Shaking it Up

Teacher Supplement

Alana Lund[1], Christopher Roemmele[2], Lisa Roetker[3], Steven Smith[4]

[1] *alund15@purdue.edu, Lyles School of Civil Engineering, Purdue University*

[2] *Department of Earth and Space Sciences, West Chester University*

[3] *Tecumseh Junior High School, Lafayette School Corporation*

[4] *Department of Earth, Atmospheric, and Planetary Sciences, Purdue University*

Table of Contents

Lesson Rubric

	Unacceptable	Needs Work	Satisfactory	Excellent
Contribution	Student refused to participate in the activity.	With some prodding, the student did some calculations to help the team progress through the activity.	Student did calculations and analyses to help the team progress through the activity.	Student did calculations and analyses. Also contributed ideas about how to progress through each puzzle in the activity.
Teamwork	Student did not engage with group members, whether that meant doing the work alone, or not working at all. No respect was shown for the efforts of other class members	Student followed direction from other group members and helped solve puzzles. Often distracted team members from the activity.	Student engaged with other team members to divide the work, brainstorm solutions, plan strategies, and get help. Student showed respect for everyone's efforts.	Student engaged with other team members to divide the work, brainstorm solutions, plan strategies, and get help. Student showed respect for everyone's efforts and encouraged communication in the group.
Grit	Student gave up after some discouragement and refused to participate in the activity.	Student continued to persevere with some encouragement from the teacher and group members.	Student continued to work diligently, despite difficulties and discouragements in the activity.	Student continued to work diligently and encourage team members, despite difficulties and discouragements in the activity.
Reflection	Student completely disregarded the importance and applicability of the activity in the real world.	Student was attentive group discussion and reflection activities. Struggled with defining the relevance to the real world.	Student was attentive group discussion and reflection activities. Some comments were made to help in the discussions, either within the group or with the class.	Student was attentive during group discussion and reflection activities. Student raised serious questions and concerns about applying engineering concepts in the real world.
Refreshing Skills	Student was stumped by minor analyses and reading exercises, even with significant help from other students and instructor.	Student completed minor analyses and reading exercises with some difficulty. Trickier computations, like the Hassan Index, were completed with significant help from the instructor.	Student completed minor analyses and reading exercises, though some parts of the reading exercises may have given them pause. Trickier computations, like the Hassan Index, were completed with more difficulty, but solved with additional examples from the instructor.	Student completed minor analyses and reading exercises without a problem. Trickier computations, like the Hassan Index, were completed with more difficulty, but solved by consulting within the group.

Materials List

General

1. Chalk/Whiteboard markers
2. Whiteboard Slates/Scrap Paper for individual work

Part 1

1. Projector or television
2. BOSS Model for Resonant Vibration in Buildings

Part 2

1. Printer Paper (12-13 sheets per group, 5 additional sheets for partial page handouts)
2. Poster Paper (1-2 sheets, on which to print the city map)
3. Transparencies (1 sheet per group)
4. Calculator (1 per student)
5. Drawing Compass (1 per student)
6. QR Code Scanner (1 per group)
7. UV ink pen (1 for the teacher)
8. UV Flashlights (1 per group)
9. 4-digit compartment lock (1 per group)
10. 4-digit lock (1 per group)
11. Key lock (1 per group)
12. 4-Letter Lock (1 per group)
13. 3-digit lockbox (2 per group)
14. Pencil Pouch (1 per group)
15. Storage Box with three lock points (1 per group)
16. Enigma Encoding Machine (1 per class), bought from (http://www.creativecrafthouse.com/index.php?main_page=product_info&cPath=96&products_id=964) Note: This design can be replicated with cardboard encryption gears.

Part 2 of the lesson can be adapted such that items 7-13 are used in only one set for the class, as opposed to one set per group. In this case, these items are stored in a central location and materials for all the groups are stored in each box. When a group has a code they want to try, they come to that location and try it on the lockboxes. When they open a box, the teacher helps them take only one set of materials to progress in the puzzle.

Vocabulary List*

<u>Seismology</u>

Aftershock

An earthquake or series of earthquakes which follow a larger event. The aftershocks are correlated with the main earthquake by their similar origin locations and time of occurrence.

Earthquake

A series of vibrations in the earth generated by the sudden release of stress along a fault.

Fault Line

A fracture or discontinuity in the earth's crust. Large faults often result from tectonic motion, which is one of the primary causes of earthquakes.

Foreshock

An earthquake or series of earthquakes which precede a larger event. The foreshocks are correlated with the main earthquake by their similar origin locations and time of occurrence.

Mercalli Intensity Scale

A measure of the responses by people, furniture, buildings and other structures, and observed ground behavior to an earthquake. The level of intensity, designated by Roman numerals I (barely perceptible) to XII (total devastation), is qualitatively assigned based on these reactions and effects.

P wave

A seismic wave that travels through the interior of the Earth, stretching and compressing the ground in the direction that the wave is moving. The P wave, also known as the primary wave, is the fastest moving seismic wave and arrives first at a seismograph recording station.

Richter Scale

A measure by which the intensity of an earthquake is quantified. This measurement system ranks the intensity of earthquakes logarithmically based on the amplitude of the seismic waves.

Seismologist

A scientist who studies earthquakes.

S wave

A shearing seismic wave that travels through the interior of the Earth, shaking the ground perpendicular (up and down) to the direction of travel. S waves, also known as secondary waves, travel more slowly than P waves and arrive second at a seismograph recording station. S waves do not travel through liquids.

Civil Engineering

Stiffness

A measure of how much force it takes to deform a material. This property is measured in units of [force/displacement].

Structural Building Plans

These documents explain the layout and construction plan for a building. Details such as the geometric properties of the building and its members are included in the plans, as well as material properties for the individual components.

Damage Prediction

Hassan Index (Hassan and Sozen, 1997)

A stiffness-based ranking for buildings showing their likelihood to be damaged in an earthquake. Rankings are determined by comparing the normalized thickness of the walls (wall index) and columns (column index) of each building. The most flexible buildings, or those with the smallest wall and column indices are ranked the most likely to be damaged. The Hassan Index is typically shown using a graph of the stiffness indices.

Column Index

The normalized column thickness of the building, used to indicate stiffness.

$$\frac{Total\ Column\ Area}{2 * Floor\ Area} * 100$$

Wall Index

The normalized wall thickness of the building, used to indicate stiffness. The areas of the north-south and east-west walls are computed separately and the direction with the least wall area is used for the final computation.

$$\frac{min(Total\ Wall\ Area\ E \rightarrow W, Total\ Wall\ Area\ N \rightarrow S)}{Floor\ Area} * 100$$

Structural Response Analysis

Frequency

Frequency is the inverse of period. The frequency measures how many cycles an object can oscillate through in one second.

Frequency Response Graph

This graph shows how the response of the building changes with increasing vibration frequency. The peak in the graph indicates the natural frequency of the building.

Natural Frequency

Each object has a natural frequency. This is the frequency that it will vibrate at when it is not constrained to act in a certain way by an outside force. When forced to vibrate at this frequency, the building will resonate. The natural frequency in Hz is calculated by $\left(\sqrt{Stiffness/Mass}\right)/2\pi$.

Peak Amplitude

The largest measurement observed in an oscillating signal.

Period

A measure used to observe vibration. The period is a record of how many seconds it takes for the vibrating object to leave a position, traverse a regular route, and return to its start.

Relative Displacement

The displacement at the roof of a building divided by the height of the building. This measurement normalizes the displacement of the structure relative to its height, allowing comparison of displacement between buildings of different heights.

Resonance

A phenomenon in which an oscillating force applied to an object at or near its natural frequency will cause stronger vibrations in the object than a force applied at other frequencies.

* Vocabulary terms listed in bold are included in the crossword puzzle in Part 2

Lesson Preparation - Part 1

Video Demonstrations

1. **Natural Frequency Demonstration -** This video shows an experiment in which 3 model buildings of varying height are subjected to vibrations of increasing frequency on a shake table. As each of the structures hits resonance, its natural frequency is displayed on the screen. (https://www.youtube.com/watch?v=iyw4AcZuj5k)
2. **Tacoma Narrows Bridge Collapse –** This video shows a record of the collapse of the Tacoma Narrows Bridge. The bridge failed due to excessive displacement caused by resonance with the wind. (https://www.youtube.com/watch?v=nFzu6CNtqec)

Discussion Questions

1. Why did all of the buildings vibrate at different frequencies?

2. What other aspects of a building, beside height, affect the frequency at which it vibrates?

3. Earthquakes tend to vibrate the most at frequencies less than 10 Hz. Based on the list of building characteristics identified in the previous question, what type of building will likely be the most damaged by an earthquake?

BOSS Model

The BOSS Model instructions are attributed to the Federal Emergency Management Administration (FEMA) and American Geophysical Union (AGU), Seismic Sleuths, Earthquakes: A Teacher's Package on Earthquakes for Grades 7-12. Washington, DC, 375pp, 1994.

The model instructions can be found on the Incorporated Research Institutions for Seismology website, https://www.iris.edu/hq/inclass/downloads/optional/747.

Lesson Preparation – Part 2

The Breakout activity contains the bulk of the material that the students will learn from the lesson. The puzzle is broken down into sections based on the steps necessary to obtain different QR Code sections, as shown in Figure 1. In each section, the students will focus on a different type of analysis task. Completing all of the analysis tasks will allow them to collect all 4 pieces of the QR Code, which reveals which structure needs a rescue team sent to it and ends the activity. The primary tasks in each section are shown in Figure 1, with the arrows describing the flow of information throughout the activity. The materials and analysis necessary to complete the activity are described in greater detail below.

In running through this activity, we've found it useful to set some ground rules for the students.

1. Each team is allowed 2 hints, which they can use at any point during the activity.
2. Only enter a combination into a lock when you have a logical guess.
3. Once a lock has been opened, it is immediately given to the teacher.
4. Don't share information about how to open the locks with your friends in another class period! It cheats everyone of a good experience.

<u>Initial Materials</u>

To start their investigation, the students are given a portfolio with various clues and prompts for the activity. The portfolio includes:

1. A newspaper article (The intro prompt)
2. A crossword puzzle
3. The Disaster Management Agency (DMA) Structural Plans
4. Structural Plan Request Form
5. A transparency with 6 frequency response graphs, which show the pre-earthquake frequency response of the buildings.

Items 1-4 are used in the first section of the game, shown in blue in Figure 1. Item 5 is used later in the game, in the orange section.

In addition to this portfolio, the map of the city is provided. This map is intended to be printed on poster paper and displayed at a central location in the classroom for all the students to reference. The students should also be given access to scrap paper or small white boards for scratch work, a drawing compass, and a calculator.

<u>Blue Section</u>

In this first section of the activity, the students identify the building where earthquake damage would have the most severe effects based on how the building is used. Form 22C should make it clear that their first tasks are to solve the crossword puzzle and calculate the Hassan Index of the DMA building. The form walks them through the calculation steps, acting as a guide for later

portions of the activity. Once those tasks have been completed, the students submit their paperwork to the teacher for a "bureaucratic check." If their answers are correct, the teacher gives the students the rest of the building plans and a UV flashlight.

The UV flashlight will reveal (1) The word "Perimeter" on Form 22C is underlined (2) The word "Hospital" on the building plan for the hospital is circled and the words "Round to Whole" are written (3) The city map has frequency response lines in the squares representing buildings, corresponding to the post-earthquake response of the buildings. The students should use the first two notes to determine that the 3-digit code for the first lockbox is the perimeter of the hospital. The third item is not relevant until the orange section.

In the lockbox, the students will find a key, the Hassan Index graph, and the first quarter of the QR code. The key can be used immediately to open one of the three locks securing the final lockbox. The Hassan Index graph is used in the green section. The QR code segment has the phrases "60-70-50" and "4 MOST DAMAGED" written on it in UV ink. The numbers represent the gearing combination for the decoder machine used in the yellow section. The words are used by the students in the green section.

Green Section

The puzzle for this section guides the students to link two different directions of thought. The students must correlate each building to a point on the Hassan Index graph **and** to a single letter code, as shown on the city map.

From the Hassan Index graph and the hint of "4 MOST DAMAGED" that they received in the blue section, the students should interpret that they need to find the 4 buildings that are most likely to experience damage based on the Hassan Index graph. To do this, they need to calculate the wall and column indices for each building and correlate them to points on the graph. Then they must determine the ranking of those buildings by using the drawing compass to find which points are closest to the origin.

In order to correlate the buildings with their single letter code, the students should observe the holes cut into the building plans. When they match their building plans against the completed crossword puzzle, a letter will appear in the holes which represents the building code.

When these two pieces of information are combined, the students will generate a 4-letter code to unlock the word lock on the pencil pouch. Inside the compartment, the students will find a phrase written in code, a website URL, and the second quarter of the QR code. The coded phrase will be used in the yellow section and the website URL will be used in both the yellow and orange sections. If it is not possible to have the school design a small web page where the students can download documents, the items on the website can also be put in the pencil pouch in paper format.

Yellow Section

In this section of the activity, the students work to interpret displacement graphs which have been recorded from the response of each building during the earthquake in order to decide which

building was damaged the most. To accomplish this, they must first decode the secret message. By combining the information about the gear order from the blue section, “60-70-50”, and the key word “DMA”, the students will be able to set the decoder machine and read the message. This message will tell them the combination for the 2nd 3-digit lock box and instruct them to find the two most damaged buildings. When they use the combination to open the 2nd 3-digit lockbox, they will find the graphs showing the relative roof displacement of each building during the earthquake.

Using the hint that they should find the two most damaged buildings and the engineering information provided at the URL from the green section, the students will determine the peak amplitude of each graph and select the two maximum displacements. When placed in order from maximum to minimum, those two displacements form the combination for one of the 4-digit locks on the final lockbox. When this lock is opened, there should only be one lock left on the box.

Orange Section

In this section, the students analyze the frequency response of each building with respect to the earthquake. In the blue section, they were provided with a transparency of frequency graphs that showed the natural frequency of each building before the earthquake. Using the UV light, which they also obtained in the blue section, they can view the frequency response of each building after the earthquake. The engineering information provided in the URL in the green section gives the students the information they need to interpret the changes between those two graphs. When they hold up the transparencies to the map and compare the pre- and post-earthquake frequency graphs, they will again be able to determine the two most damaged buildings. The combination to the final 4-digit lock on the final lockbox is then the peak amplitude on the post-earthquake graphs for each of those damaged buildings, in order from most to least damage. Opening that lock will allow the students to open the final lockbox and reveal the last two QR code segments.

Activity Conclusion

When the students have all 4 QR code segments, they will be able to assemble and scan the code. When they have done so, the building to send their rescue teams to will be revealed!

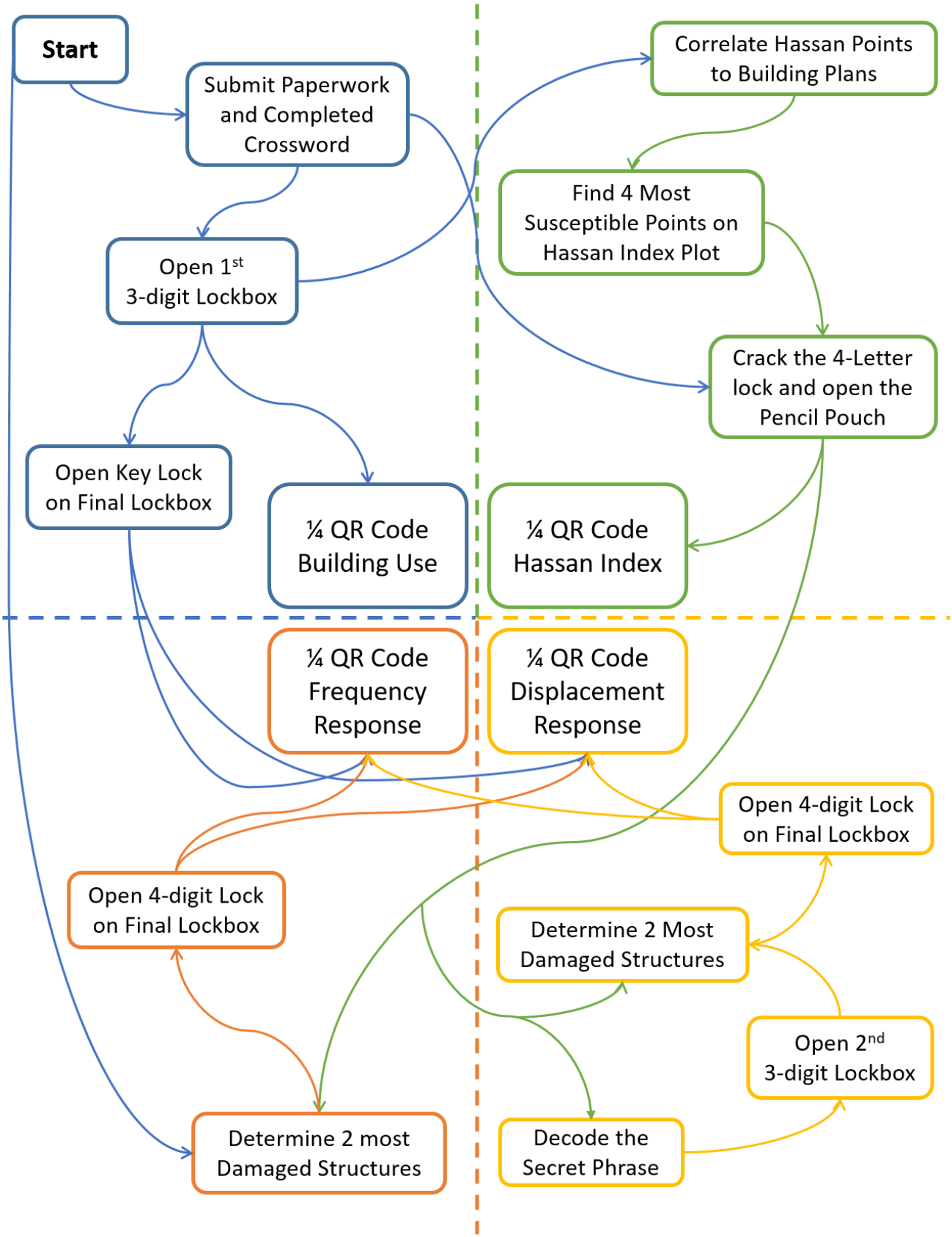


Figure 1. Flow Diagram for Breakout Activity

Material Preparation

In general, we found it useful to laminate as many pages as possible to preserve them for future use.

QR Code (pg. 19)
The QR Code sheet should be split into quarters so that each section contains a picture with its corresponding description and a portion of the QR Code. On the segment labeled "Building Use: Hospital" the teacher should write "60-70-50" and "4 MOST DAMAGED" in invisible ink. The first item corresponds to a gear order for the decoder used in the yellow section. The second item refers to the Hassan Index graph used in the green section.

Ponderosa Valley City Map (pg. 20)
The city map should be printed on poster size paper. Each of the building locations is marked by an empty square. In these squares, the post-earthquake frequency response (pg. 41) should be drawn in invisible ink. In our class, we accomplished this by printing the post-earthquake frequency responses, using an Exacto knife cut out the line describing the response, and tracing that line onto the map with invisible ink. Be sure to scale the paper and the frequency graphs so that each graph will fit in each square.

Each of the buildings on the map is represented by a letter. The building that corresponds to each letter is listed below:

- Y = Disaster Management Agency
- R = Middle School
- A = Police Station
- T = Hospital
- D = Church
- M = Library

By ordering these letters from most damage to least damage based on the Hassan Index graph, the students will be able to open the 4-letter lock. The letters for the buildings are based on the available lock combinations in a Master Lock 4691DWD. The letters chosen for the combination are common, however, and should work with most 4-letter locks.

Structural Plan Request Form (pg. 25)
The word "Perimeter" should be underlined in invisible ink.

Building Plans (pg. 27)
Each page of building plans contains 3 black squares. Each square must be cut out so that the students can see through the paper at these points. We accomplished this with an Exacto knife. When the building plan sheets are aligned with the crossword puzzle page, exactly one letter will appear in the holes. This is true even if the building plans are turned upside-down. Both pages must be face up when they are aligned, however.

On the plans for the hospital, the word “Hospital” should be circled in invisible ink. The words “Round to Whole” should also be written in invisible ink somewhere on this page, to indicate to the students that they should round their solution for the perimeter to a whole number.

Hassan Index (pg.33)

The column index and wall index for each building are included in the following table. Note that the wall index does not include area from the columns and windows that intersect the wall.

Table 1. Hassan Index Answer Key

Building	Wall Index	Dominant Direction	Column Index
DMA	0.201	E – W	0.075
Middle School	0.252	N – S	0.111
Police Station	0.394	Same	0.136
Hospital	0.306	N – S	0.367
Church	0.270	E – W	0.169
Library	0.119	N – S	0.088

Coded Message (pg. 34)

The coded message noted in this section must be translated in code prior to incorporating it into the clues for the students. To do this, a specific encryption method must be chosen. In our class, we used a replica enigma encryption machine, with a 60-70-50 gear order and a key word of DMA. If the encryption method changes, different clues will need to be distributed to help the students figure out the encryption key.

Frequency Response Graphs (pg. 40)

The pre-earthquake frequency response graphs should be printed on transparencies and included in the initial materials. The post-earthquake frequency response graphs should be transferred to the city map in their respective buildings using invisible ink.

Lock and Box Preparation

<u>Blue Section</u>
Packet from Teacher:
- Building Plans
- UV Flashlight

3-digit lockbox: Combination = 761 (*This combination comes from the perimeter of the Hospital*.)
- Key
- Hassan Index Graph
- ¼ QR Code Segment

Key Lock on Final Lockbox: Opened by Key
- Nothing revealed at this time

<u>Green Section</u>
4-letter lock on pencil pouch: Combination = MYRD (*This combination comes from the order of likely to be damaged buildings in the Hassan Index graph*)
- Coded Phrase
- Website URL (links to PDFs of second phase prompt and Engineer's Guide to Damage Detection)
- ¼ QR Code Segment

<u>Yellow Section</u>
3-digit lockbox: Combination = 582 (*This combination comes from the decoding of the secret phrase. As it is not connected to any data, this number can be changed if necessary.*)
- Relative Displacement Graphs

4-digit lock on Final Lockbox: Combination = 1411 (*This combination comes from the peak values of relative displacement for the building M (1.4) and D (1.1), respectively*)
- Nothing Revealed at this time

<u>Orange Section</u>
4-digit lock on Final Lockbox: Combination = 1075 (*This combination comes from the frequency graphs of the post-earthquake peak values for the two most damaged buildings, D (10) and M (7.5)*).
- 2x ¼ QR Code Segments

QR Code Segments

HASSAN INDEX

LIBRARY

Library Figure Accessed From:
http://www.businessinsider.com/most-beautiful-library-every-us-state-2017-1

FREQUENCY GRAPH

CHURCH

Church Figure Accessed From:
https://en.wikipedia.org/wiki/Church_of_the_Immaculate_Conception,_Farm_Street

BUILDING USE

HOSPITAL

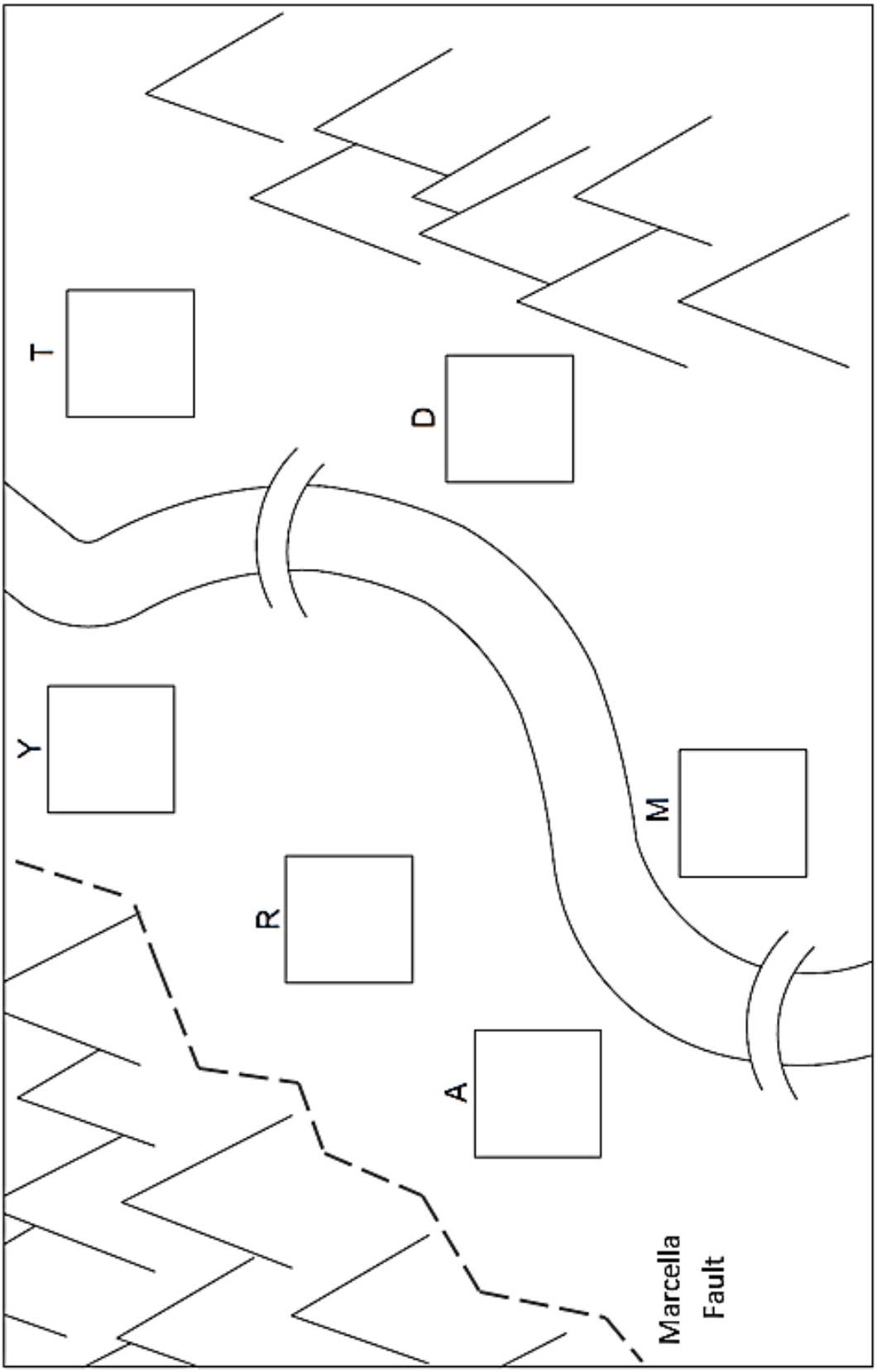
Hospital Figure Accessed From:
https://www.nytimes.com/2017/02/22/well/live/bad-hospital-design-is-making-us-sicker.html

DISPLACEMENT GRAPH

LIBRARY

Library Figure Accessed From:
http://www.businessinsider.com/most-beautiful-library-every-us-state-2017-1

Ponderosa Valley City Map



Introductory Prompt

Breaking News: Imminent Disaster in Ponderosa Valley

(Emma Lanely: Ace Reporter)

The local branch of the United States Geological Survey (USGS) has been analyzing a series of small Richter magnitude earthquakes plaguing the region. They have tracked the origin of these quakes to the Marcella Fault, a fault line that runs along the mountain side at the edge of Ponderosa Valley. Seismologists anticipate that these earthquakes could be foreshocks of a larger event. Sudden and severe vibrations could ripple through the city at any moment.

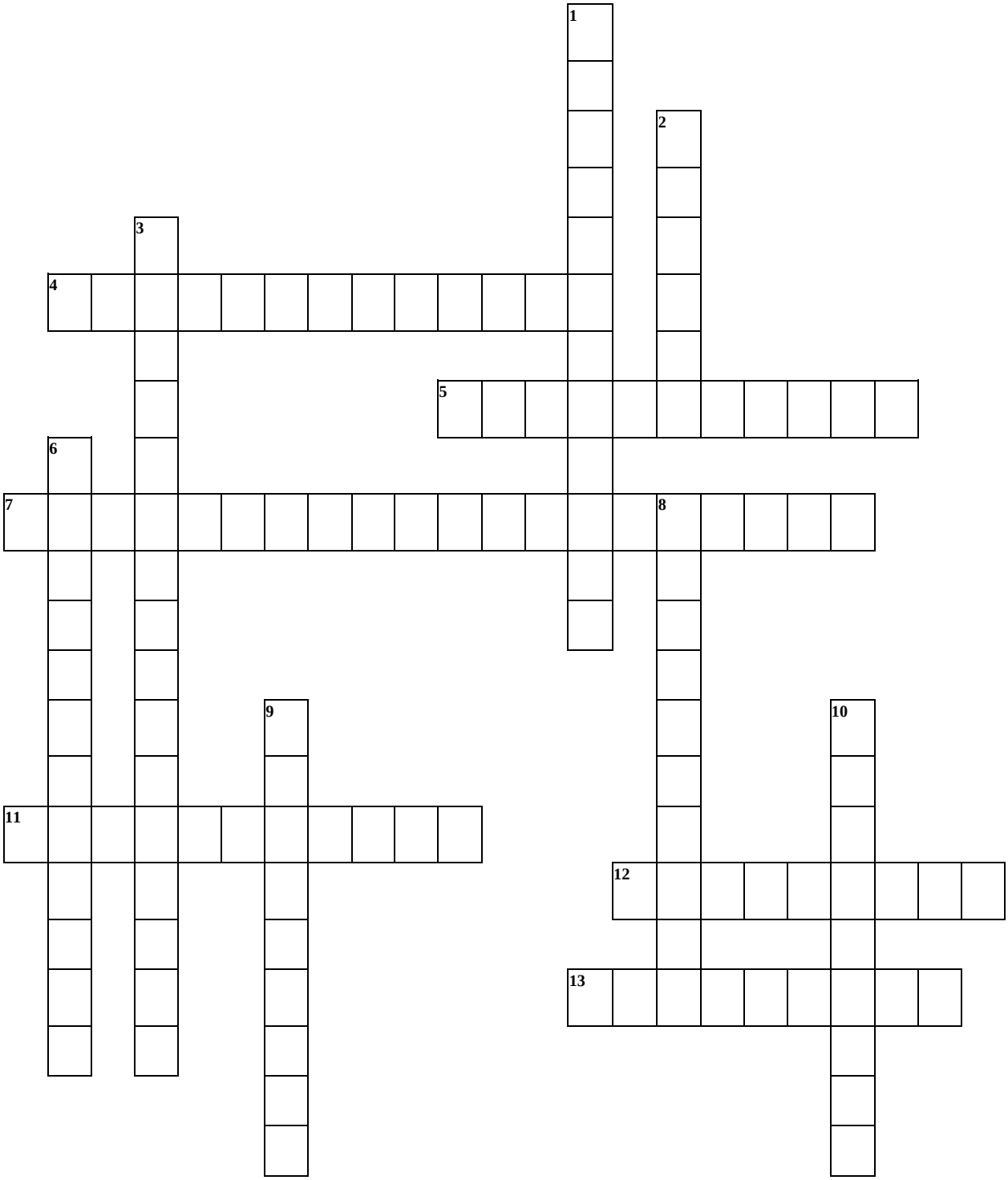
The Ponderosa Valley Disaster Management Agency (DMA) is concerned for the safety of the community and is working to halt the disastrous effects that this emergency could have on its citizens. Efforts are underway to conduct a survey of the buildings within the city using the Hassan Index. This index gives a priority ranking of the buildings in a community, in order of most risk to least risk. It is determined from two geometric properties of a structure, the column index and wall index. These measurements account for the ratio of column area to floor area and the ratio of wall area to floor area, respectively. When plotted, each point of the Hassan Index represents a building with its location on the graph indicating its potential level of damage in an earthquake. However, even this precaution can only give us an idea of which buildings will be damaged. The actual results may be very different, so take care!

Engineers are especially concerned about how building columns will respond to the earthquake. These elements are particularly important as they support the walls and ceiling of the building and need to have enough stiffness, or rigidity, to withstand an earthquake. When the earthquake strikes, the ground motion will cause the buildings to vibrate with high frequency. Each building has a way it likes to vibrate, its natural frequency, and if the earthquake shakes it in that way the building may resonate and experience excessively large displacements compared to its height. If the earthquake occurs, engineers will be on the lookout for those peak amplitudes in the relative displacement data to examine where damage is the most severe in town.

With all of this information, the engineers will be able to guess which building will be the most damaged and hopefully evacuate its occupants in time. They are expecting to report their results within the hour.

Crossword Puzzle

Let's Shake it Up!



Across

4. The maximum value that an oscillating function reaches when graphed.

5. The point described by (CI, WI). If the point is closer to the origin the building it describes is more likely to be damaged in an earthquake.

7. A measurement of how much the building has moved at the roof level divided by the height of the building. Used to compare the responses of multiple buildings.

11.

$$\frac{\text{Total Column Area}}{2 * \text{Floor Area}} * 100$$

12. A segment of earth that accumulates stress prior to an earthquake.

13. A unit describing how many times an object can vibrate back and forth in one second.

Down

1. A common measure of the magnitude of an earthquake.

2. A structural element of a building designed to support the walls and ceiling.

3. The rate at which an object tends to vibrate, due to its geometric properties.

6. A scientist that studies the motion of the earth.

8. A sudden ground motion along a fault. Causing vibrations that can be felt at great distances from the origin.

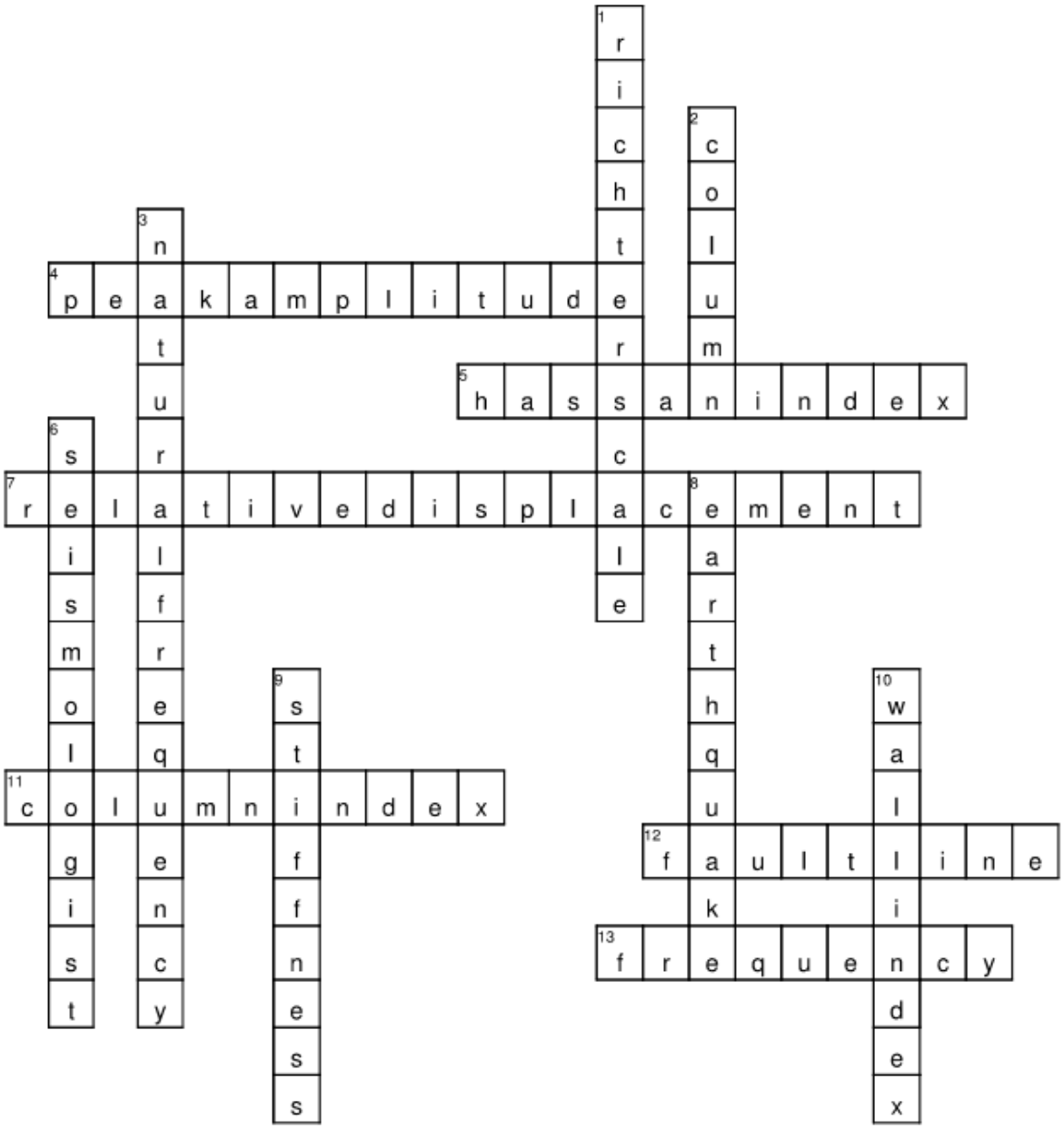
9. A measure of how rigid an object is. Influenced by the height and the thickness of that object.

10.

$$\frac{\min(\text{Total Wall Area E} \rightarrow \text{W}, \text{Total Wall Area N} \rightarrow \text{S})}{\text{Floor Area}} * 100$$

Crossword Puzzle Answer Key

Let's Shake it Up!



Structural Plan Request Form

PONDEROSA VALLEY DISASTER MANAGEMENT AGENCY

FORM 22C
REQUEST FOR STRUCTURAL PLANS

<u>To obtain building plans, please submit the following documents:</u>

1) Completed Cross Word Puzzle

2) DMA Perimeter =

3) Floor Area =

4) Wall Area (East to West) =

5) Wall Area (North to South) =

6) Wall Index =

7) Single Column Area =

8) Total Column Area =

9) Column Index =

Round to two decimal places.

FOR OFFICE USE ONLY
SUBMIT TO RECORDS CLERK FOR APPROVAL

Structural Plan Request Form Answer Key

PONDEROSA VALLEY DISASTER MANAGEMENT AGENCY

FORM 22C
REQUEST FOR STRUCTURAL PLANS

To obtain building plans, please submit the following documents:

Round to two decimal places.

1) Completed Cross Word Puzzle

2) DMA Perimeter = 700 ft.

3) Floor Area = 30,000 ft^2

4) Wall Area (East to West) = 60.42 ft^2

5) Wall Area (North to South) = 140 ft^2

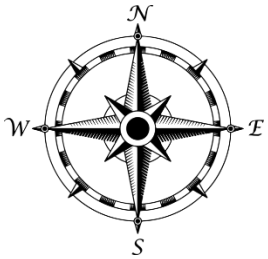
6) Wall Index = 0.20

7) Single Column Area = 2.25 ft^2

8) Total Column Area = 45 ft^2

9) Column Index = 0.08

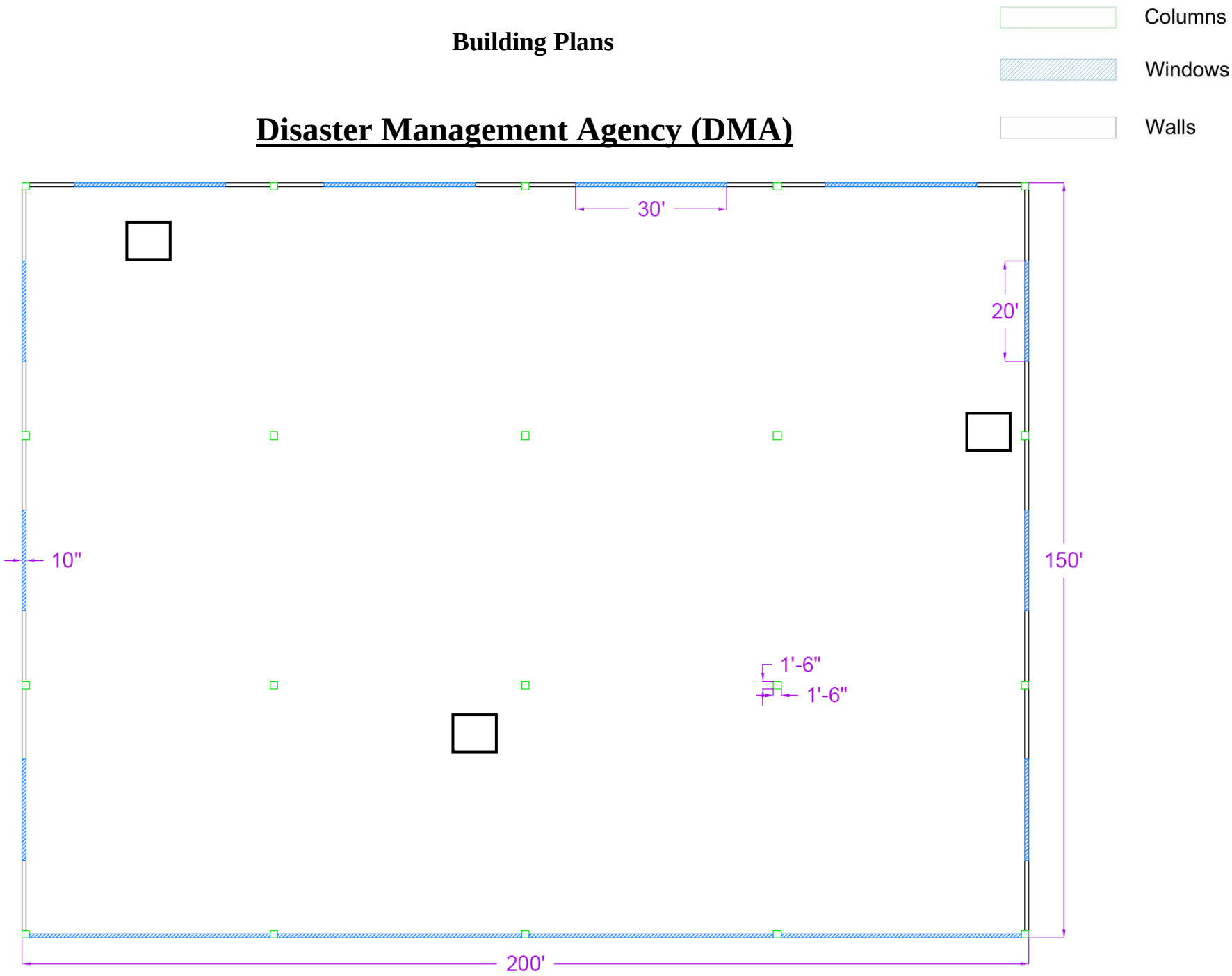
FOR OFFICE USE ONLY
SUBMIT TO RECORDS CLERK FOR APPROVAL

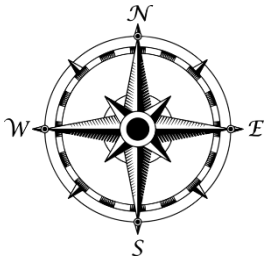


Compass Figure Accessed From: http://www.bauervswild.com/2014/11/stick-sun-shadow-compass.html

Building Plans

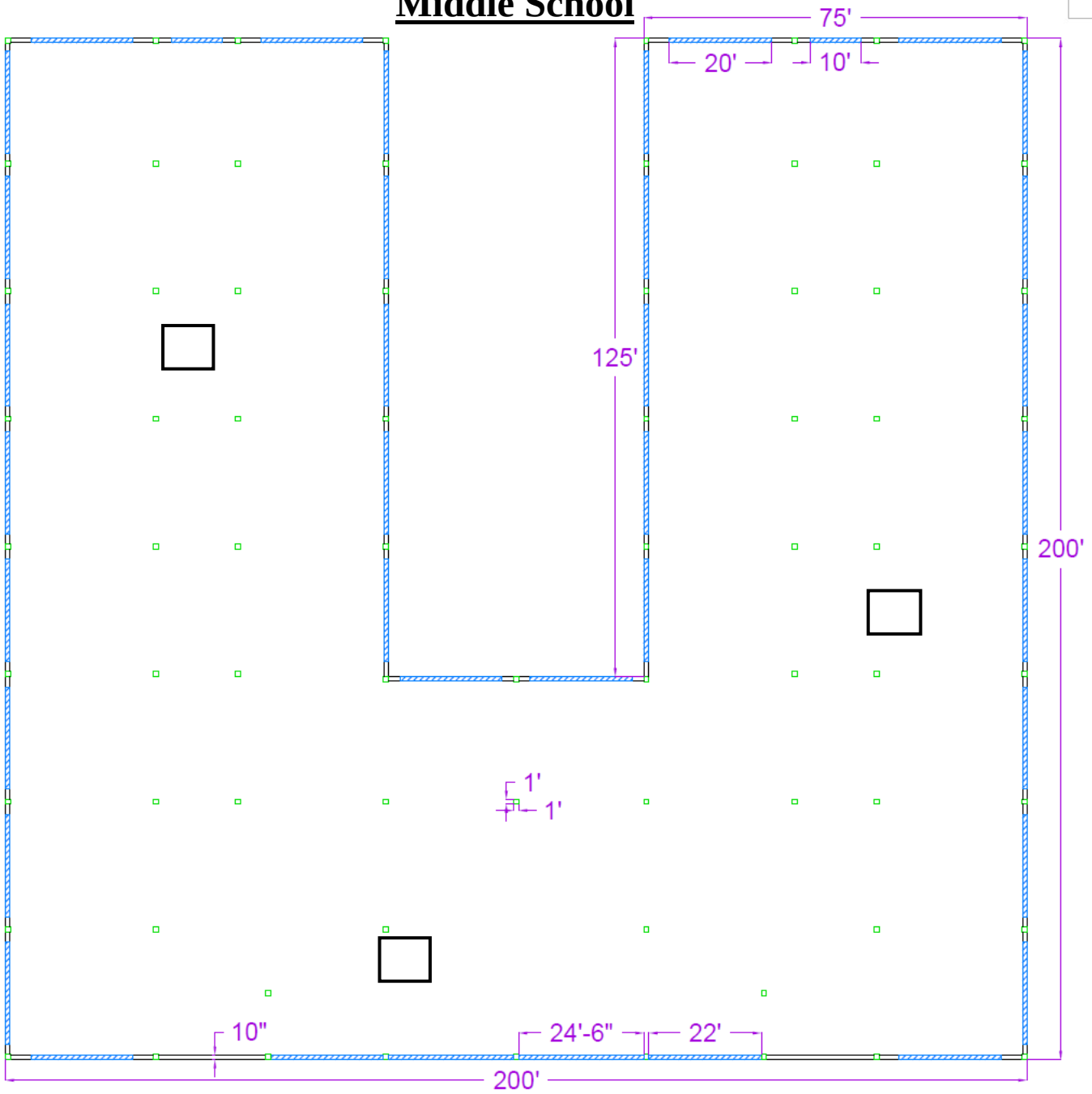
Disaster Management Agency (DMA)





Compass Figure Accessed From: http://www.bauervswild.com/2014/11/stick-sun-shadow-compass.html

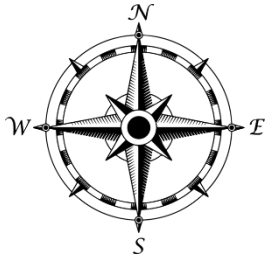
Middle School



Columns

Windows

Walls



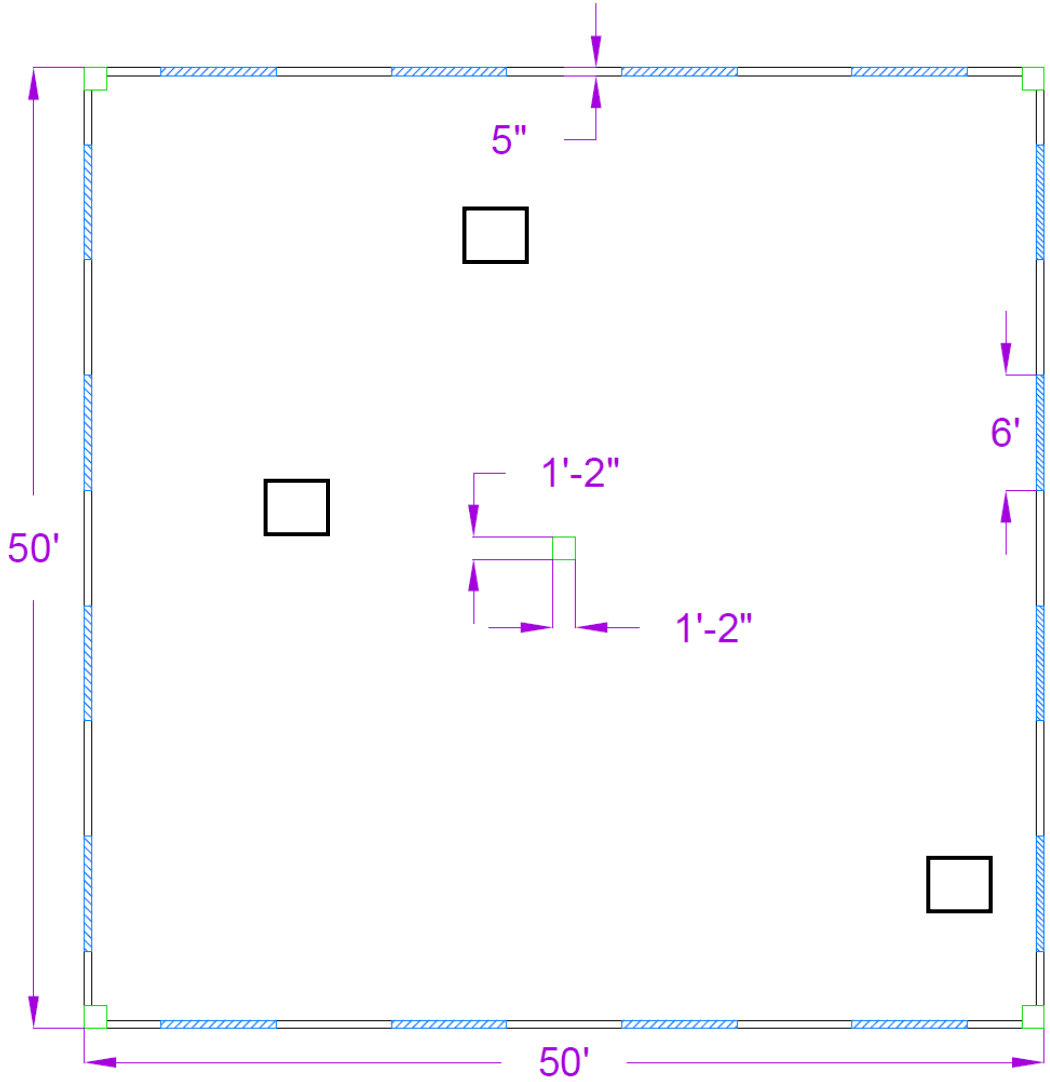
Compass Figure Accessed From: http://www.bauervswild.com/2014/11/stick-sun-shadow-compass.html

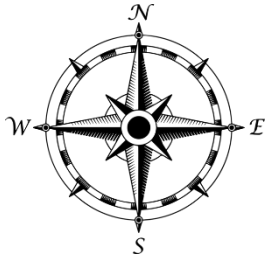
Columns

Windows

Walls

Police Station





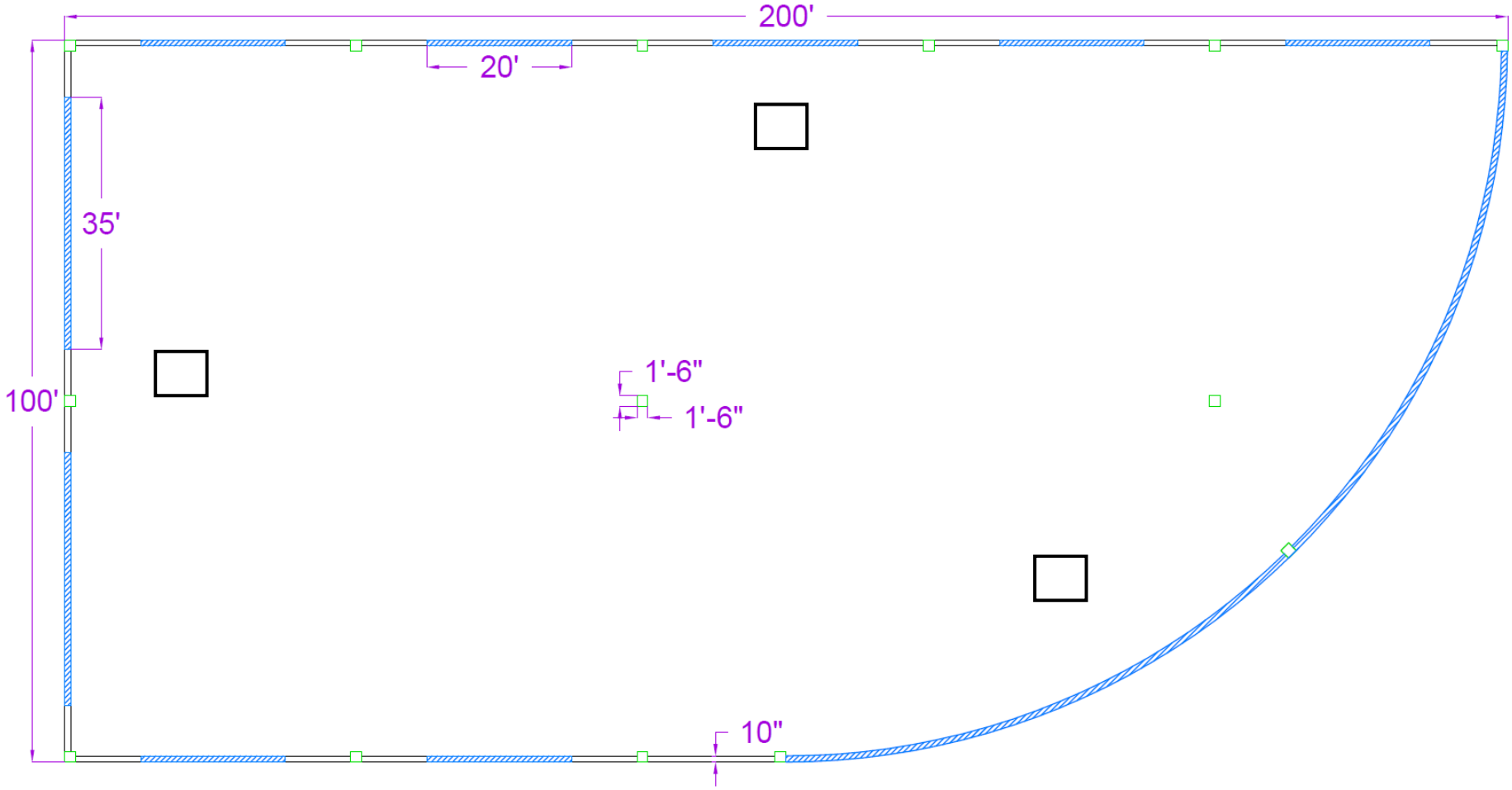
Compass Figure
Accessed From:
http://www.bauervswild.com/2014/11/stick-sun-shadow-compass.html

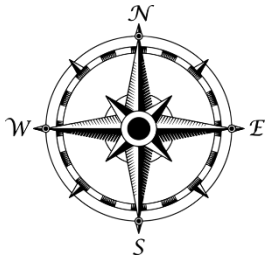
Library

Columns

Windows

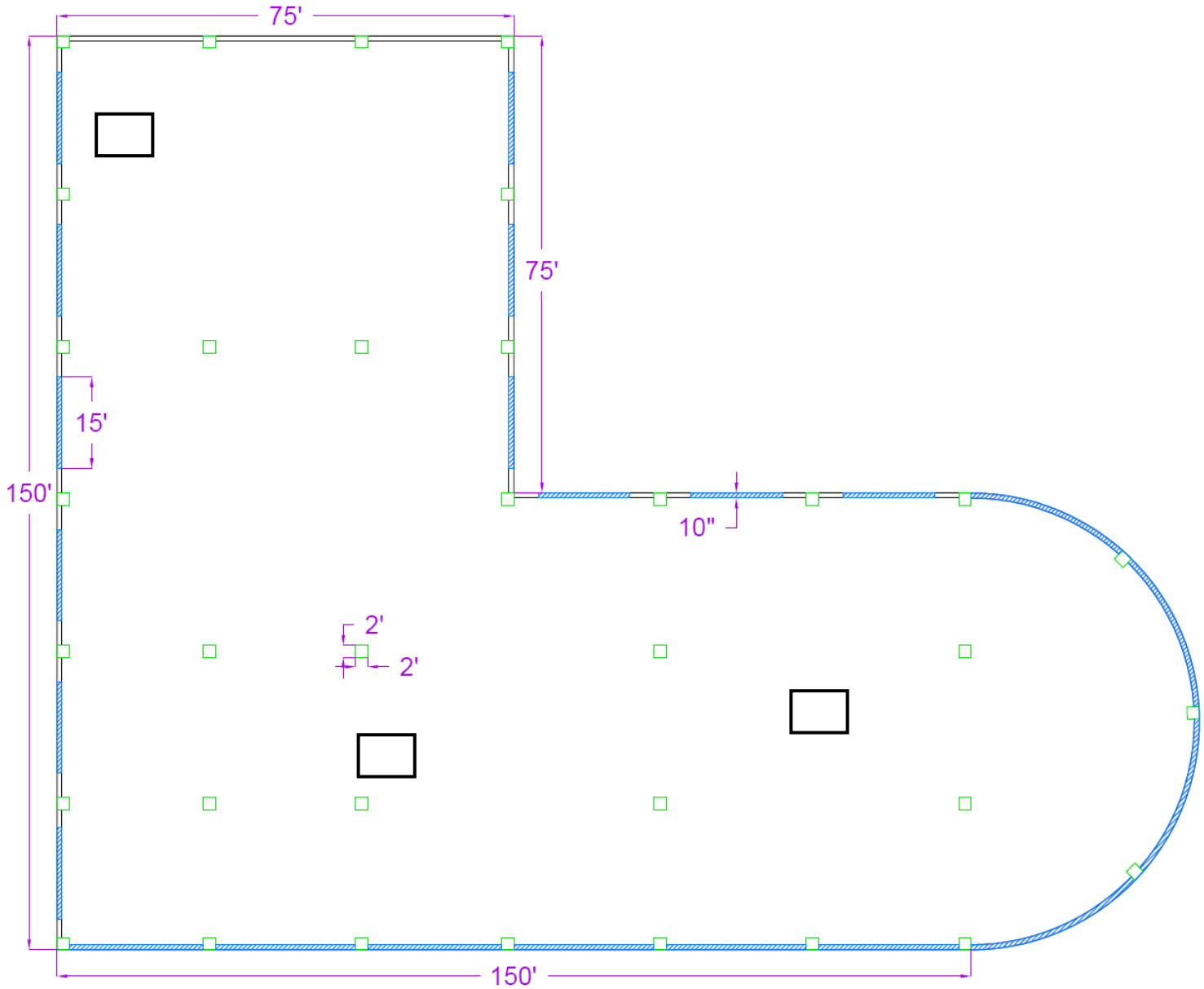
Walls





Compass Figure Accessed From: http://www.bauervswild.com/2014/11/stick-sun-shadow-compass.html

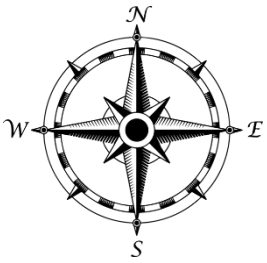
Hospital



Columns

Windows

Walls



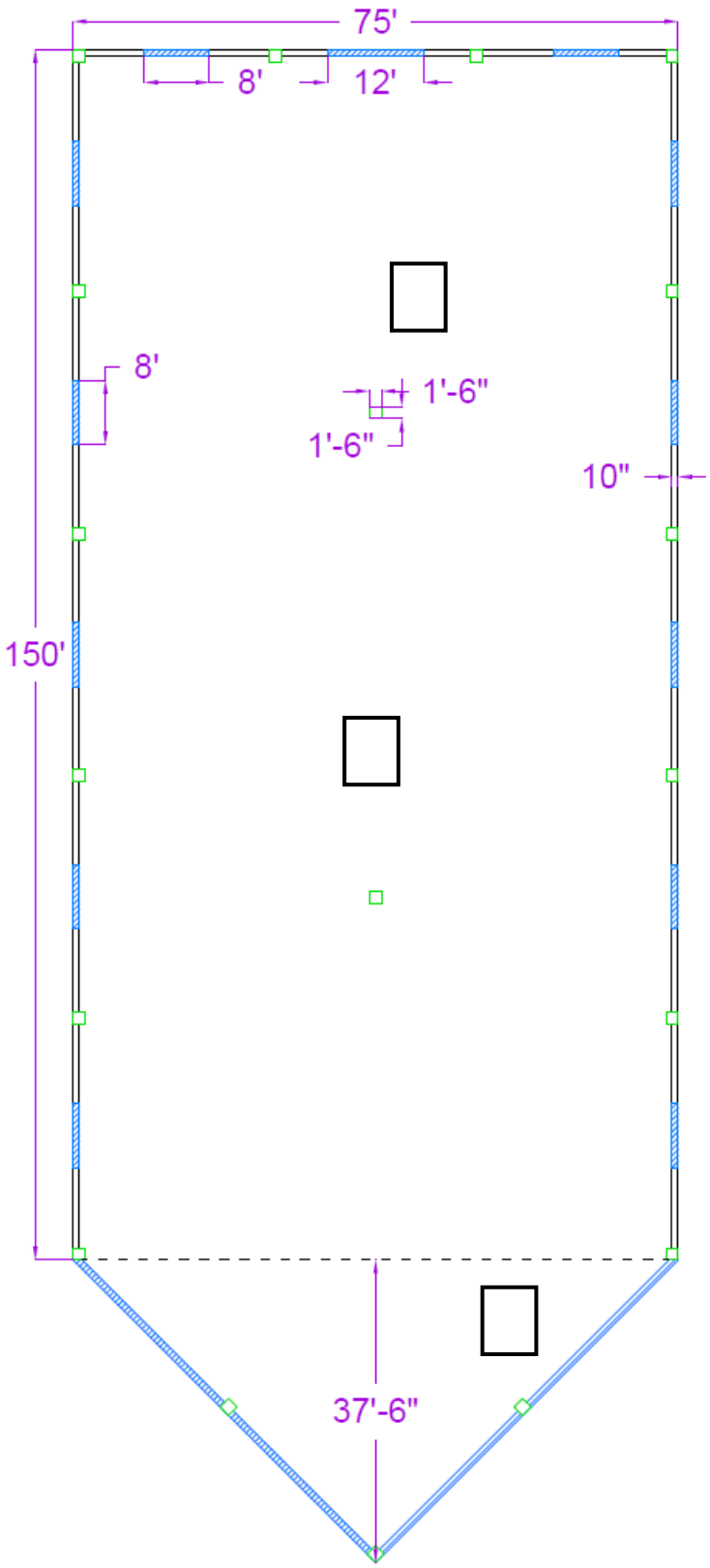
Compass Figure Accessed From: http://www.bauervswild.com/2014/11/stick-sun-shadow-compass.html

Columns

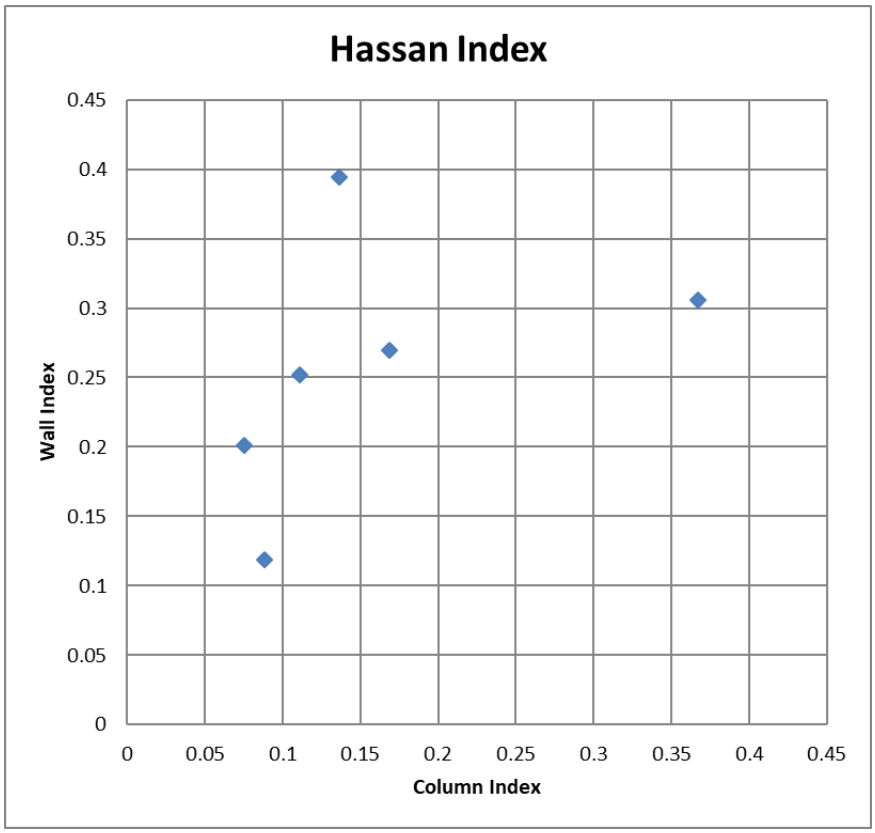
Windows

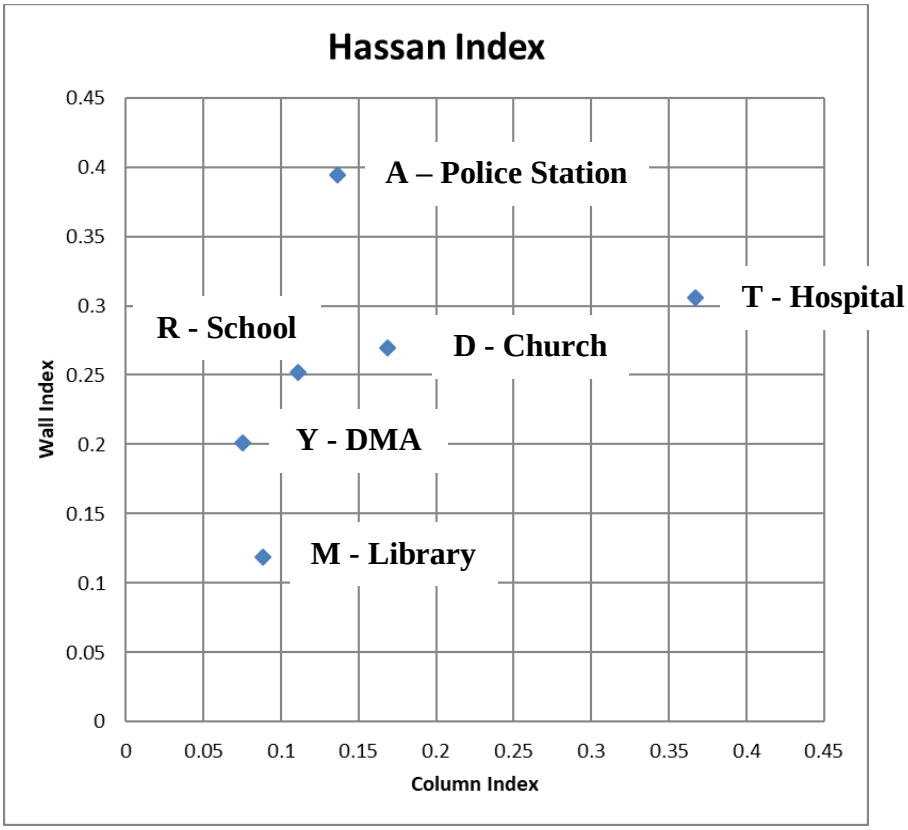
Walls

Church



Hassan Index Graph and Answer Key





Phase 2 Prompt

Telephone Transcript
(708) 437-8053 to Ponderosa Valley DMA
7:18 PM

Caller: Hello? Hello?! Is anybody there? Please! We need help!

DMA: I'm here! Who are you? What's wrong?

Caller: The earthquake! The building wouldn't stop shaking and I can't find a way out and we're trapped! Please, please help!

DMA: Where are you?! We'll find you! We'll get you out!

Caller: At the *phone line cuts out*

Coded Message

In our class, we coded this message using a replica enigma encryption machine. However, any encryption technique can be worked into the puzzle instead. Note that the two hints required to decrypt the message are the gear order "60-70-50", which was written on the first ¼ QR code segment, and the key word "DMA" which is repeated throughout the game. The coded phrase is given to the students.

FIVE EIGHT TWO
TWO MOST DAMAGED
POST QUAKE PEAK

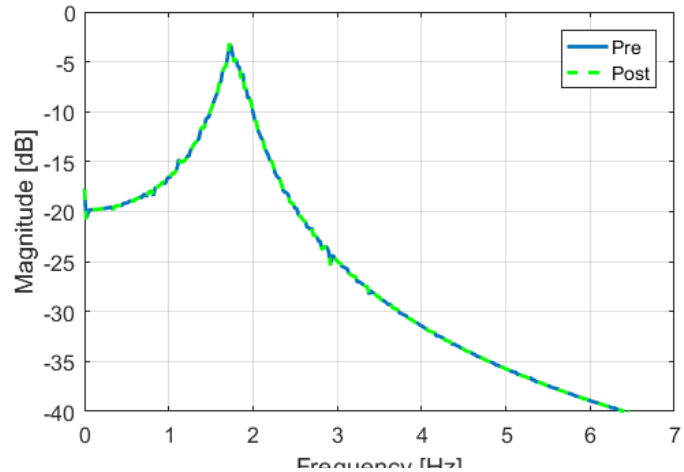
The first line is the combination for one of the 3-digit lockboxes, which holds the relative displacement graphs. The second line indicates to the students that in this part of the game they need to focus on the two most damaged structures. The third line gives instruction for interpreting the clue in the frequency graphs, that the students should find the magnitude values of the post-earthquake peaks.

The Engineer's Guide to:
Earthquake Damage Analysis

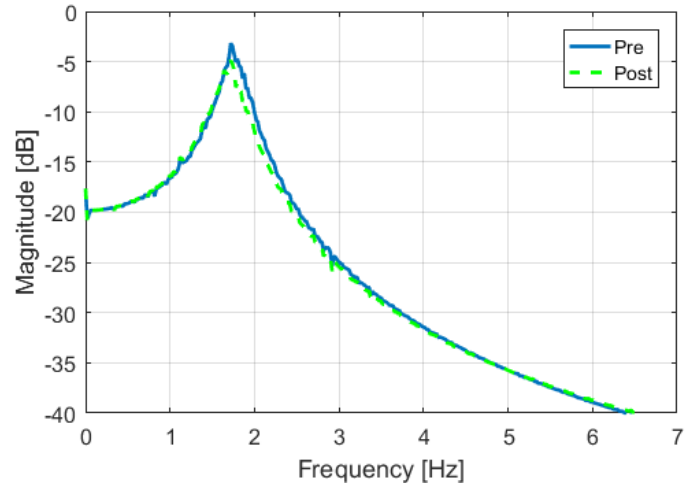
1) Frequency Response Graphs

The frequency response graph shows how the structure normally likes to behave. If the graph is different from before the earthquake to after the earthquake, this is an indication that the building has been damaged. When the building is damaged, the peak value on the graph will move down and to the left. Movement left is a more critical damage indicator than movement down.

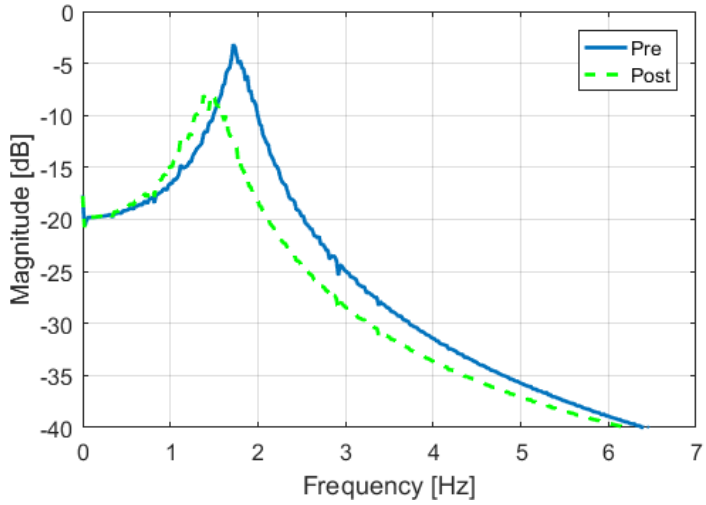
No Damage



Slight Damage



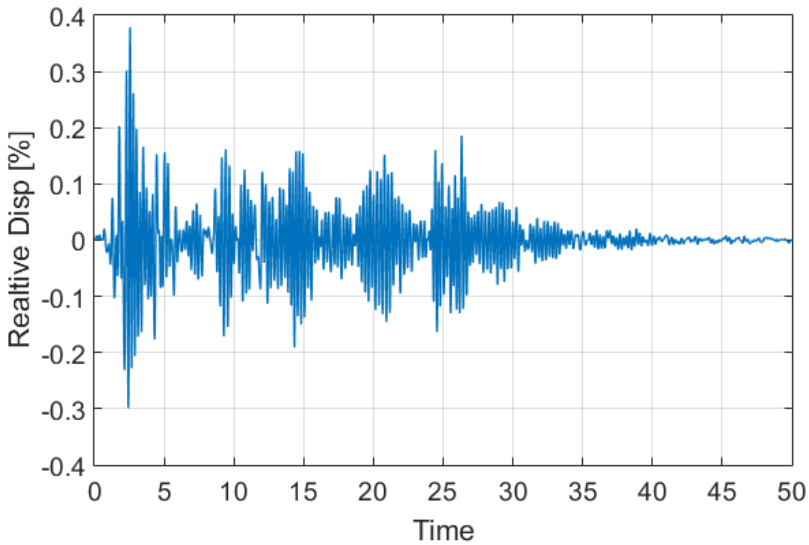
Severe Damage



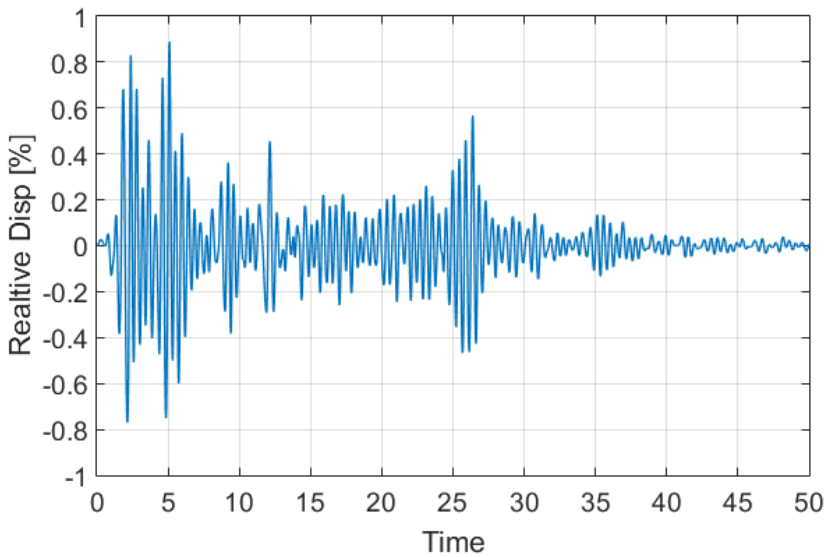
2) Relative Displacement Response Graphs

The relative displacement response graph shows how much the structure moves during the course of the earthquake relative to its height. Taller buildings are better able to accept large displacements, because they can spread the effects of the displacements all along their height. Because of this, we divide displacement by height to compare between buildings. The peak value that the graph reaches, whether it's a positive peak or a negative peak, indicates the level of damage there is the building. If the peak is higher, then there is likely to be more damage.

Lesser Damage

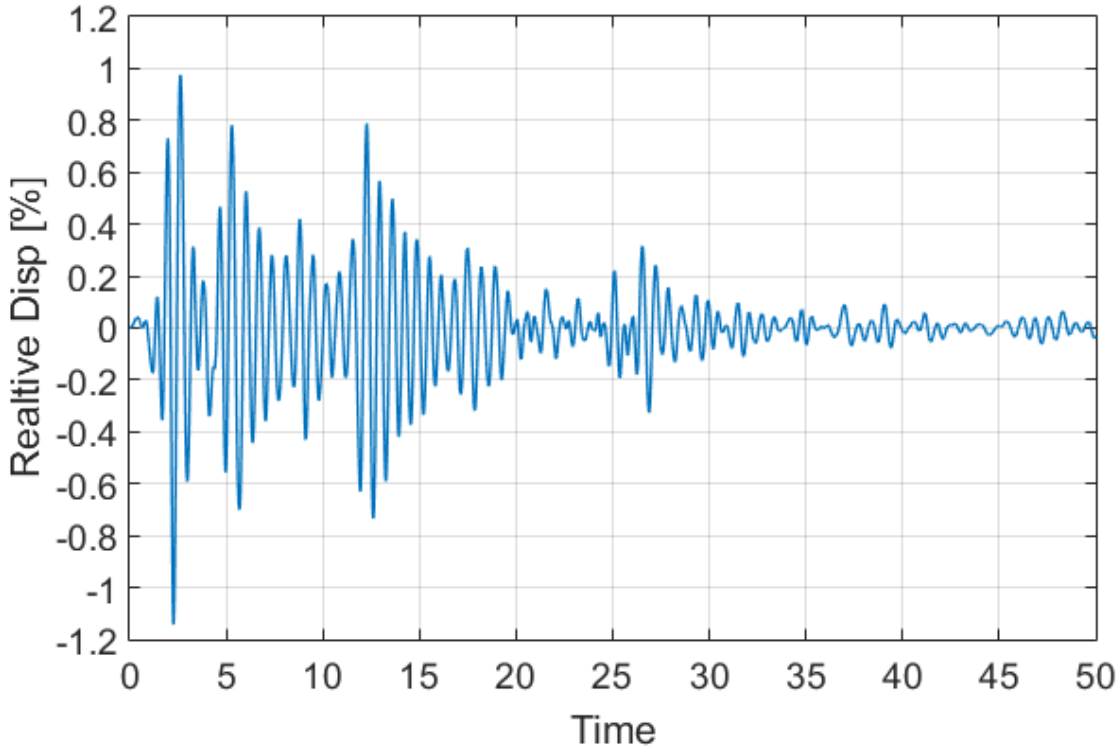


Greater Damage

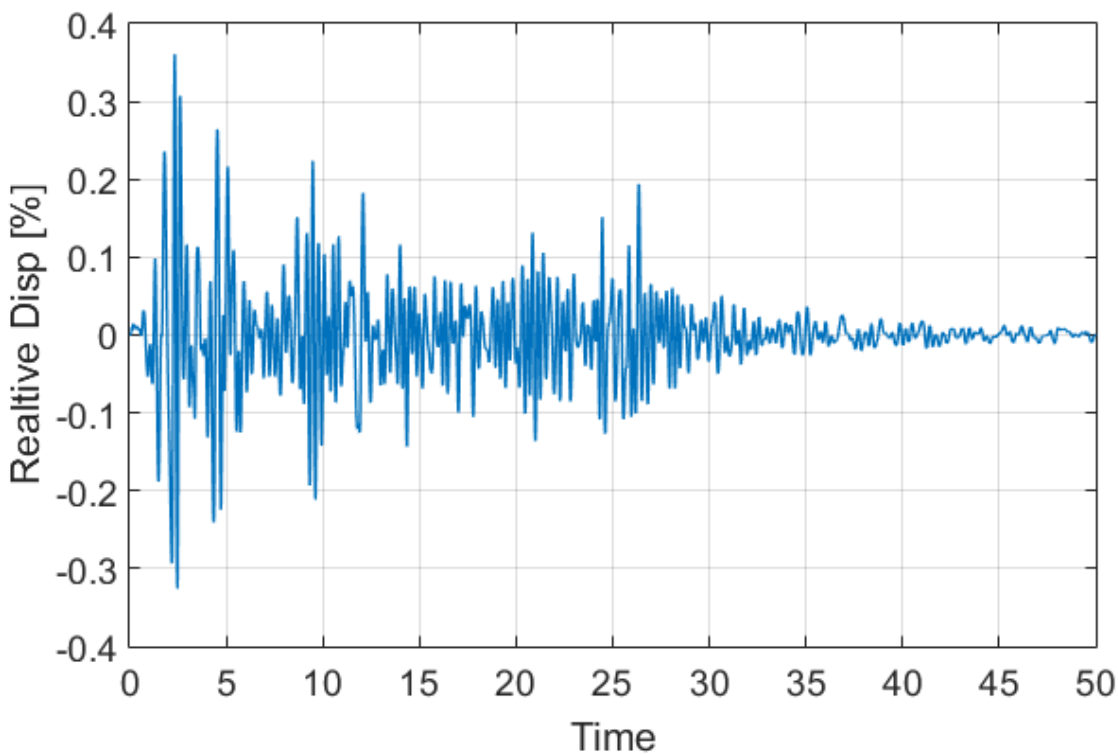


Relative Displacement Response Graphs

D **Second Most Damaged**

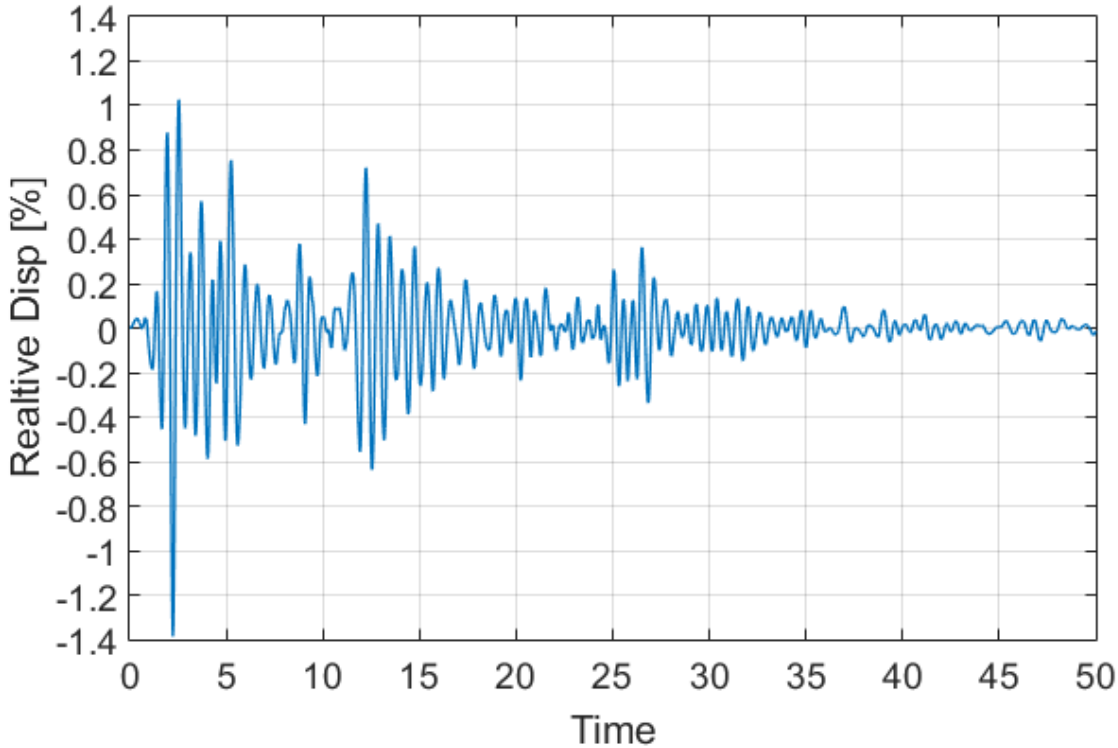


A

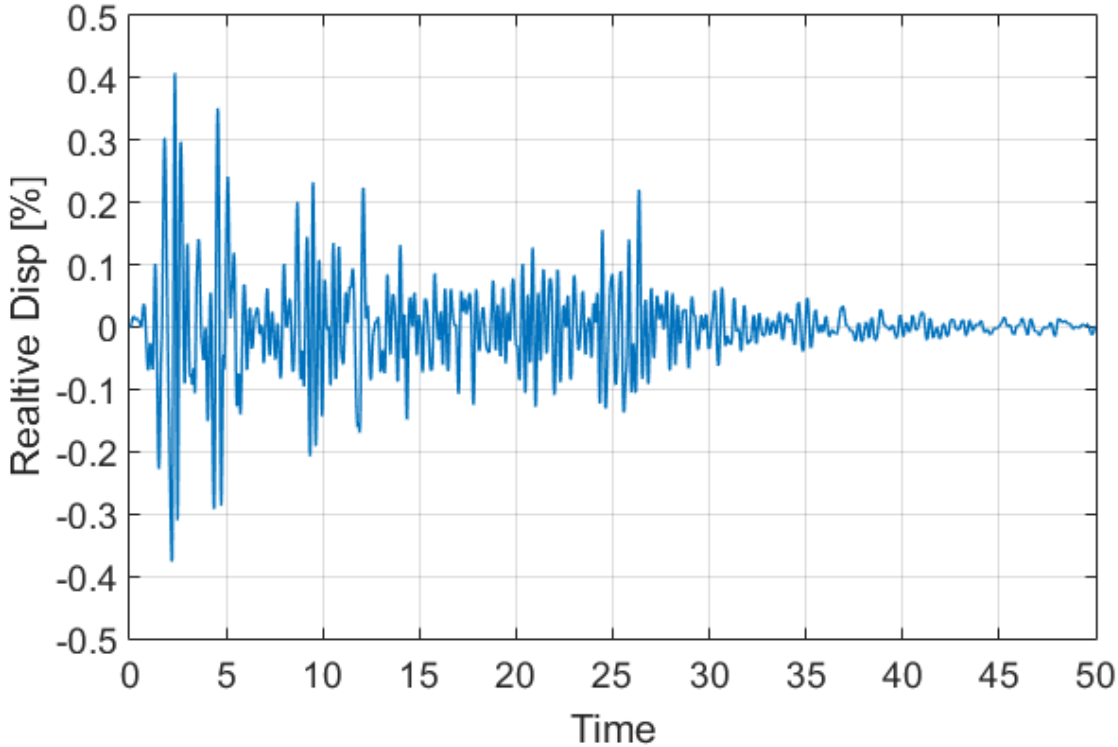


M

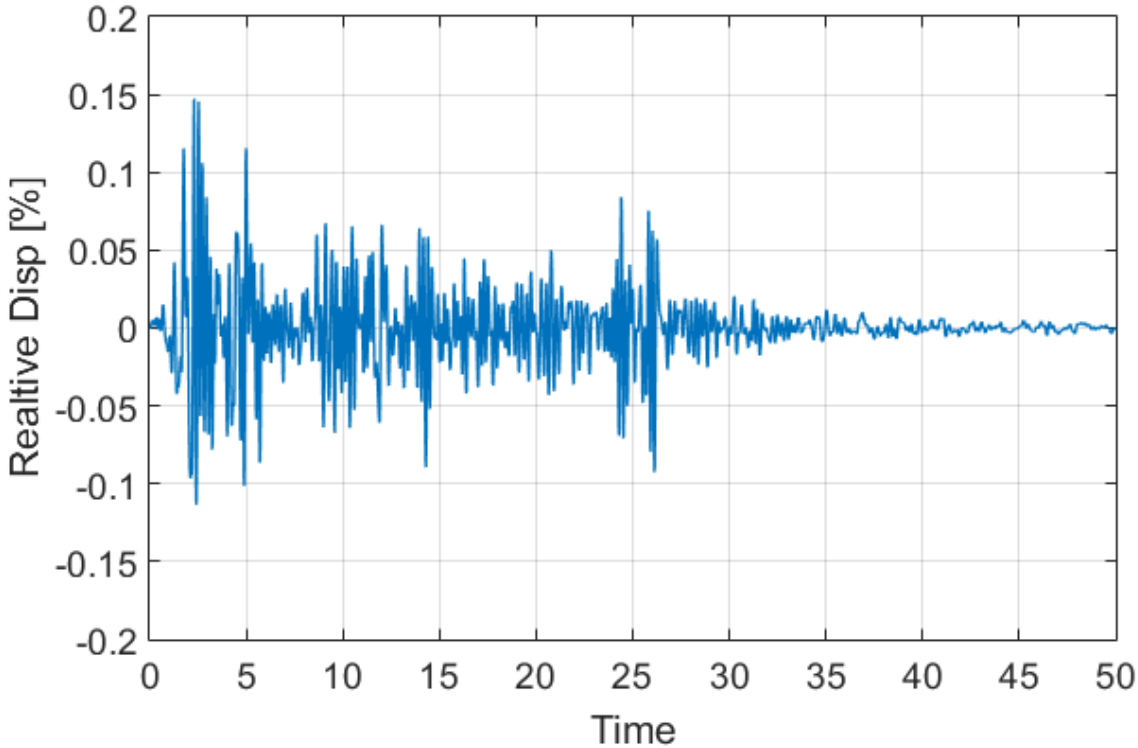
Most Damaged



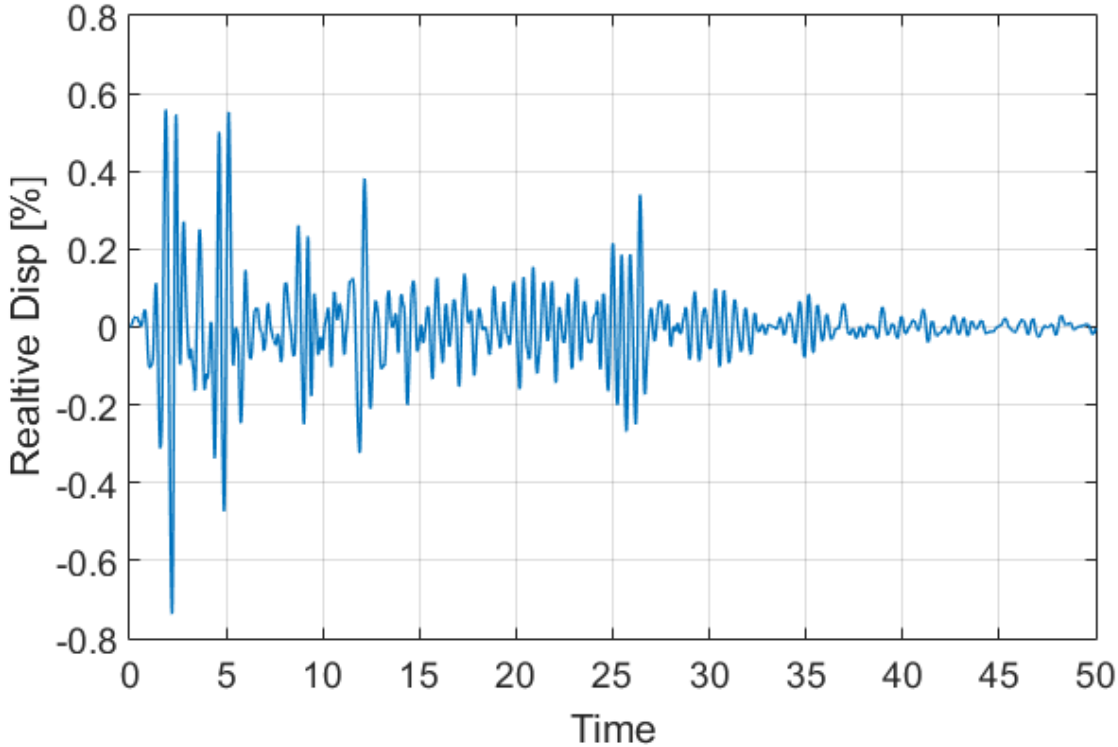
R



T

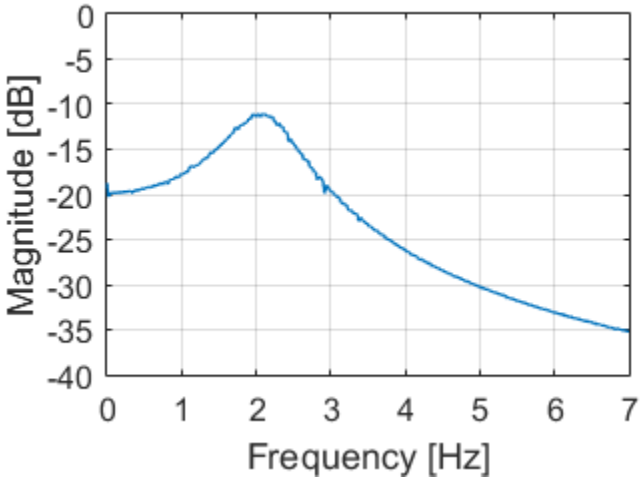

0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
Realtive Disp [%]
0
5
10
15
20
25
30
35
40
45
50
Time

Y

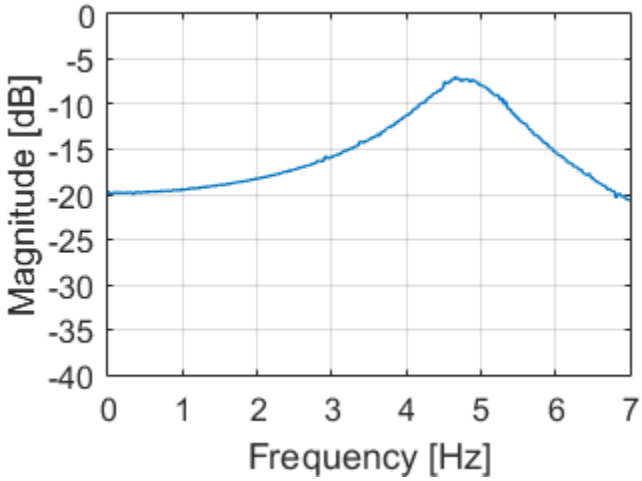

0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Realtive Disp [%]
0
5
10
15
20
25
30
35
40
45
50
Time

Pre-Earthquake Frequency Response Graphs

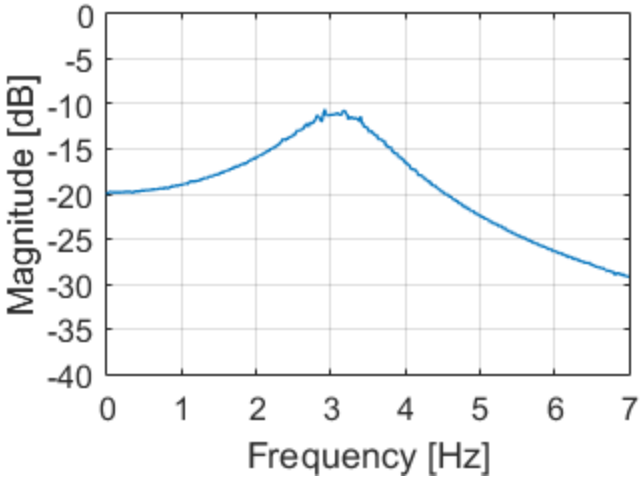
Y



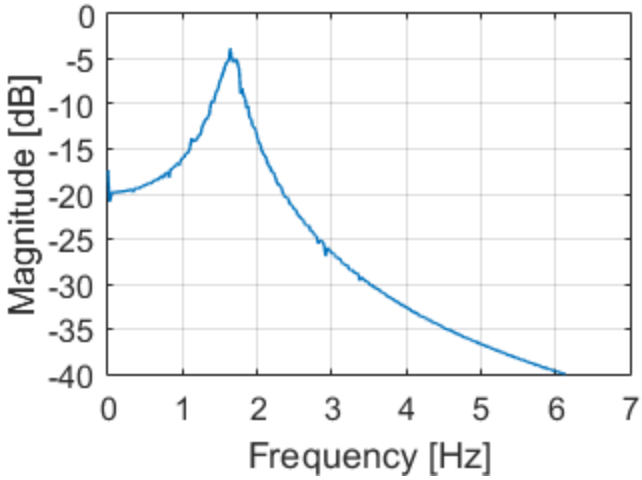
T



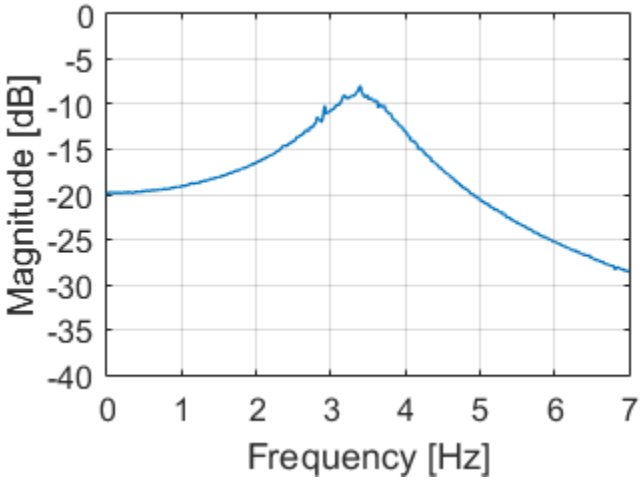
R



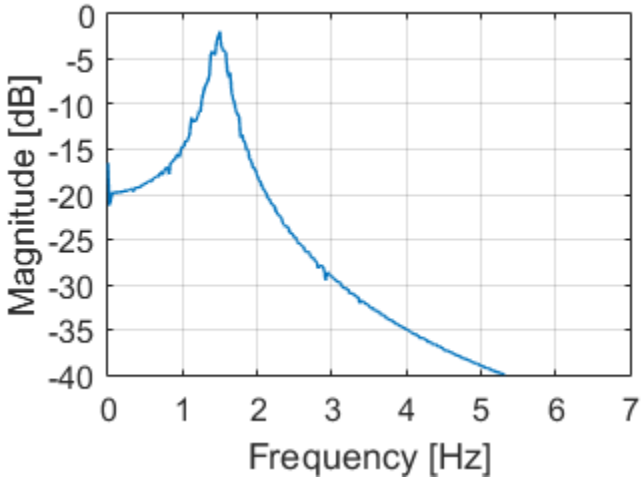
M



A

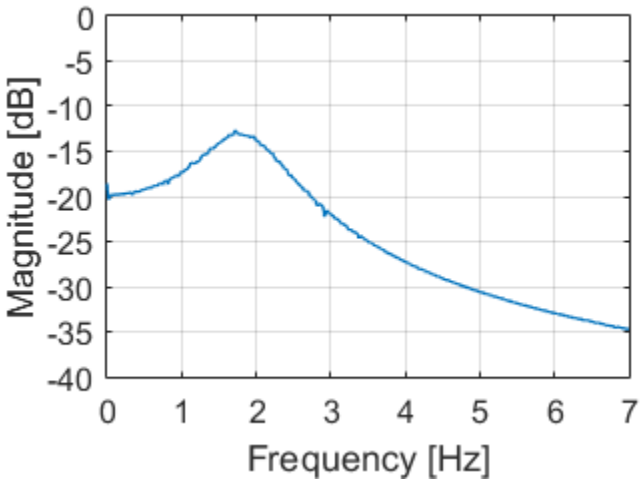


D

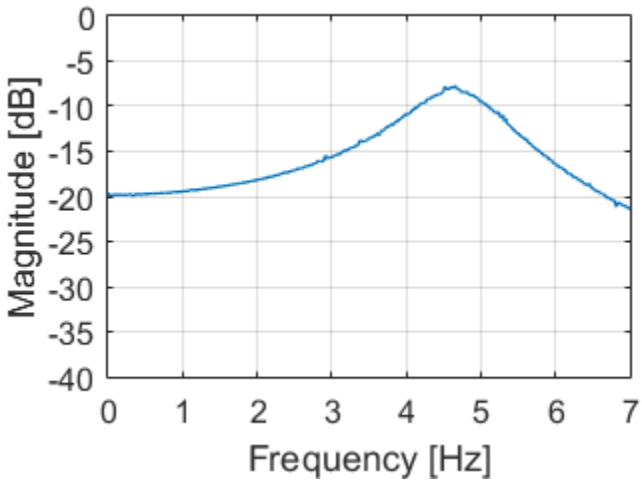


Post-Earthquake Frequency Response Graphs

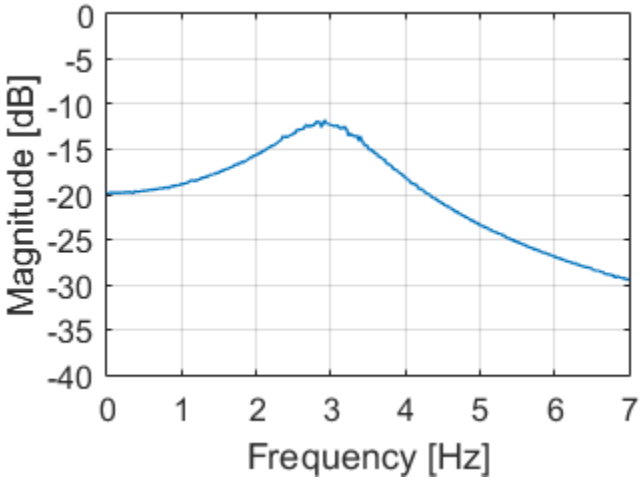
Y



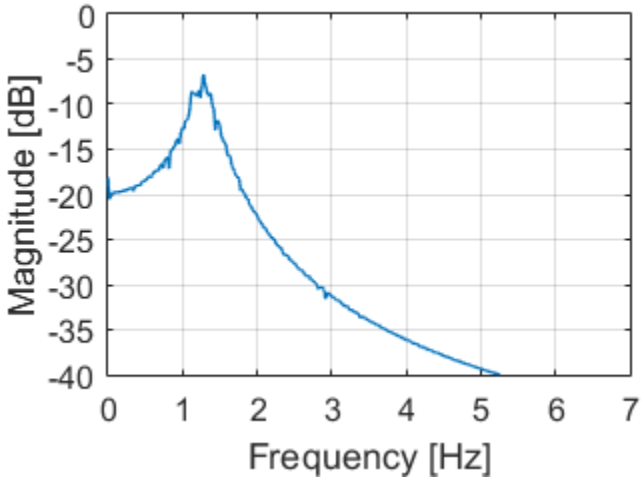
T



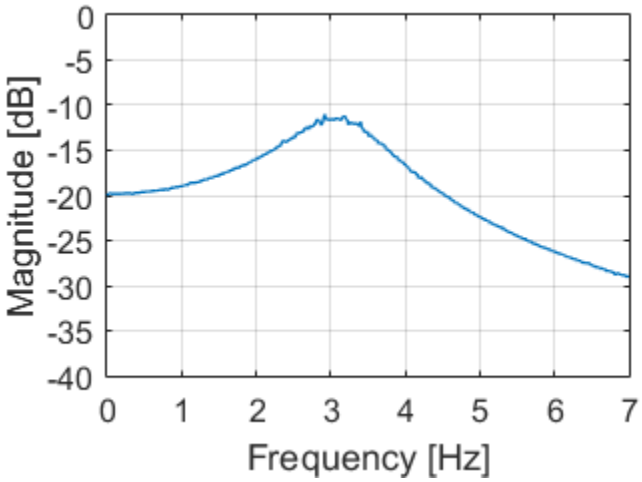
R



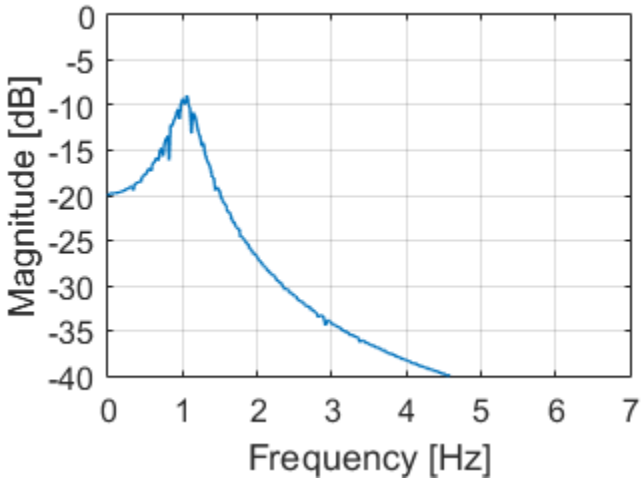
M



A

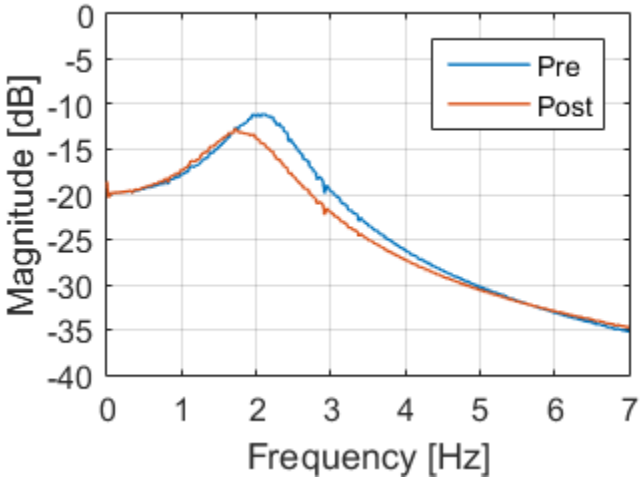


D

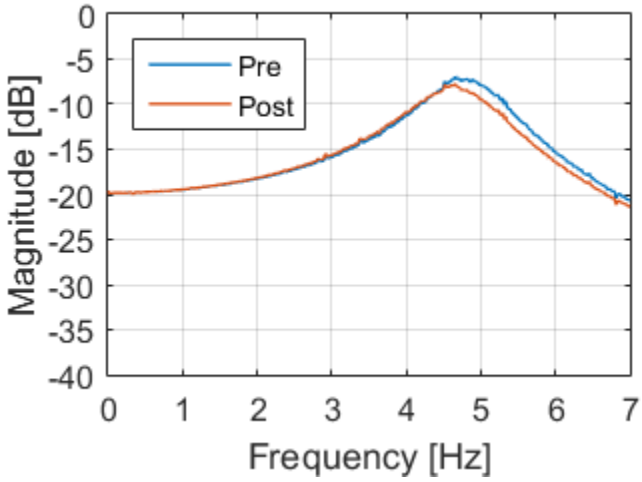


Frequency Response Graph Answer Key

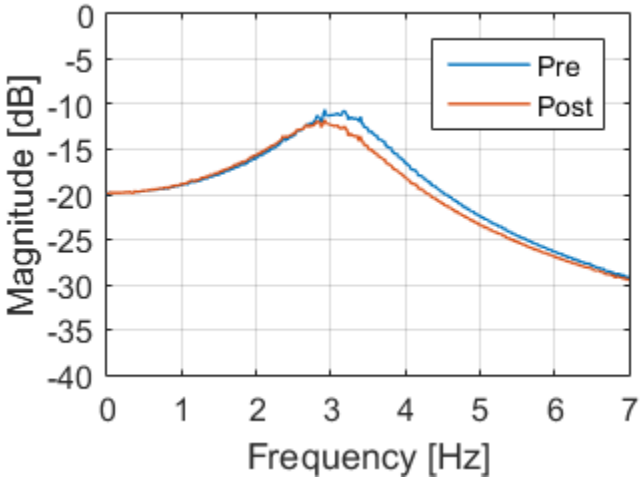
Y - DMA



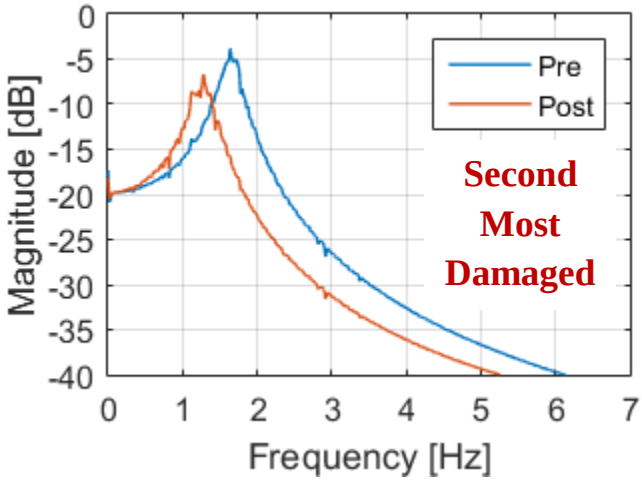
T - Hospital



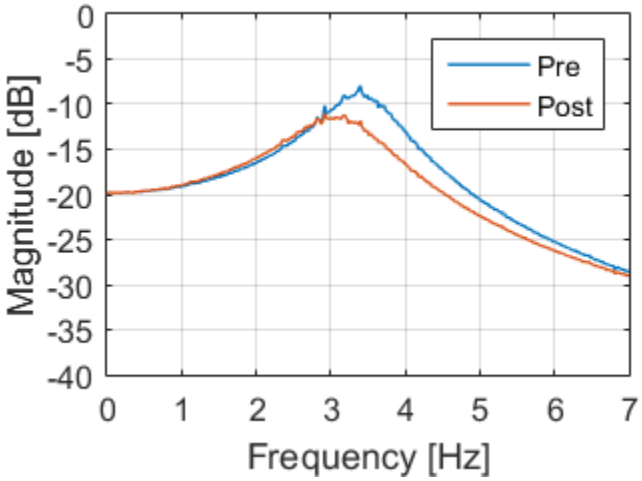
S - School



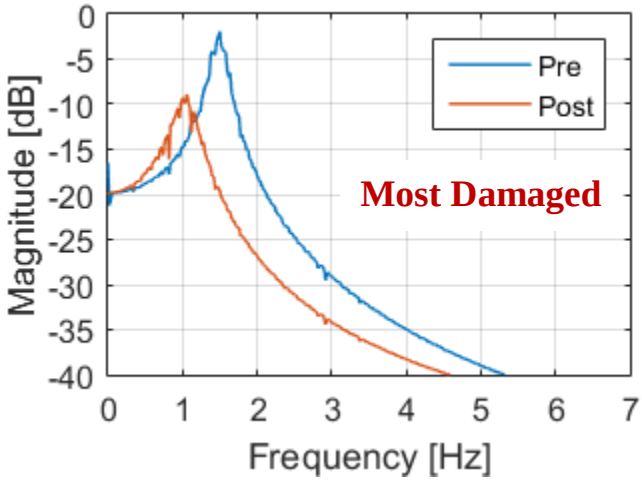
M - Library



A – Police Station



D - Church



Lesson Preparation - Part 3

Discussion Questions

1. What parts of the activity were easy? Why?

2. What parts were difficult? How did you overcome the difficulties?

3. We analyzed our buildings using four different methods. How did they differ? Why did we use all four to solve our problem?

4. The Hassan Index tells us that buildings with thicker walls and columns are less likely to be damaged. What are the benefits of constructing these features? What are the detriments?

5. What factors influence the balance of cost and safety as we construct buildings for different purposes? When and why might safety be sacrificed?

We found in our class that discussing the economic and moral implications of disaster preparedness inspired the students to think more deeply about these concepts. For example, building owners must balance the cost of safety improvements to their structure with the likelihood a disaster will strike. They have a moral and ethical responsibility to the tenants of the building, but they also must work on a budget. How should we balance these ideas as they build their structures?

References

American Geophysical Union and Federal Emergency Management Agency (AGU/FEMA). 1995. *Lesson 4.3: The BOSS model: Building oscillation seismic simulation. In Seismic sleuths: Earthquakes: A teacher's package for grades 7–12, 247–256.* Washington, DC: American Geophysical Union. www. fema.gov/media-library-data/20130726-1646-20490-4697/fema253.pdf.

Hassan, A.F., and M.A. Sozen. 1997. *Seismic vulnerability assessment of lowrise buildings in regions with infrequent earthquakes.* ACI Structural Journal 94 (1): 31–39.

Acknowledgements

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. DGE-1333468. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.