Earthquake Engineering

In comparison to the total number of earthquakes that occur each year, the number of disastrous quakes is relatively small. The extent of these disasters depends on many factors.

If a building is well designed, properly constructed, and built on solid ground, it might withstand an earthquake. Most deaths in earthquakes have been the result of faulty building construction or poorly chosen building sites.

For example, one earthquake in Agadir, Morocco, was not strong enough to be recorded on seismographs at a distance more than 1,000 miles away, but the quake completely destroyed the city and killed more than 12,000 people. It wasn't the severity of the quake, but the poor construction of buildings that killed so many people.

Figure 13 – San Francisco after the 1906 earthquake.

Building to Withstand Earthquakes

The best known Greek temples were constructed between 480 B.C. and 323 B.C. Many of these temples were built on foundations designed to be resistant to earthquakes. Several layers of marble were joined with iron dowels embedded in lead.

China, Japan, and Greece endure frequent earthquakes. Ancient builders used timber post and beam construction with flexible joints. During an earthquake, this type of structure may shake and the internal walls may fall, but the building remains intact.

In the aftermath of the 1906 earthquake in San Francisco, the downtown was littered with collapsed masonry buildings, but most wood-framed and steel-framed structures survived with little damage. Everyone realized that this type of construction was superior in resisting the strong lateral forces of an earthquake. Another big earthquake hit Tokyo in 1923, and engineers drew the same conclusions.

An earthquake produces a series of waves that move horizontally across the ground causing buildings to sway from side to side. A rigid structure, such as one constructed of unreinforced masonry, can withstand only minimal shaking. The best defense is to build a building that will move with the earthquake. By bending with the wave, a structure can absorb much of the wave's destructive energy. Steel and concrete reinforced with steel are the best answers to balancing flexibility and load-bearing capacity for large structures.

The value of earthquake-resistant buildings can be shown by comparing two recent earthquakes. The Loma Prieta Earthquake of October 17, 1989, in San Francisco reached a magnitude of 7.1 on the Richter scale and killed 62 people. In San Francisco, older buildings built on unstable soil collapsed, but newer buildings survived. The 1988 earthquake in Armenia, a former republic of the Soviet Union, reached a magnitude of 6.7 and killed 25,000. In the Soviet Union, none of the buildings were earthquake resistant.

Until recently, engineering buildings to withstand earthquakes has not been a priority because few people choose to spend money to prepare for something that may never happen. Public awareness in earthquake-resistant designs has increased since we have learned how building design can make the difference between life and death.

To design a structure to be earthquake resistant, you must know a little about how buildings react during an earthquake.

Remember that periodic motions, such as the vibrations of the earth or the shaking of a building during an earthquake, are designated by a value known as frequency. Frequency is defined as the number of complete cycles of wave motion that occurs in a unit of time. It is measured in units known as hertz (1 hertz = 1 cycle per second). The period of the motion is the time (in seconds) it takes to complete one cycle, or the reciprocal of the frequency.

During an earthquake, a typical 10-story building will shake back and forth once during a period of one second. That is, the building will have a natural frequency of one hertz (1 cycle per second). A 20-story building will have a frequency of two hertz and a period of 0.5 second (1 cycle/2 cycles per second = 0.5 second). A five-story building will have a frequency of 0.5 hertz and a period of two seconds (1 cycle/0.5 cycle per second = 2 seconds) (Figure 14).

The most powerful earthquake vibrations range from about 0.5 hertz to about five hertz. Because a building that sways at the same frequency as the earthquake may break, buildings in the range of five to 20 stories are most likely to suffer earthquake damage (Figure 15). Buildings of less than five stories are relatively safe because their resonant frequency of vibration is less than 0.5 hertz.

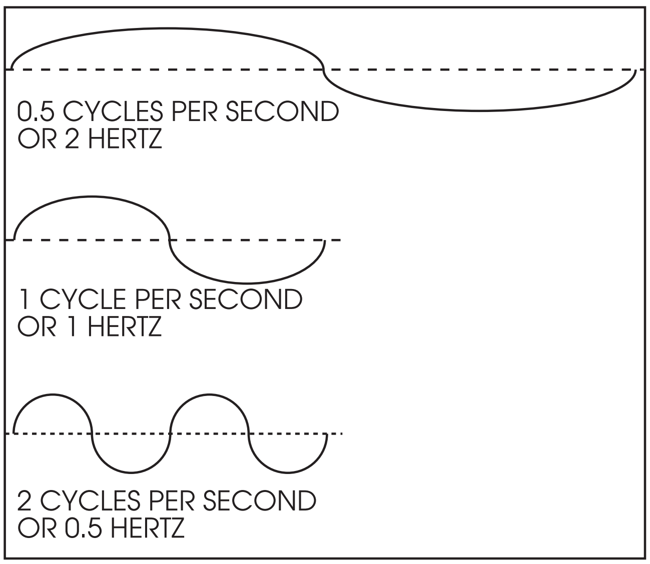


Figure 14 – A building that sways at the same frequency as the earthquake will crack apart.

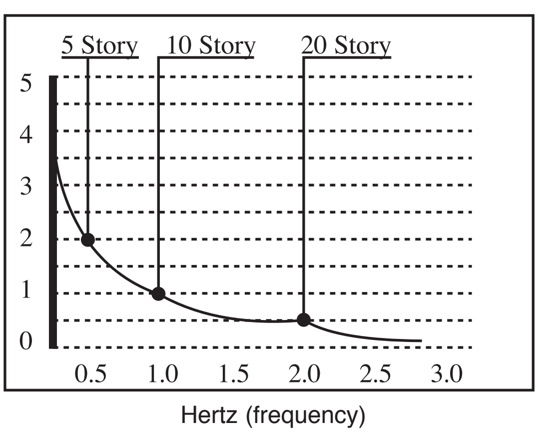
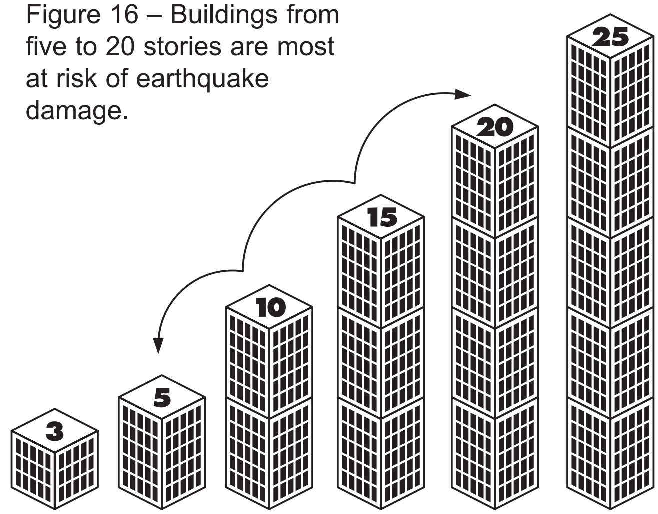


Figure 15 – A building that sways at the same frequency as the earthquake will break. Buildings outside this range will be less at risk for earthquake damage.

Buildings of more than 20 stories also do relatively well in earthquakes, because they have a frequency of more than two hertz (Figure 16). Taller buildings flex more because they were designed to withstand movement caused by wind. Reinforced concrete and steel columns and beams make tall buildings more flexible. However, nonstructural cladding on tall buildings may separate from the building as it flexes. Falling debris may cause death and injury.

Figure 16 – Buildings from five to 20 stories are most at risk of earthquake damage.



Buildings are susceptible to resonance. To understand resonance, think of a child on a swing. The arc of the swing has its own cycle. If force is applied just as the swing reaches maximum height and begins to drop, you add energy most efficiently. If the earthquake is vibrating at two hertz, five-story buildings will be the most vulnerable to damage. The building amplifies the motion it experiences at ground level, which causes upper stories to experience larger vibrations.

Damage is also affected by the soil. Dry sandy soil settles and becomes more dense due to the vibrations. Wet soil tends to liquefy. The building may be intact but will sink, tilt, or fall over in wet or sandy soils. One solution to making buildings more earthquake resistant in these soil conditions is to place steel reinforced piles below the building to transmit the load through weak soils to stronger soils at greater depth.

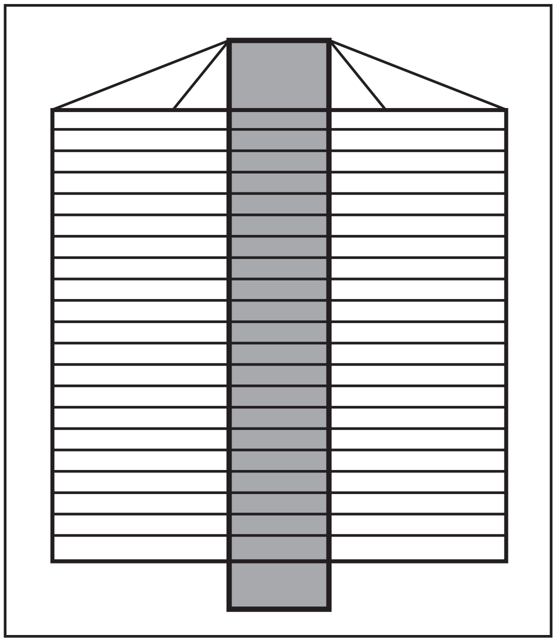


Figure 17 – The central column holds up all floors in tension.

Engineering to Avoid Damage

Buildings can be constructed withstand a seismic impact by controlling the dangerous tremors. There are several techniques to achieve this goal.

The base isolation technique supports the entire building on bearings made from alternate layers of rubber and steel that act like springs. These bearings are placed between the foundation and the building so the structure floats in isolation and dampens the vibrations. The building vibrates at a lower frequency and earthquake damage is reduced.

Another method places motion sensors on the building that send signals to a computer. The computer analyzes the data and makes the building react to the thrusting and rolling.

Some buildings use massive weights that swing back and forth to counterbalance the movements. Other buildings use flexible cables that pull the building back to center when it begins to ***oscillate***. Some systems make the building move back if the quake moves it forward. These systems require a backup power supply in the event of power failure.

Activity 3

Activity 3: Designing an Earthquake-Resistant Structure

Challenge

Engineers around the world are researching earthquake-resistant structures. Models are designed, built, and tested to understand how a building will react to the violent shaking of an earthquake. In this activity you will design and build a model earthquake-resistant structure and test it on the EQ^s Tremor Table.

This activity simulates a 20-story, 200-foot tall building, measuring 40 feet by 40 feet at the base. Such a building would weigh about 1.5 million tons, so five wooden floor plates with load masses added to them will be built into your structure. These will approximate the weight distribution to scale.

Procedure

To complete the activity, follow these steps:

1. Brainstorm solutions
2. Make a concept sketch
3. Draw a full-size pattern
4. Construct the model
5. Test the structure

Epicenter Assessment

Your tower will be placed on the EQ^s Tremor Table and tested until the structure fails. Failure occurs when any member of the structure fails. The tower can be tested manually at various frequencies and time intervals. The EQ^s Tremor Table also has the ability to remember a sequence of frequencies and corresponding time intervals – so all towers within a class can be tested with the same simulated earthquake.

Performance

Testing includes timing how long the tower lasted in the simulated earthquake. For those towers that lasted the same amount of time, the winner is the tower with the least amount of mass.

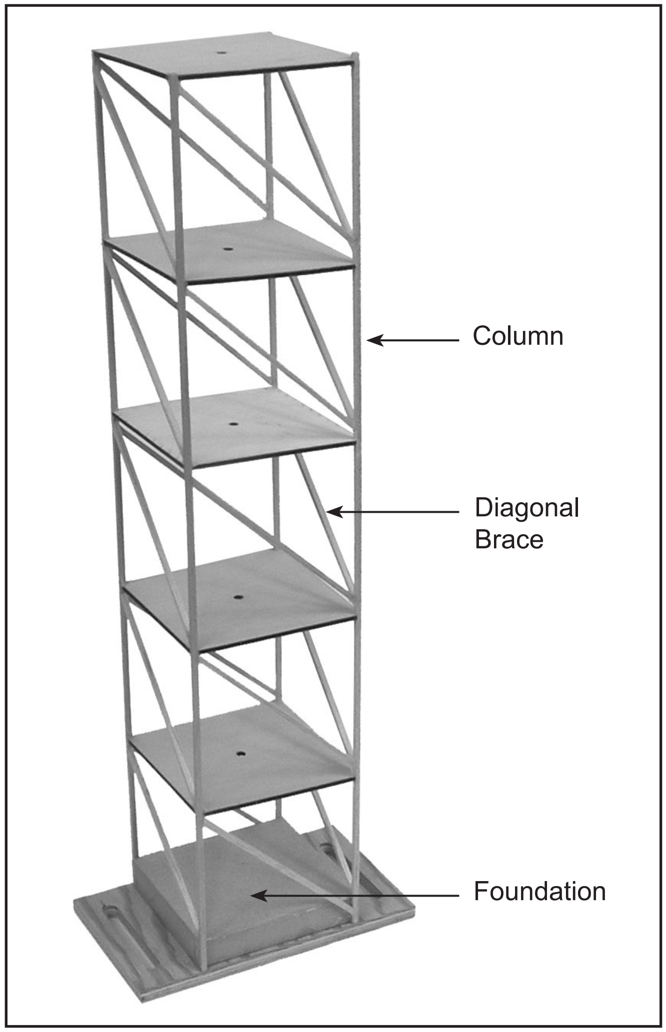


Figure 18 – This partially completed tower shows the assembly of the columns, diagonal braces, and foundation.

Activity 3

Materials Required

- Graph paper 11" x 24" (you might have to splice two pieces of graph paper together)

Equipment Required

- Ruler
- Pencil
- Drafting equipment (optional)

Specifications

Exact height	19.7" (500 mm)
Exact width	4" (100 mm)
Exact depth	4" (100 mm)
Exact foundation size	4" x 3.75" x .75" (100 mm x 96 mm x 19 mm)
Exact floor plate size	3.93" x 3.93" x .25" (100 mm x 100 mm x 6 mm)
Plate notch size	1/8" (3 mm) square notches at the corners
Number of floor plates	5 spaced as shown
Balsa wood pieces	18 – 24" x .25" x .25" (600 mm x 3 mm x 3 mm)

Width and depth are measured from the outside of one column to the outside of the other column (Figure 19).

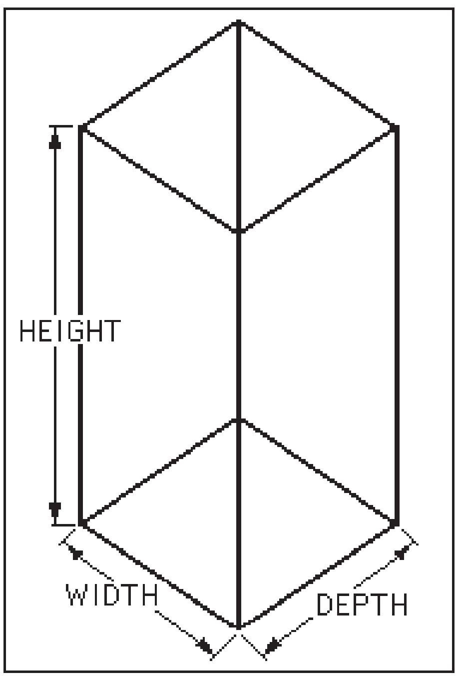


Figure 19 – Overall dimensions.

Diagonal bracing may be placed on the outside of the columns or can be in line with the outside of the columns. Height is measured to the top of the highest floor plate.

The 4" x 3-3/4" x 3/4" wood foundation block sits inside the tower. Glue the vertical columns to the foundation so the outside dimensions are exactly 4" x 4".

Colored Structures Glue from Pitsco is recommended, but CA glues and epoxies are allowed. Hot-melt glue should not be used. Laminations are allowed, but remember that your material is very limited.

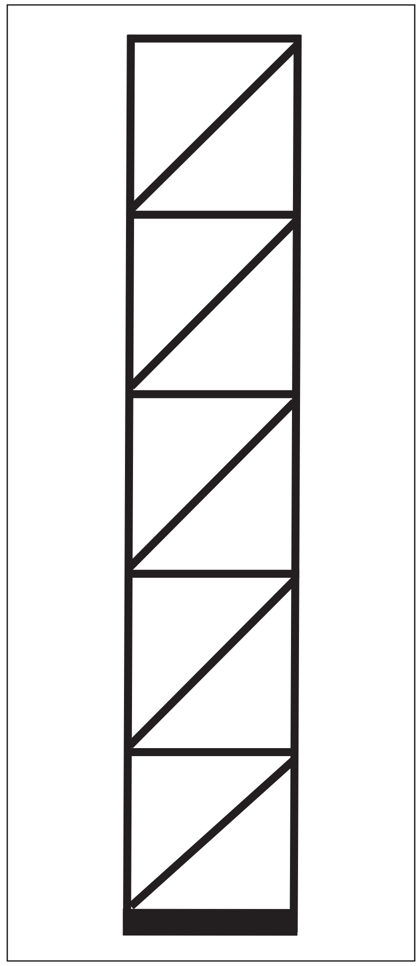


Figure 20 – Diagram shows the location of columns, floor plates, and the foundation.

Activity 3

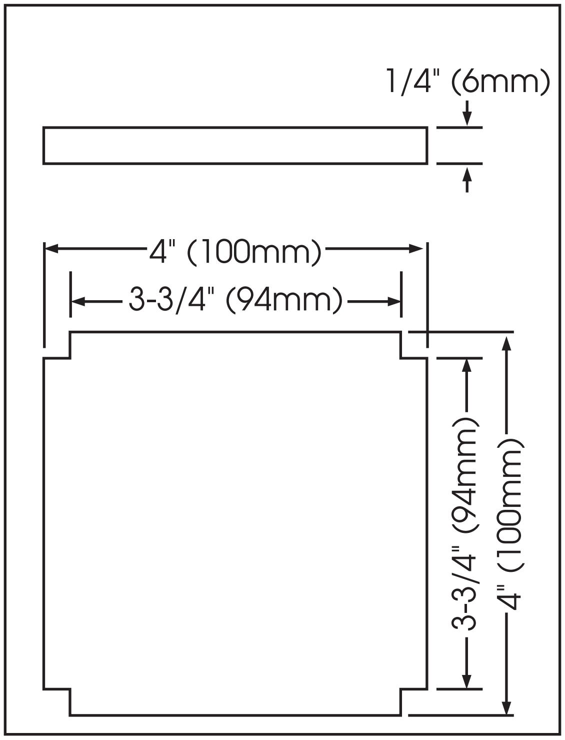


Figure 21 – Floor plates.

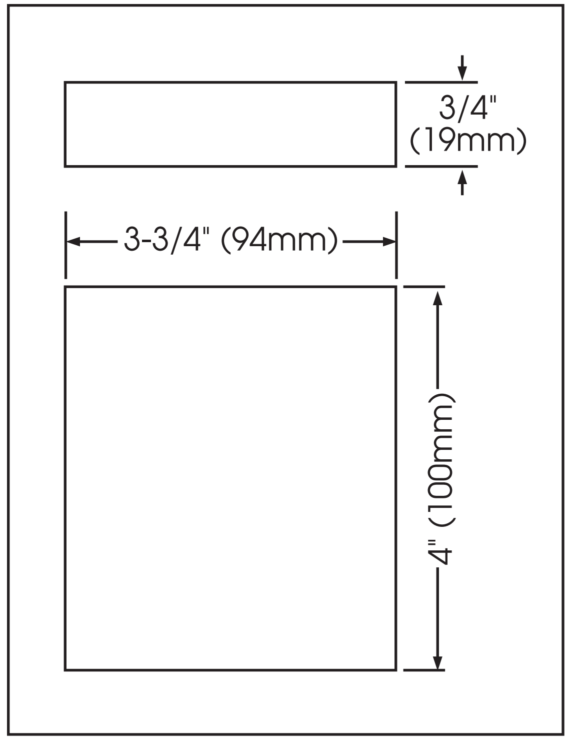


Figure 22 – Foundation block.

The wooden floor plates are used to construct a tower for the EQ[s] Tremor Table are machined to exact size in the inch system.

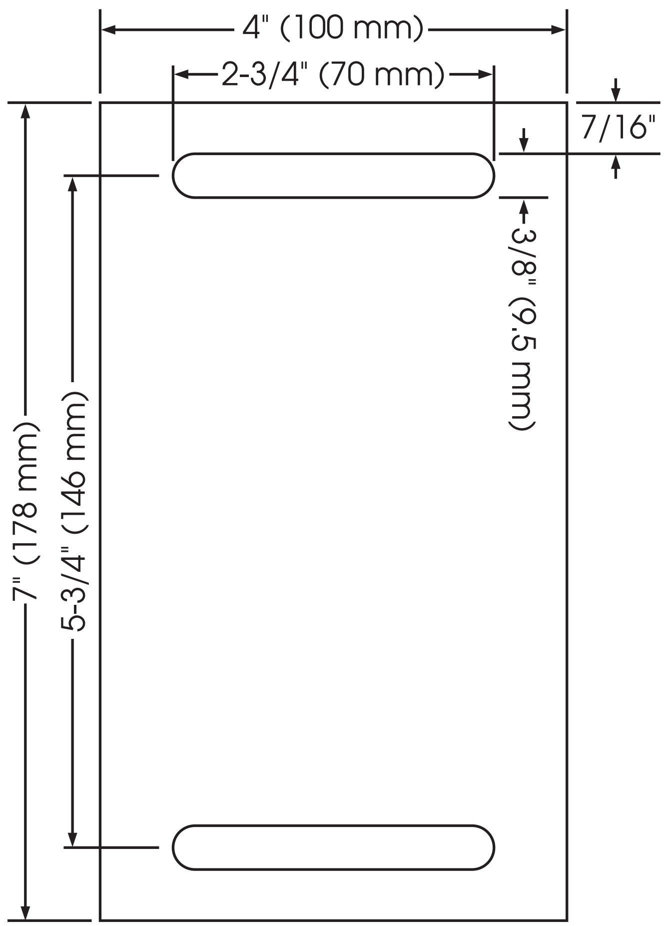


Figure 23 – Tower base block.

Activity 3

Design Considerations –
Models, Mockups, and Prototypes

When making models, it is important to use methods of construction similar to those used on full-size buildings.

The vertical components of a tower are called columns. They transmit the load to the ground.

In the model pictured, there are four vertical columns joined by floor plates (total of five on the tower), which act as girders.

In this example, each of the floor plates is glued to all four columns.

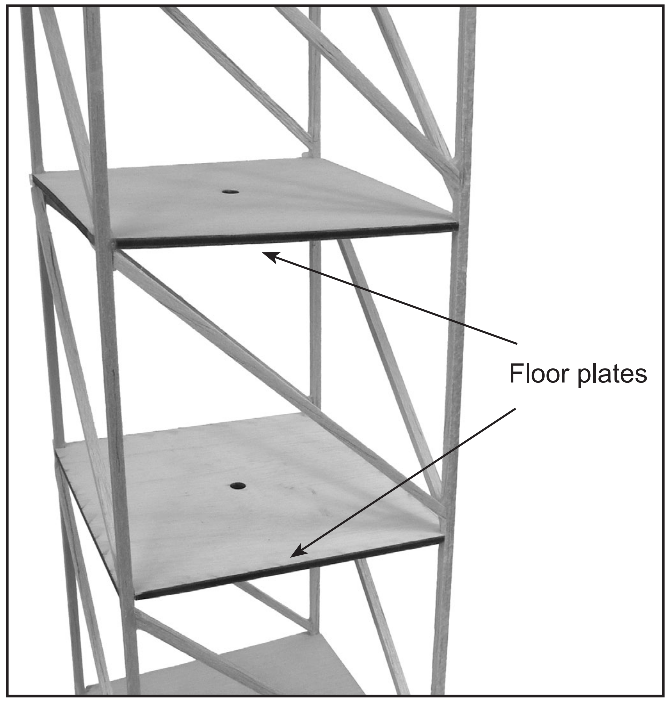


Figure 24 – Floor plates acting as girders.

Activity 3

Design Tips

The connection between floor plate, beam, and column plays a crucial role in the overall strength of the frame. The most critical aspect of making the tower strong is the quality of the wood joints. When a joint fails, the entire structure is weakened. Total failure of the structure will follow. Also, keep in mind that glue does not bond well to the end grain of wood.

For additional strength, girders (horizontal pieces between the vertical columns) can be added below and adjacent to the floor plates.

Figure 25 – Only the load-bearing column in the center of the building remained standing after the earthquake.

Activity 3

Brainstorming Solutions

Study the sketches and diagrams in this book, particularly those on this page (Figures 28-31). Brainstorm ideas for building your tower. What type(s) of bracing, joints, and other construction methods will provide the most stable, quake-resistant structure?

Make notes and sketches of what you think will work best.

Making a Concept Sketch

Choose one design. Sketch the front, top, and side view of the tower showing some construction details.

Draw a Full-Size Pattern for One Side

Draw the front, top, and side views of your tower to full scale. First, draw the columns and floor plates in the specified locations. After these parts are located, draw the girders below the floor plates. The cross-bracing is drawn last.

Draw a Full-Size Pattern for Second Side

Draw a second, full-size side of your tower on the graph paper.

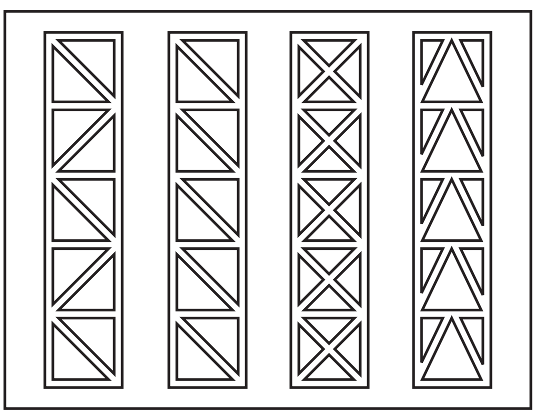


Figure 26 – Brainstorming

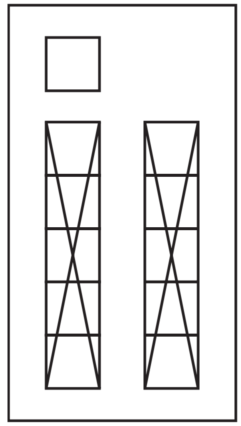


Figure 27 – Concept sketch

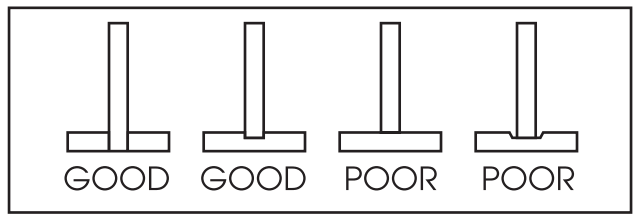


Figure 28 – Types of joints between columns and girders

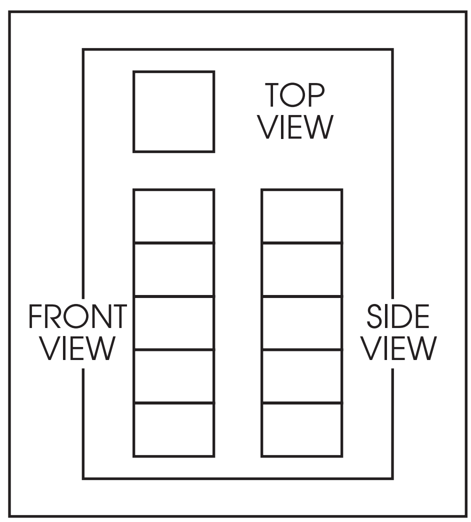


Figure 29 – Location of the front, top, and side views