

# General

Dec 1st - March 2th

TOPIC: What is the best building shape/structure when facing an earthquake?

NAME: Standing Strong: Testing Building Models Against Seismic Forces

An analysis of lateral displacement in structural models under simulated seismic conditions.

RESEARCH:

Earthquakes:

Earthquakes are caused by slow but yet constant movement of the tectonic plates—massive irregularly shaped slabs of solid rock which lifts everything together from the mantle. These plates are so giant that slight movement could cause severe earthquakes. Earthquakes happen when there are sudden violent shaking of the ground caused by release of built-up energy in the Earth's crust which also creates seismic waves that radiate outward, causing vibrations felt on the surface. Thus causing great destruction, for example, broken infrastructure (roads, bridges), collapsing buildings, and could potentially cause severe tsunamis.

The severity of earthquakes changes depending on the area we live in, certain areas where they are located away from tectonic plate boundaries, for example, central Canada, have a more “stable” region since it is often located in the middle of the plates. Even if an earthquake occurs in these regions, the shaking and the aftershocks are usually less intense. But places along the edges of the tectonic plates or, also known as the Pacific “Ring of Fire”, have a highly active seismic zone because the four major tectonic plates—the Pacific, Philippine Sea, Eurasian, and North American plates—constantly collide and grind against each other.

Despite the fact that this natural disaster is so dangerous, there are numerous solutions to solve this problem. Engineers design special buildings to absorb the seismic waves and to distribute the force to save human lives in case of an earthquake. Countries where severe earthquakes occur the most, like Japan and Chile, use earthquake-resistant designs to ensure that their buildings are strong and flexible enough to withstand the forces of earthquakes.

Buildings:

For this experiment, instead of using earthquake-resistant designs, we opted for the most common designs used in the construction of tall buildings. Even though earthquakes occur less frequently and less violently located away from the tectonic plates, they still happen and could cause serious damage as well. We chose to include the cross-braced frame (X-bracing), moment resisting frame, and the shear wall building design in our experiment.

Cross-braced frame (X-Bracing)

Cross-braced frames are one of the most popular choices for earthquake-resistant design due to their high structural stiffness, strength, and ability to disturbed energy through the diagonal, X-shaped material. Unlike most frames that rely on beams and columns, cross-bracing uses an axial-like structure. The use of triangular structures to resist lateral forces (side to side earthquake shaking) can

create a sturdier and stronger building compared to the other designs. Cross-bracing buildings convert the violent seismic motion into tension and compression, which effectively prevents excessive sway and structural collapse.

#### Moment Resisting Frame

Instead of the diagonal braces used in the cross-bracing building, moment resisting frames rely on strong beam-column joints. These joints resist bending moments which prevent the building from collapsing. The strong beams and columns used in the construction resist lateral loads (wind, seismic movements) primarily through bending. This structure form is also very popular in the architectural industry due to its flexible architectural spaces while withstanding significant deformations in steel or concrete, making it strong and sturdy.

#### Shear Wall Building

Unlike other buildings, this structure uses solid vertical walls (typically filled with concrete or reinforced timber) to secure itself from lateral movements. These walls provide structural stiffness, preventing deformation, and reducing sway due to the stiff and heavy material used in the making of this building. These types of structures are most commonly used in high-rise buildings, for example, apartment buildings. It absorbs kinetic energy which reduces inter-story distortion, lateral displacement/movement between two consecutive floors of a building.

# JMA Seismic Intensity Scale

<b>0</b>	Nobody feels the tremor.
<b>1</b>	Some people indoors may feel a slight tremor.
<b>2</b>	Many people indoors feel the tremor. Hanging fixtures, such as lights, may shake slightly.
<b>3</b>	Most people indoors feel the tremor. Electrical wires may shake slightly.
<b>4</b>	Most people get a shock from the tremor, and hanging fixtures such as lamps shake considerably; dishes in the cupboard may rattle and objects may topple.
<b>Lower</b> <b>5</b>	Most people get a shock from the tremor and feel a sense of danger. Dishes in the cupboard and books in the shelves may fall. Items that are not supported well may fall. Unsecured furniture may shift.

<b>Upper 5</b>	It is difficult to walk without holding on to something. Heavy furniture, such as bureaus, may fall over. Brick walls that are not supported well may also topple.
<b>Lower 6</b>	Most people get a shock from the tremor and there is a sense of extreme danger. People cannot maintain a standing position. Furniture that is not secured may move or topple over. Many doors cannot open due to obstruction. Glass windows begin to shatter and collapse.
<b>Upper 6</b>	It becomes impossible to move without crawling. Furniture that is not secured may move or topple over. Most brick walls that are not supported collapse.
<b>7</b>	People are unable to move or act by will. Most furniture are displaced and some unsecured objects such as microwaves, books and kettles may seem to fly in all directions.

#### HYPOTHESIS:

Our hypothesis for this experiment is that the shear wall building will be shaken the least because it is the heaviest building model out of the three because of the amount of skewers and addition of popsicle sticks added to it. We believe that the heavier the building model is, the more secure it will be since there is more pressure pressing on the platform—making it more sturdy.

#### PROCEDURE:

1. Place one of the models on platforms
2. Secure the model with clay
3. Turn on the massage gun and put it inside the box and let the building vibrate for 10 seconds
4. Check how much the model shook and record on piece of paper

5. Find the average of how much the buildings shook after each level  
Repeat the process 3 times per level  
There are a total of 3 levels that we've tested

#### SOURCE OF ERROR:

There are a couple errors that we had in our experiment:

- Weight difference between buildings

Due to the different amount of glue and materials used in each building, the weight between them would be different. This difference could potentially cause a change in the overall experiment since weight can tend to make the buildings to be more secured on the platform, which makes it sturdier. To solve this problem, we could choose to attach some weights on the buildings when they are being shaken

- No actual stages of earthquakes (like in real life)

Our buildings were mainly shaken by the massage gun, which couldn't mimic a real earthquake since earthquakes in real life have different stages to measure on. We could solve this by buying one of the earthquake simulators online to ensure the quality of the violence being done to the buildings

- The smoothness of the platform

Our platform was made from a flat cardboard box being shaken by the massage gun we have. Due to its smoothness, it is unrealistic since in the real world, earthquakes are created by the constant and slow movement of the tectonic plates. This means the results could vary according to smoothness and the roughness of the platform. To reduce these errors, we could attach layers of popsicle sticks onto the platform to mimic the movement of the tectonic plates when the building is being shaken.

#### VARIABLES:

Independent variable:

- movement speed of the platform

- different structure shapes

Dependent variable:

- the resistance of each model

Controlled variable:

- the size of structures
- platform used

#### APPLICATIONS:

These results from the experiment could be applied to real-life situations in many different ways. This can help us better understand the risk and the benefits of different types of building structures which would help us in the future if we want to be engineers. The major purpose of this experiment is to learn about how secure each building structure is to reduce life loss in case of an earthquake.

#### CONCLUSION:

In conclusion, this experiment shows that different building structures have different abilities when withstanding strong vibrations. Structures with reinforcement systems, shear walls models, swayed less than simple structures, moment-resisting models. This indicates that additional support materials are used to distribute forces and minimize lateral movement during earthquakes. Overall, the results from this experiment confirms that the shear wall model is the sturdiest out of our three models and that structural design significantly improves a building's ability to resist shaking and potential collapse.

#### TALL BUILDING MODELS:

- Rigid frame : moment resisting frame
- Cross-braced frame (X-bracing)
- Shear wall building
- Narrow base
- Broad Base
- Add weight on top(to see effect of center mass)
- Tall vs short buildings (which one falls first?)

#### HOUSE MODELS

- The "Stick-Frame" or "Platform Frame" House (North American Standard stuff?)
- The "Unreinforced Masonry" House (old with no internal support, known as hazardous?)
- The "Confined Masonry" (Basically columns?)
- The "Geodesic Dome" (Maybe don't do this one?)

#### OTHER(INNOVATIONS? THINGS TAKEN FROM NATURE?):

#### MATERIALS:

- Popsicle sticks
- styrofoam boards? (probably not environmentally friendly but good use for shear wall)
- Toothpicks/skewers
- Hotglue (for securing everything together)
- Cardboard

Base can be 20x20cm

It'll be best if all the models weigh the same and have the same base sizes.

#### **LINKS:**

[https://www.researchgate.net/figure/Categories-of-steel-structural-systems-for-high-rise-buildings\\_figure\\_3\\_237188711](https://www.researchgate.net/figure/Categories-of-steel-structural-systems-for-high-rise-buildings_figure_3_237188711) tall building structures

Earthquakes:

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<https://www.usgs.gov/programs/earthquake-hazards/science-earthquakes>

Sun, Alice. "Why do earthquakes happen far away from plate boundaries?" LiveScience, May 13, 2024,

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Buildings in General:

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Steel Specialties Inc. The Ultimate Earthquake Survivors: Steel Frames and Structures. January 21, 2020,

<https://www.steelspecialtiesinc.net/the-ultimate-earthquake-survivors-steel-frames-and-structures/>

Moment-resisting frame, Wikipedia, Wikimedia Foundation, July 15, 2025,

[https://en.wikipedia.org/wiki/Moment-resisting\\_frame](https://en.wikipedia.org/wiki/Moment-resisting_frame)

Cross-Bracing Frame:

Fiveable Content Team. 7.2 Seismic design of braced frames. [Fiveable.me](https://fiveable.me), August 2025,

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Shear Wall:

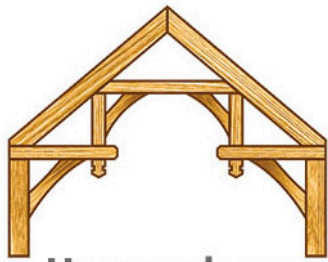
S3DA. Distribution of Shear Walls for Lateral Load Resistance

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Suryakanta. "Why are Buildings With Shear Walls Preferred in Seismic Regions?" [CivilBlog.Org](https://civilblog.org), July 12, 2015,

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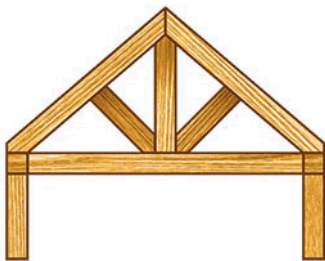
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[https://en.wikipedia.org/wiki/Shear\\_wall](https://en.wikipedia.org/wiki/Shear_wall)



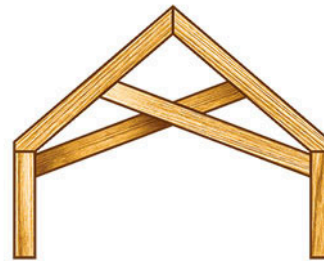
**Hammerbeam**



**Queen Post (modified)**



**King Post w/Struts**



**Scissor**

House structures

<https://www.instructables.com/Construction-of-an-Earthquake-Simulator/> the earthquake stimulation machine.

# Experiment results

## Detailed results

	Level 1		Level 2		Level 3	
	#1 attempt R	#1 attempt L	#1 attempt R	#1 attempt L	#1 attempt R	#1 attempt L
Moment-resisting	0.3 cm	1.1 cm	2.5 cm	2 cm	2.5 cm	2.5 cm
Shear Wall	0.6 cm	0.6 cm	0.6 cm	0.3 cm	1 cm	1 cm
Cross-bracing	0.5 cm	0.7 cm	0.8 cm	1 cm	1.7 cm	1.6 cm
	#2 attempt R	#2 attempt L	#2 attempt R	#2 attempt L	#2 attempt R	#2 attempt L
Moment-resisting	0.2 cm	1 cm	1.5 cm	1.6 cm	2 cm	2.3 cm
Shear Wall	0.6 cm	0.7 cm	0.7 cm	0.5 cm	1 cm	1.2 cm
Cross-bracing	0.5 cm	0.9 cm	0.8 cm	0.9 cm	1.5 cm	1.2 cm
	#3 attempt R	#3 attempt L	#3 attempt R	#3 attempt L	#3 attempt R	#3 attempt L
Moment-resisting	0.9 cm	2 cm	2 cm	2.5 cm	2 cm	2 cm
Shear Wall	0.5 cm	0.6 cm	0.4 cm	0.3 cm	1.2 cm	1.3 cm
Cross-bracing	0.4 cm	0.6 cm	1.2 cm	1 cm	1.7 cm	2 cm

R = right, L = left

	Total R	Total L	Total R	Total L	Total R	Total L
Moment-resisting	0.5 cm	1.4cm	2 cm	2 cm	2.2 cm	2.3 cm
Shear Wall	0.6 cm	0.6 cm	0.7 cm	0.4 cm	1.1 cm	1.2 cm
Cross-bracing	0.5 cm	0.7 cm	0.9 cm	1 cm	1.6 cm	1.6 cm

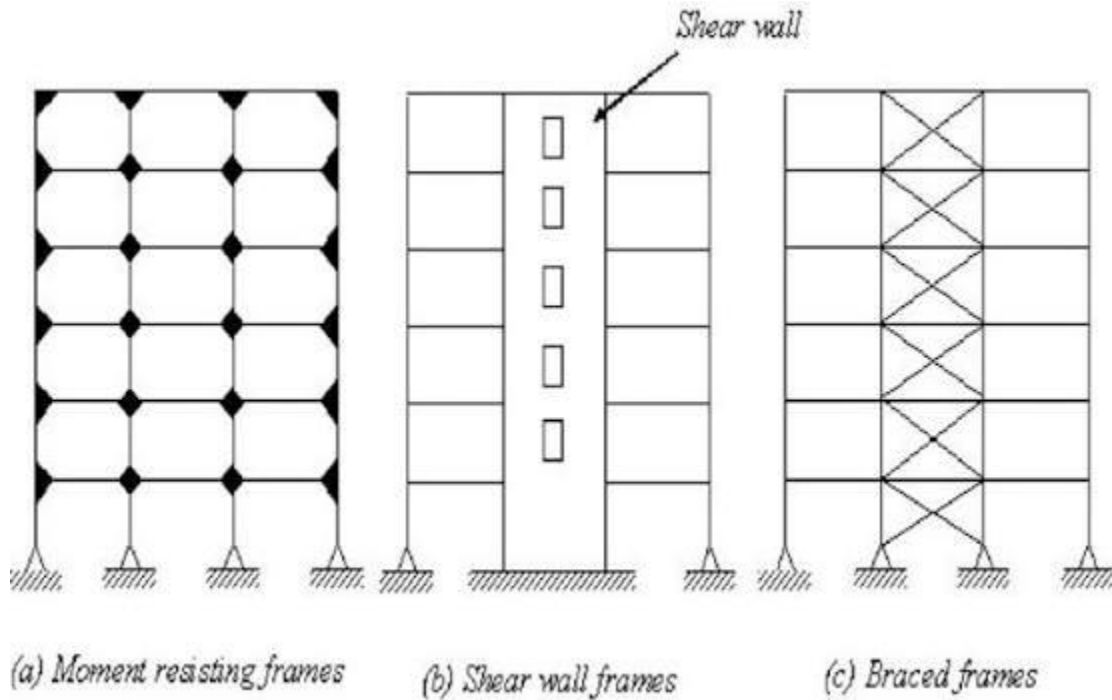
## Overall Results

	Overall Total Level 1	Overall Total Level 2	Overall Total Level 3
Moment-resisting	0.9 cm	2cm	2.3 cm
Shear Wall	0.6 cm	0.6cm	1.2 cm
Cross-bracing	0.6 cm	1cm	1.6 cm

# Tall Building Models

Rigid frame: moment resisting frame

1.



2.

**Types of Lateral-Resisting Systems in Commercial Buildings**

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The diagram illustrates three types of lateral-resisting systems. On the left is a 'Moment Frames' system, a central 'Shear Walls' system, and on the right is a 'Braced Frames' system. Each system is shown with a grid of columns and beams, and a list of characteristics below it.

**Moment Frames**

- Suitable for low-rise buildings
- Allow for large openings and small wall sections

**Shear Walls**

- Suitable for medium- to high-rise buildings or any building in a high seismic or wind activity area
- Few openings

**Braced Frames**

- Suitable for low- to mid-rise buildings
- Common for steel construction

3.

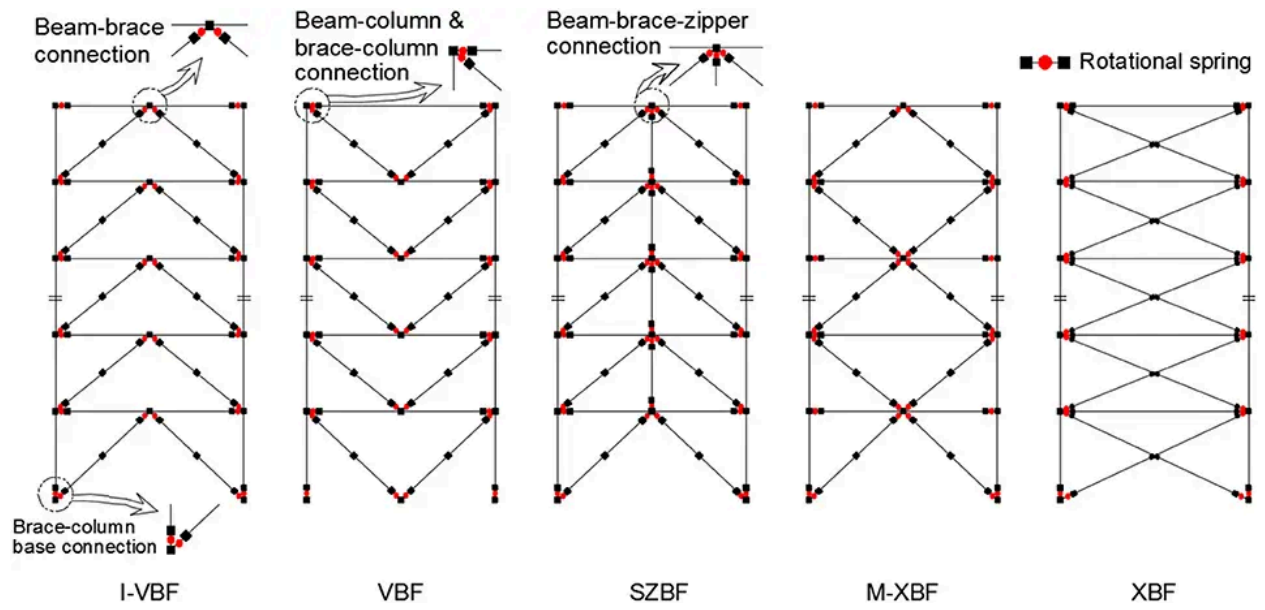


LINKS:

1. [https://www.researchgate.net/figure/1-Moment-Resisting-Frames-Shear-walls-and-Braced-Frames\\_fig3\\_308024223](https://www.researchgate.net/figure/1-Moment-Resisting-Frames-Shear-walls-and-Braced-Frames_fig3_308024223)
2. <https://ccpia.org/types-of-lateral-force-resisting-systems-in-commercial-buildings/>
3. <https://www.steelspecialtiesinc.net/the-ultimate-earthquake-survivors-steel-frames-and-structures/>

## Cross-brace frame (X-bracing)

1.



2.

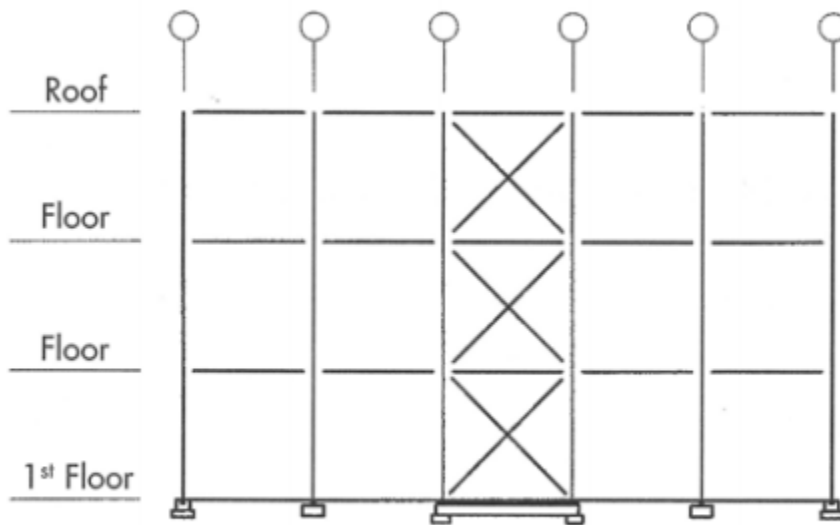
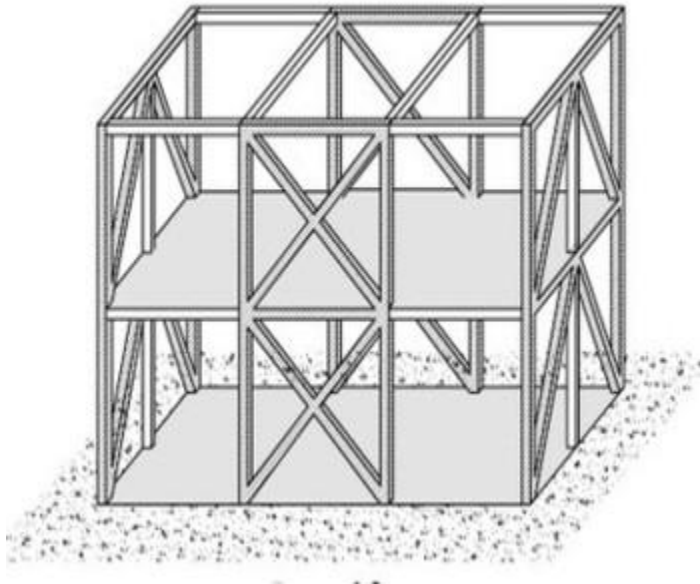


Fig. 5. Cross-braced building elevation.

3.

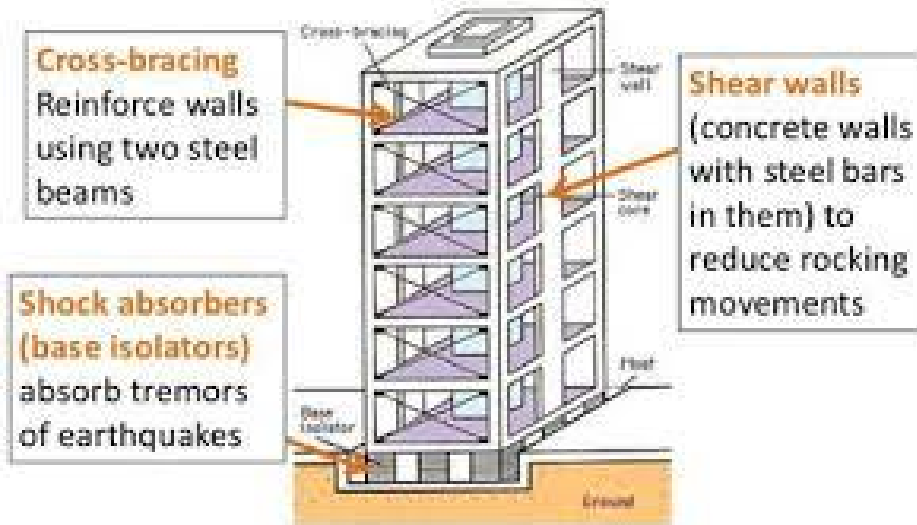


LINKS:

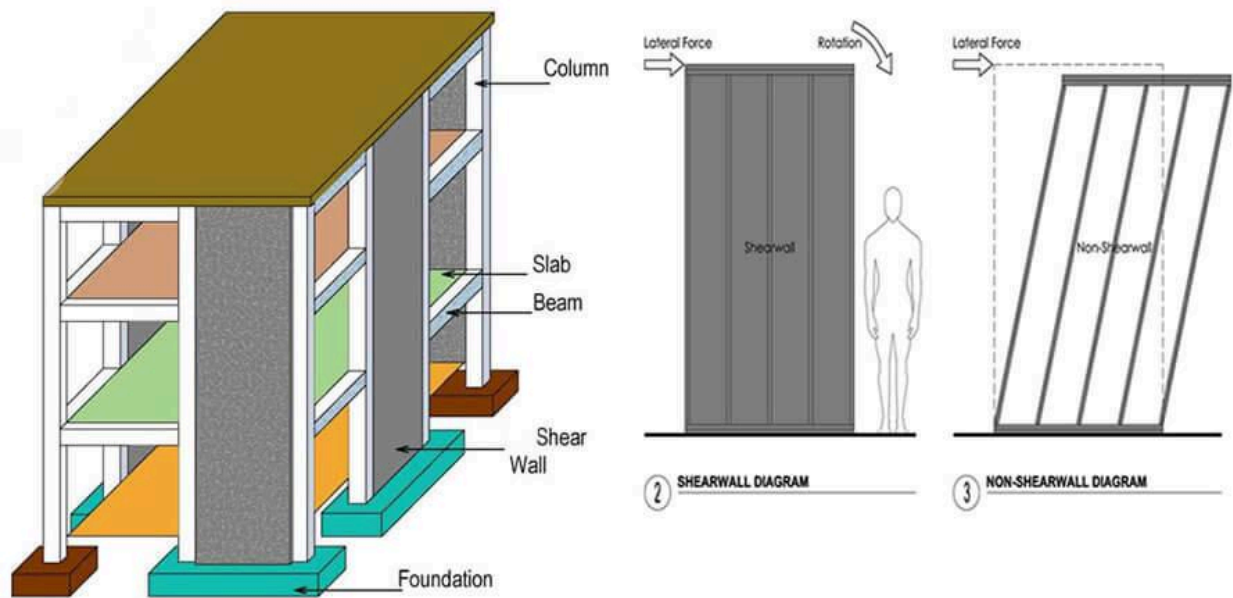
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2. <https://www.aisc.org/architecture-center/engineering-basics/lateral-systems/>
3. <https://taxonomy.openquake.org/terms/braced-frame-lfbr>

# Shear wall

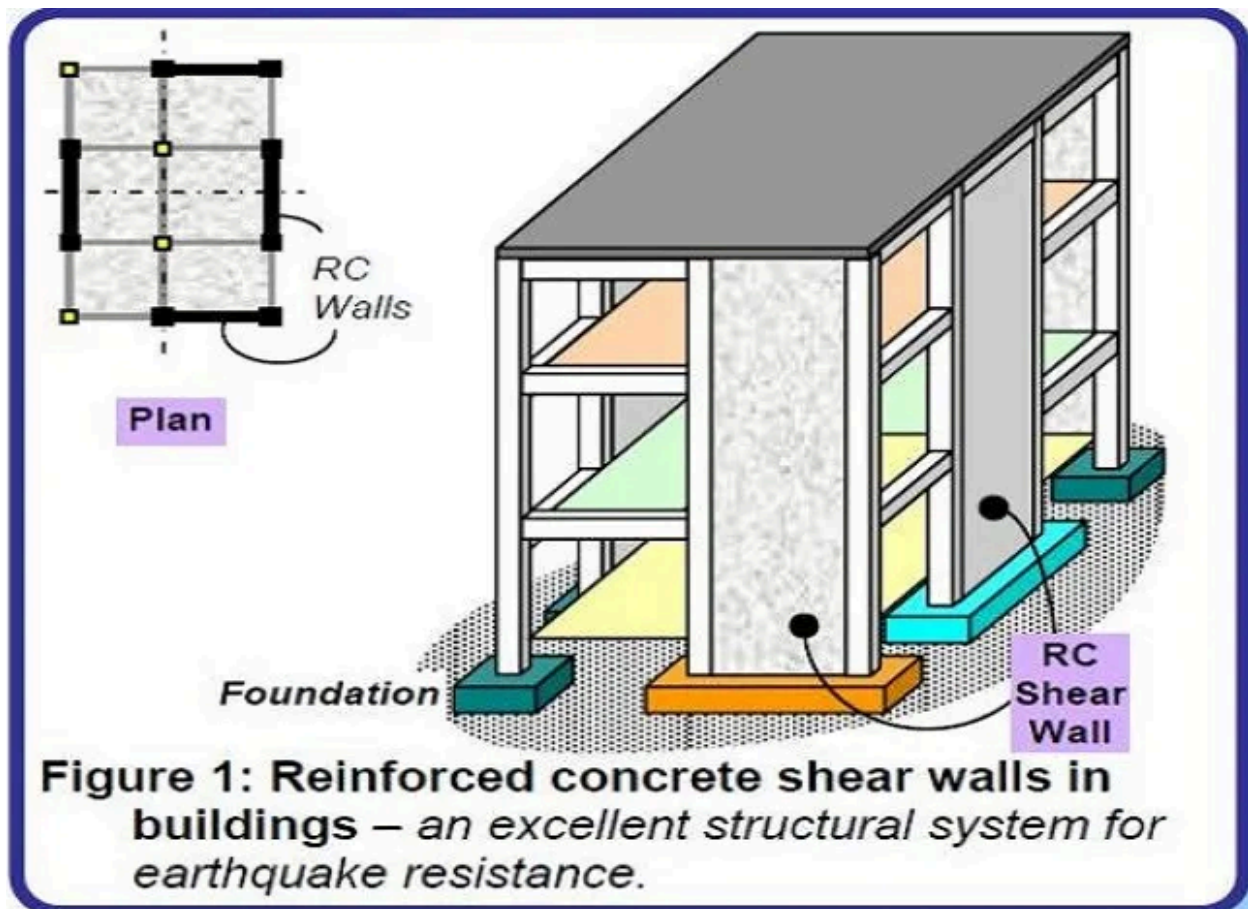
1.



2.



3.



**Figure 1: Reinforced concrete shear walls in buildings – an excellent structural system for earthquake resistance.**

LINKS:

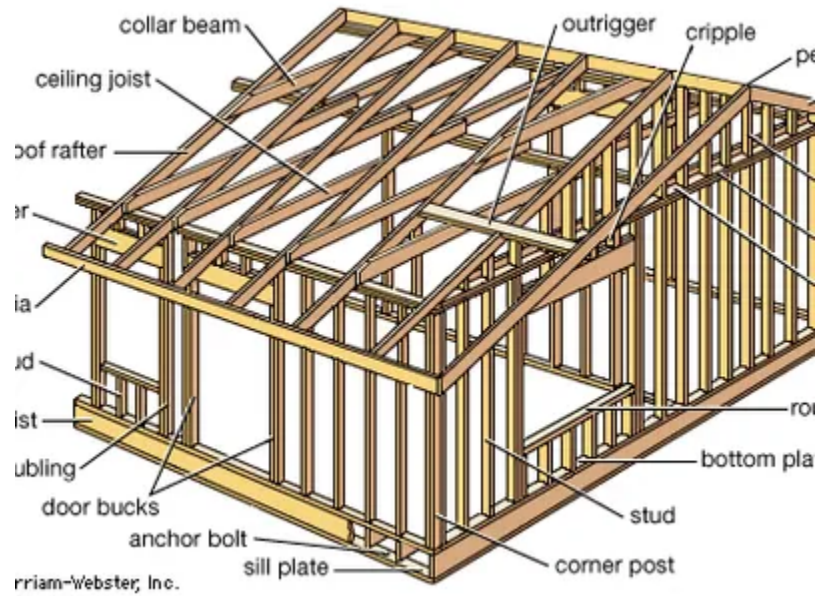
1. [https://www.researchgate.net/figure/Earthquake-resistant-in-a-structure\\_fig1\\_381193294](https://www.researchgate.net/figure/Earthquake-resistant-in-a-structure_fig1_381193294)
2. <https://s3da-design.com/shear-walls-for-lateral-load-resistance/>
3. <https://civilblog.org/2015/07/12/why-are-buildings-with-shear-walls-preferred-in-seismic-regions/>

Design of shear wall:

[https://structurepoint.org/publication/html/DE-Special-Structural-Shear-Wall-Compressive-Stress-A-CI-318-19-spColumn-v1010/index.html#t=DE-Special-Structural-Wall-Compressive%2F00%2F00.htm%231271290&rhtocid=\\_0](https://structurepoint.org/publication/html/DE-Special-Structural-Shear-Wall-Compressive-Stress-A-CI-318-19-spColumn-v1010/index.html#t=DE-Special-Structural-Wall-Compressive%2F00%2F00.htm%231271290&rhtocid=_0)

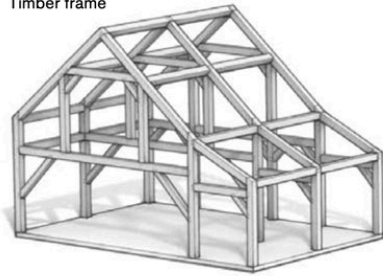
# House Models

## Stick frame



## History of House Frames

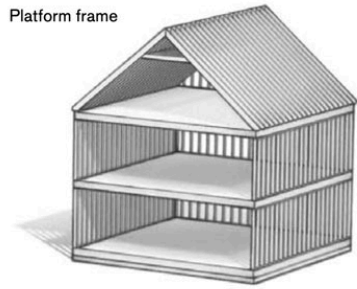
Timber frame



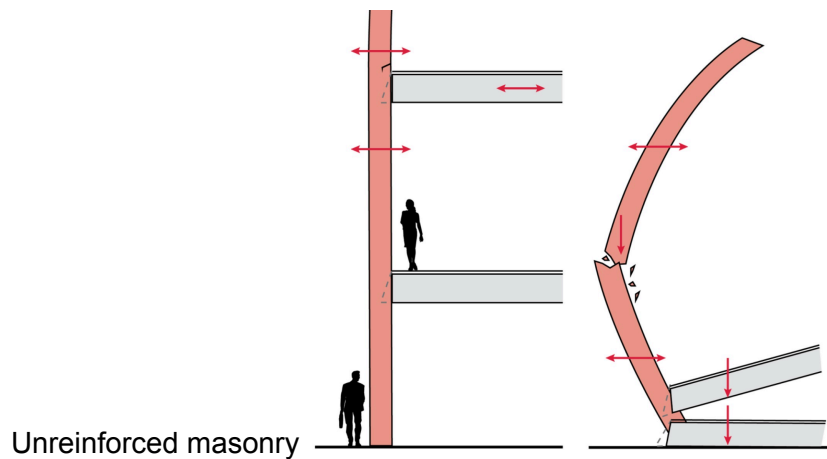
Balloon frame



Platform frame



<https://www.finehomebuilding.com/project-guides/framing/evolution-of-the-house-frame>



Unreinforced masonry



Confined masonry

