2)

What is an Impact Hammer?

An impact hammer, or impulse force test hammer, adapts your FFT analyzer for structural behavior testing. Impulse testing of behavior of mechanical structures involves striking the test object with the force-instrumented hammer, and measuring either the resultant motion with an accelerometer or the acoustic signature with a microphone. [3] (Figure 4)

Real-World Applications:

- Nursing Homes/Hospitals (Fall Detection)
  - **Falls are a direct cause of death for nearly 2,000 nursing homes and assisted living patients each year. [4]**
- High Security Buildings (Non-Intrusive Monitoring)
  - **Cameras and on-person tracking devices pose threats to the privacy of employees.**
- Smart Buildings (Occupancy/Traffic/Structure Health)
  - **Typically, logistics such as these require contacting costly professional services.**

Methods

This preliminary study used piezoelectric accelerometers in conjunction with oscilloscopes to observe the excitation and response of a classroom concrete floor in a 1960’s era building. Various known and unknown impact events were evaluated through a series of tests and configurations including excitation events such mass drops, footfalls, and strikes from an instrumented hammer. A total of 45 trials were conducted. The acquired data was then further analyzed using Microsoft Excel.

Unknown Impact Setup:

Four Accelerometers placed in a straight line at 2 ft increments (Figure 1) with two accelerometers outputs going to each oscilloscope.

Known Impact Setup:

Four Accelerometers placed in a straight line at 2 ft increments (Figure 1) with one accelerometer output and a shared impact hammer output going to each oscilloscope.

In both cases, plots were saved as png files and data was recorded in a csv format to be further analyzed in Microsoft Excel later on.

Equipment:

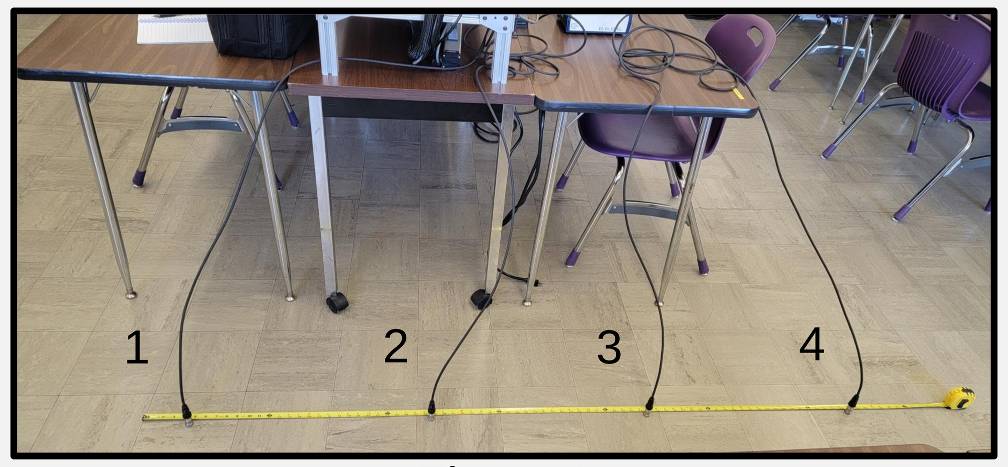


Figure 1

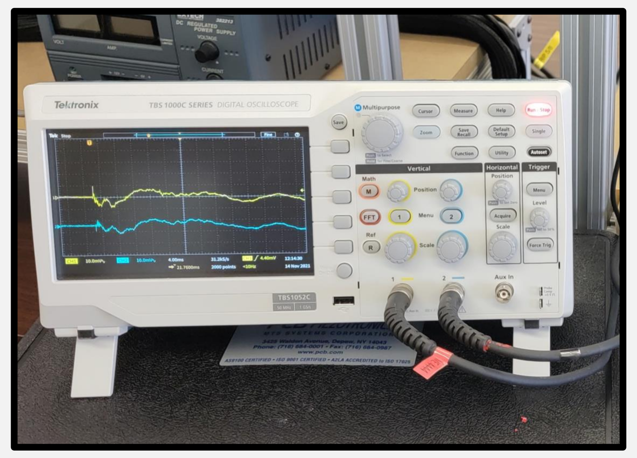
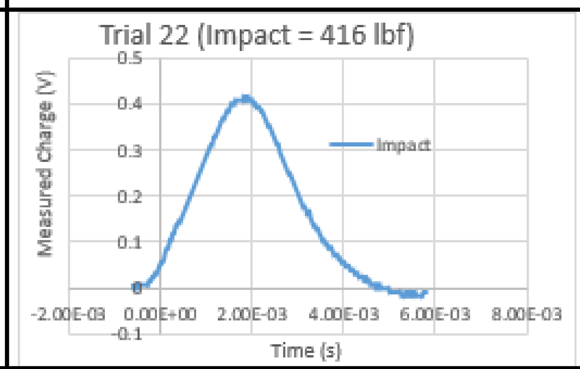
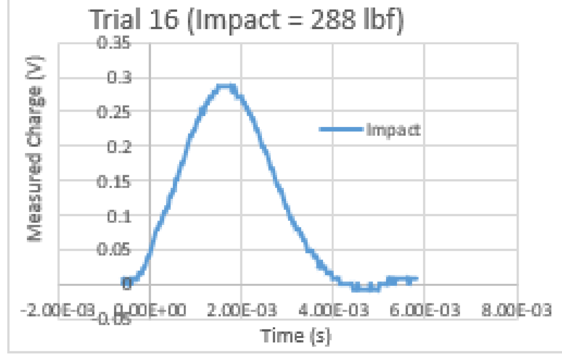
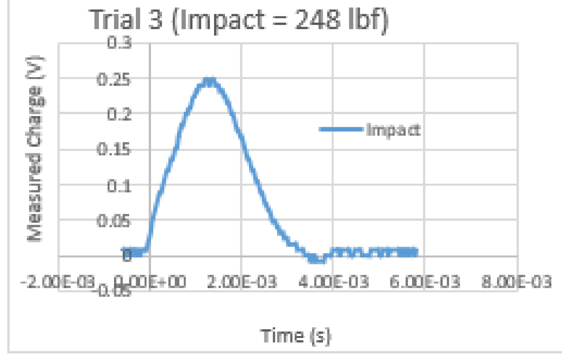
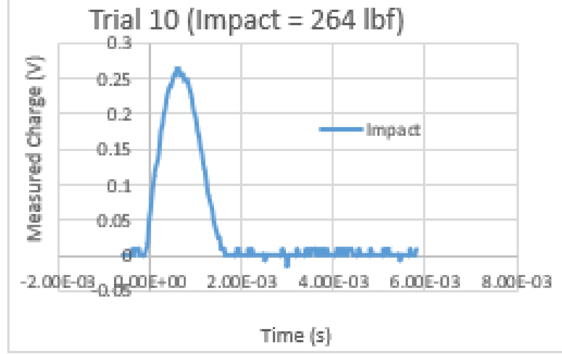


Figure 2


Figure 3


Figure 4

Results

Trial Description	Impact (Next to Sensor 1)	Range of Response
Hammer Tip (Grey Rubber – Super Soft) 		Max @ Sensor 1: 0.2580 g Max @ Sensor 4: 0.1289 g
Hammer Tip (Brown Rubber – Soft) 		Max @ Sensor 1: 0.1860 g Max @ Sensor 4: 0.0513 g
Hammer Tip (Red Rubber – Medium) 		Max @ Sensor 1: 0.1960 g Max @ Sensor 4: 0.0454 g
Hammer Tip (Black Plastic – Hard) 		Max @ Sensor 1: 0.3720 g Max @ Sensor 4: 0.1085 g

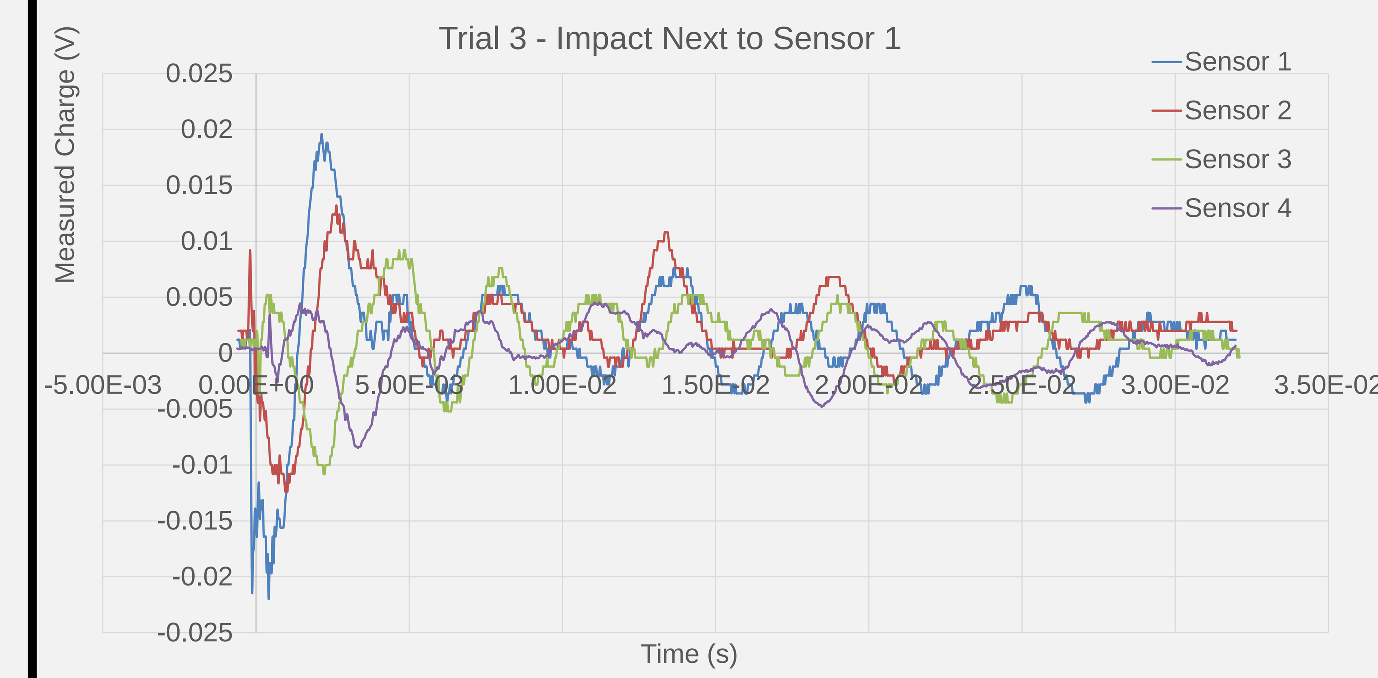
The table to the left displays a comparison of known impacts with their corresponding range of response for each style of hammer tip. The effect that the type of tip has on the frequency of the initial impact as well as the longevity of the response is clearly seen.

The table below displays a comparison of unknown impacts. An approximation of the force of impact of the tape roll drop is attainable through use of the equations in the table to the right.

$$PE = KE$$
$$mgh = \frac{1}{2}mv^2 \mid v = \sqrt{2gh}$$
$$W_{net} = \frac{1}{2}mv_{final}^2 - \frac{1}{2}mv_{initial}^2$$
$$W_{net} = \frac{1}{2}mv_{final}^2 \mid v_{initial} = 0$$
$$F = \frac{W_{net}}{d} \mid d(m) = 0.0001$$

Tape Roll Drop 	$m = 0.1424\ kg$ $h = 0.1\ m$ $v = 1.4\frac{m}{s}$ $KE = 0.1396\ J$ $d = 0.0001$ | (PCB Website) $\rightarrow F = 1395.52\ N\ or\ 313.73\ lbf$	Max @ Sensor 1: 0.1160 g Max @ Sensor 4: 0.0240 g
Foot Stomp 	Unknown: Behaves very similarly to the grey impact hammer tip trial.	Max @ Sensor 1: 0.1760 g Max @ Sensor 4: 0.0980 g

Results Cont.



The figure above shows a comparison of the accelerometer readings for Trial 3 where the impact occurred next to Sensor 1. These readings were the result of an initial impact of 242 lbf. The decay between sensors is quite evident.

Conclusion/Future Work

Results indicate that it is possible to approximate the location and extent of impact; however, the rate of degradation of the response monitored is highly subjective to the extent and location of the initial impact and the location of the sensors relative to the supporting structures of the room. The type of material that is exciting the surface also plays a very important role.

One should expect a decay rate of :
- Softer Materials: ~ 0.0108 g/ft - 0.0225 g/ft
- Medium to Harder Materials: ~0.0251 g/ft - 0.0439 g/ ft

Further analysis and testing are required to refine and interpret these results to serve as background for future studies, specifically in the new engineering building currently under construction. Simultaneous data acquisition with more elaborate sensor configurations and noise filtering as well as computational simulations for floor responses could serve as major additions to this study going forward.

Contact Information

Researcher:
Warren Sims
Cell: (423) 582-6483
Email: wcsims42@tntech.edu

Advisor:
Dr. Sally Pardue
Office: (931) 372-3309
Email: spardue@tntech.edu

References

[1] Vinci, A. et al., Tektronix: What is an Oscilloscope? (2021).
[2]OMEGA,. What is an Accelerometer? (2018).
[3] PCB PIEZOTRONICS., Model 086D20 Impact Hammer Installation and Operation Manual (2015).
[4] Nursing Home Law Center LLC., Statistics on Nursing Home Falls Injuries & Death (2022).

Acknowledgements

This research was supported by Tennessee Technological University through involvement with the Honors Program as an enrichment option.

A special thanks to Dr. Sally Pardue for her invaluable guidance throughout the entire process. This research would not have been possible without her.