Falling Water Restoration

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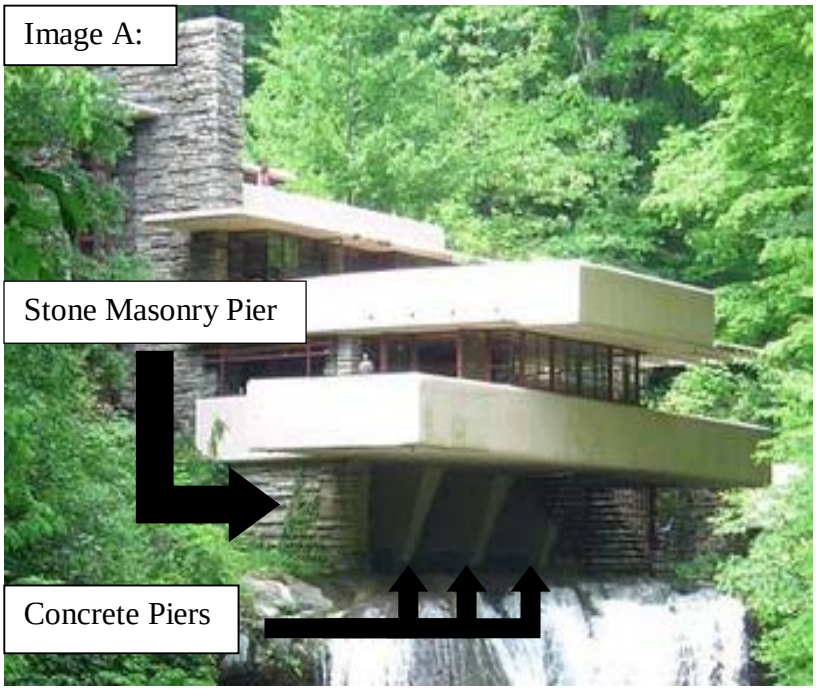
History:

Falling Water is a modernistic home built for the Kauffman family by Frank Lloyd Wright in 1935. Originally, the home was going to sit beside a waterfall on bear- run creek, but wright was inspired by the beauty and serenity of the location, and decided to build the house atop the waterfall. Later, Kauffman quotes, "The visit to the waterfall in the woods stayed with me, and a domicile has taken vague shape in my mind to the music of the stream." Due to limited land for a foundation, wright took inspiration from the rocks jutting out of the waterfall and decided to use a cantilevered structure; In doing this, he hoped to create the illusion that the water had eroded the foundations of the structure over time; magnifying the power of water.

Structure:

The Basic foundation of Falling Water stands on four main piers (visible in image A.): three of which are made from reinforced concrete, while the fourth pier is made up of stone masonry mined from a nearby stone quarry that was reopened during construction. The first floor consists of four cantilevered beams, which project 15’ from the piers into mid-air. The beams are supported by concrete joists which transfer the weight from the first floor to the beams. For further strength, wright designed a 4” concrete slab to be monolithically cast to the underside of the beams and concrete joists; this method provided an efficient inverted T- Beam System.

Image A:

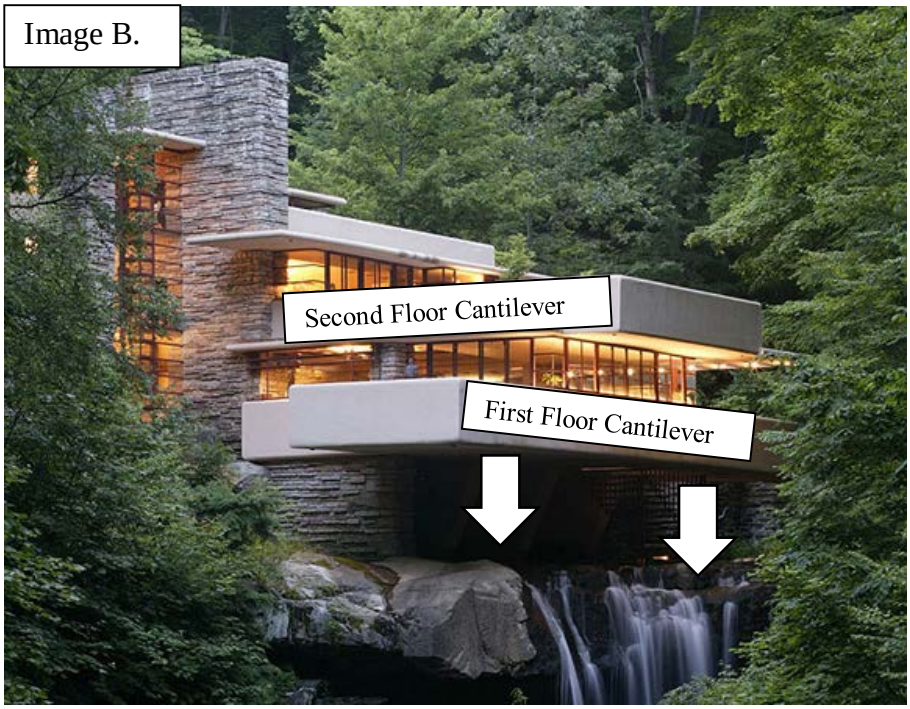


The cantilever on the second floor overhangs the first floor by 6’. Structurally, the second floor consists of joists and a concrete slab that are compressed between two edge beams which provide extra strength for the structure.

Failures:

After the first floor was completed and the framework was removed, workers recorded a 1.75" deflection in the cantilever. Following the completion of the second cantilever, two large cracks appeared in the ceiling of the first floor; at this point it became obvious that there was a problem with the structural design. In 1995, further examination of Falling Water showed a deflection of 7" in the first floor cantilever (the tilt can be seen in image B). The reasoning behind such a large deflection lies in the insufficient structural capacity of the cantilevered girders. Because the girders did not have a sufficient amount of negative reinforcement steel, the existing steel reached its holding limit and began to expand; deflecting the first floor cantilever and threatening to collapse the building. Furthermore, during construction, it was believed that the second floor terrace acted independently, however, this was not the case; contradictory to beliefs, the second floor terrace transferred its weight to the edge of the first floor cantilever by means of the four steel window mullions. This extra weight to the edge of the cantilever added to the significant deflection of the first floor.

Image B.

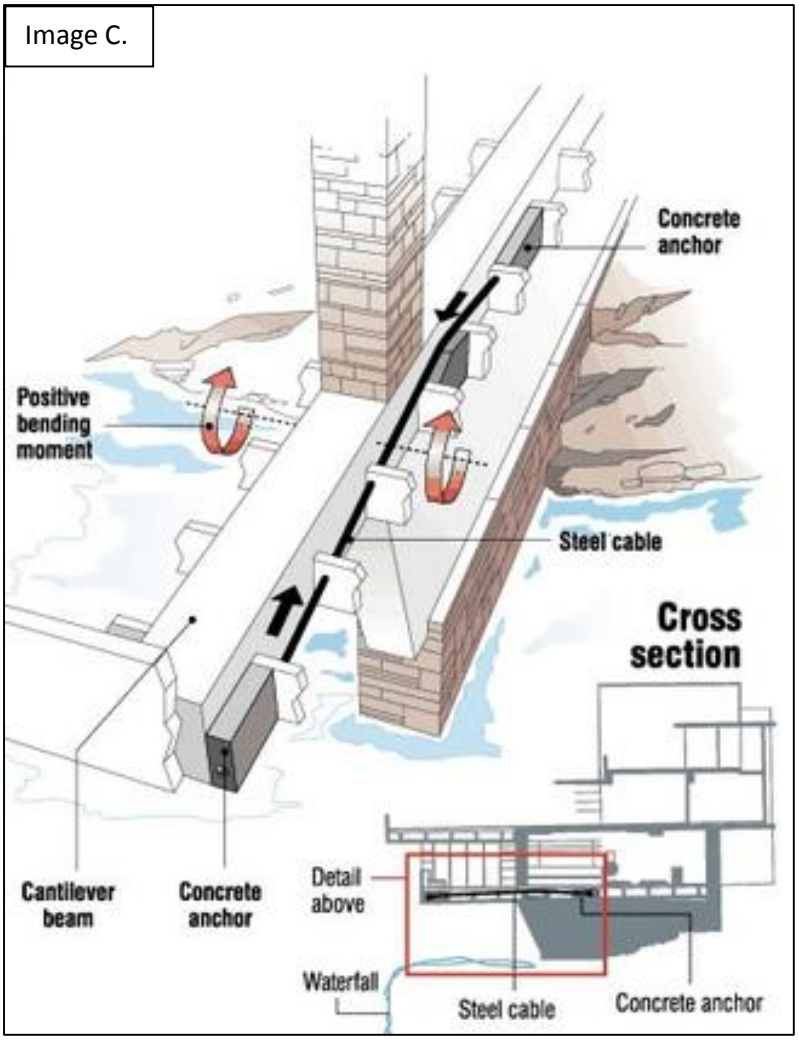


Restoration:

Following the major deflection discovery in 1995, the Western Pennsylvania Conservatory decided to take steps towards restoring Falling Water. While a permanent solution to the problem was being solved in 1997, temporary shoring was placed beneath the first floor to support the structure and prevent any further damage to the building. Finally, in 2002, Falling water was repaired permanently using post- tensioning.

Post- Tensioning involves applying tension to the rebar, after the concrete has been set. In the case of Falling Water, this tension was achieved by using large steel cables (see image C).

Image C.


Concrete anchor
Positive bending moment
Steel cable
Cross section
Cantilever beam
Concrete anchor
Detail above
Waterfall
Steel cable
Concrete anchor