

Structural Renovation of Fallingwater



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Background:

- It was designed by Frank Lloyd Wright.
- It is one of the best-known works of architecture nationally and internationally.
- Voted “Best work ever produced by an American architect” by AIA 1991.
- Commissioned by Edgar Kaufmann, Sr. , a wealthy businessman in Pittsburgh.



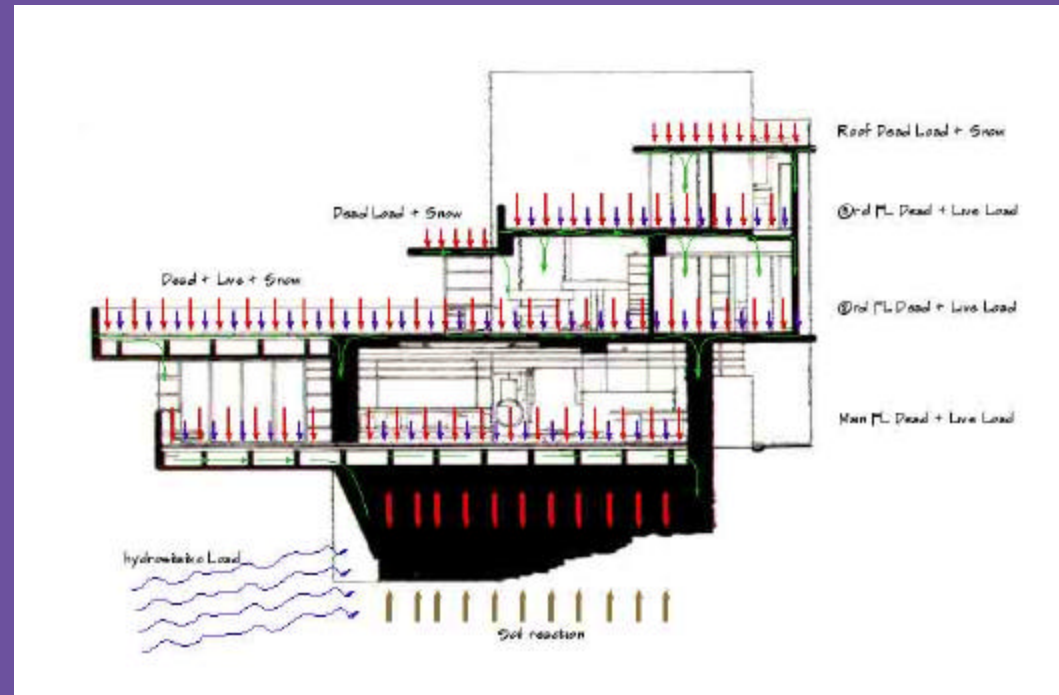
Background (continued):

- Structural design and calculations by Mendel Glickman & William Peters.
- Signature feature is terraces cantilevered over the Bear Run Stream.
- The cracks and sagging in terraces were a big concern to the owner from the start.



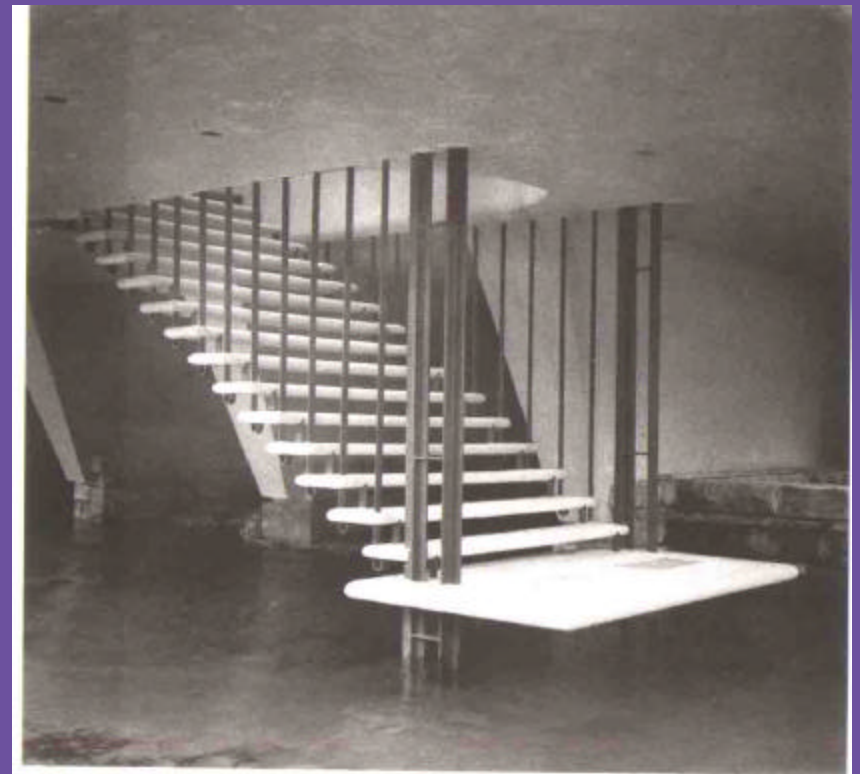
Gravity Loads:

- Transferred through masonry walls and 3 concrete bolsters.
- Dead Load+Live Load+ Snow
- Loads Decrease in higher levels.
- The aim was to balance the weight of the cantilever by stacking levels on the north side.

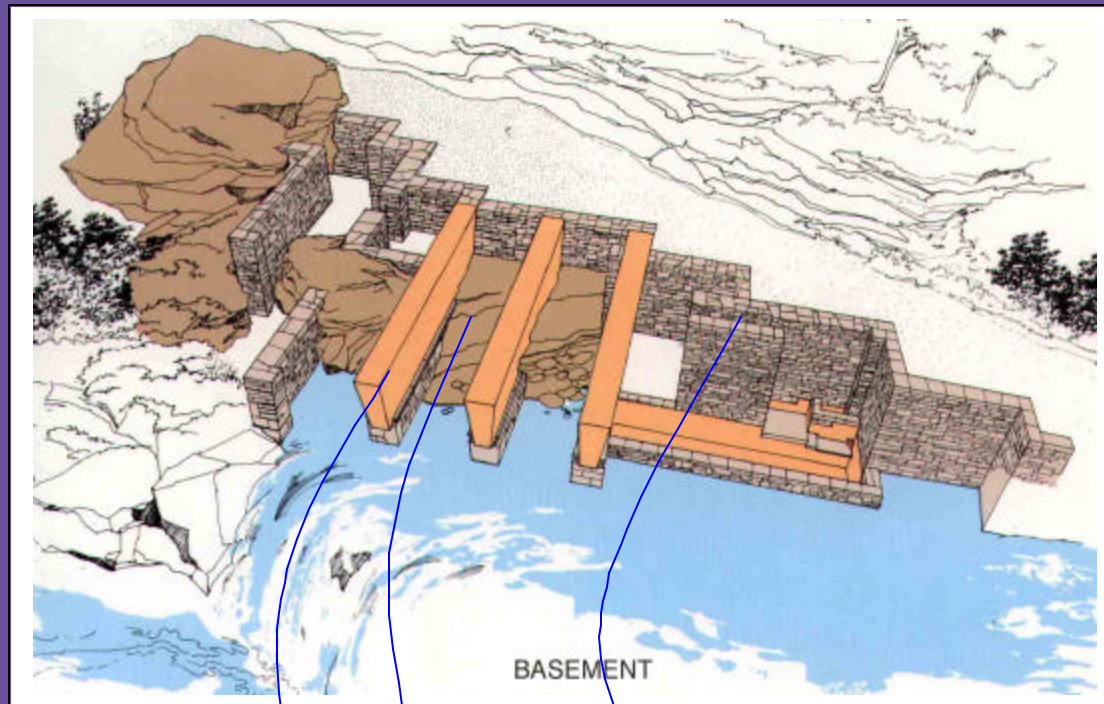


Dynamic & Impact Loads:

- A force is applied suddenly or changes rapidly
- During storms rocks in river hit the building.
- Steel columns of the staircase to the stream buckled due to impact loads.
- Water levels rise and increase the force applied to the building



Foundation: Series of four bolsters built into the natural sandstone ledge comprise the main foundation

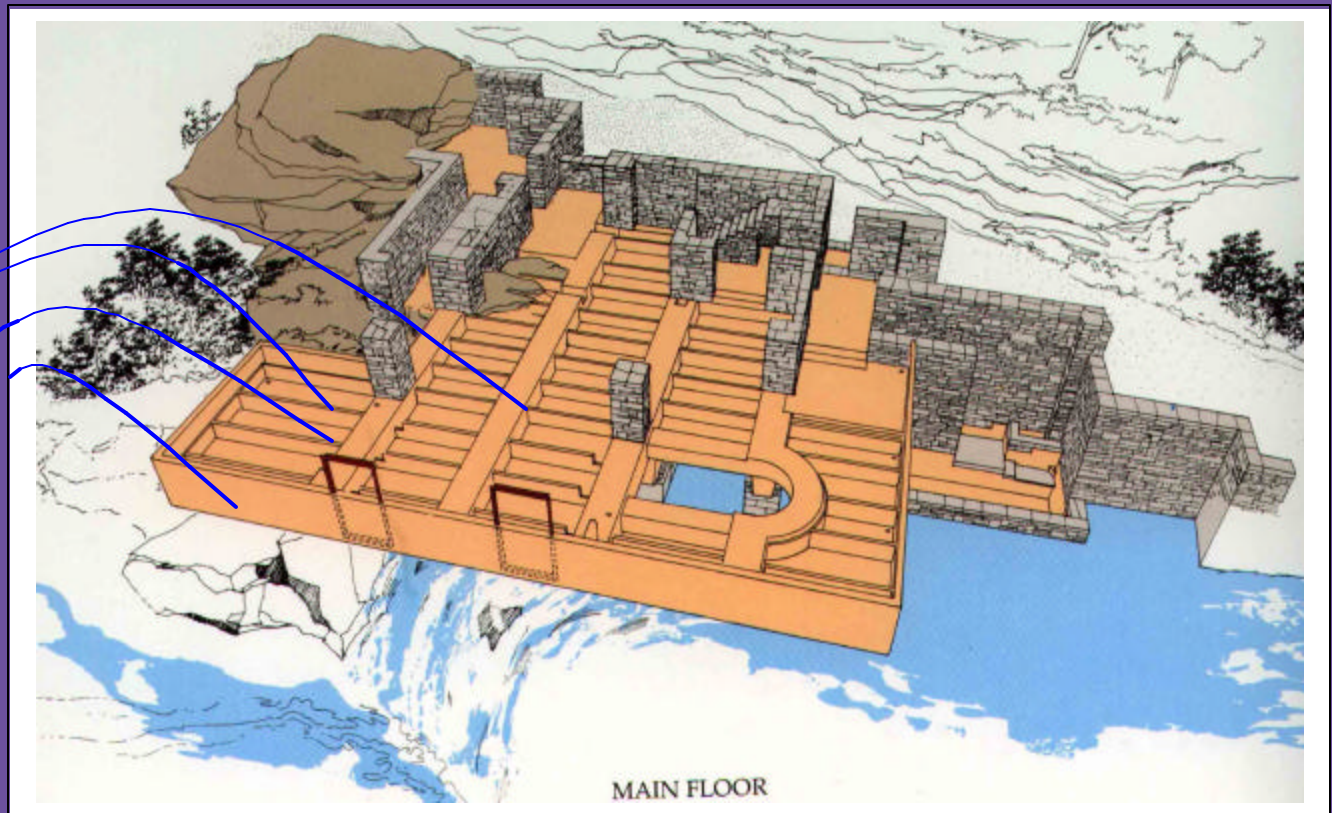


Concrete Bolsters

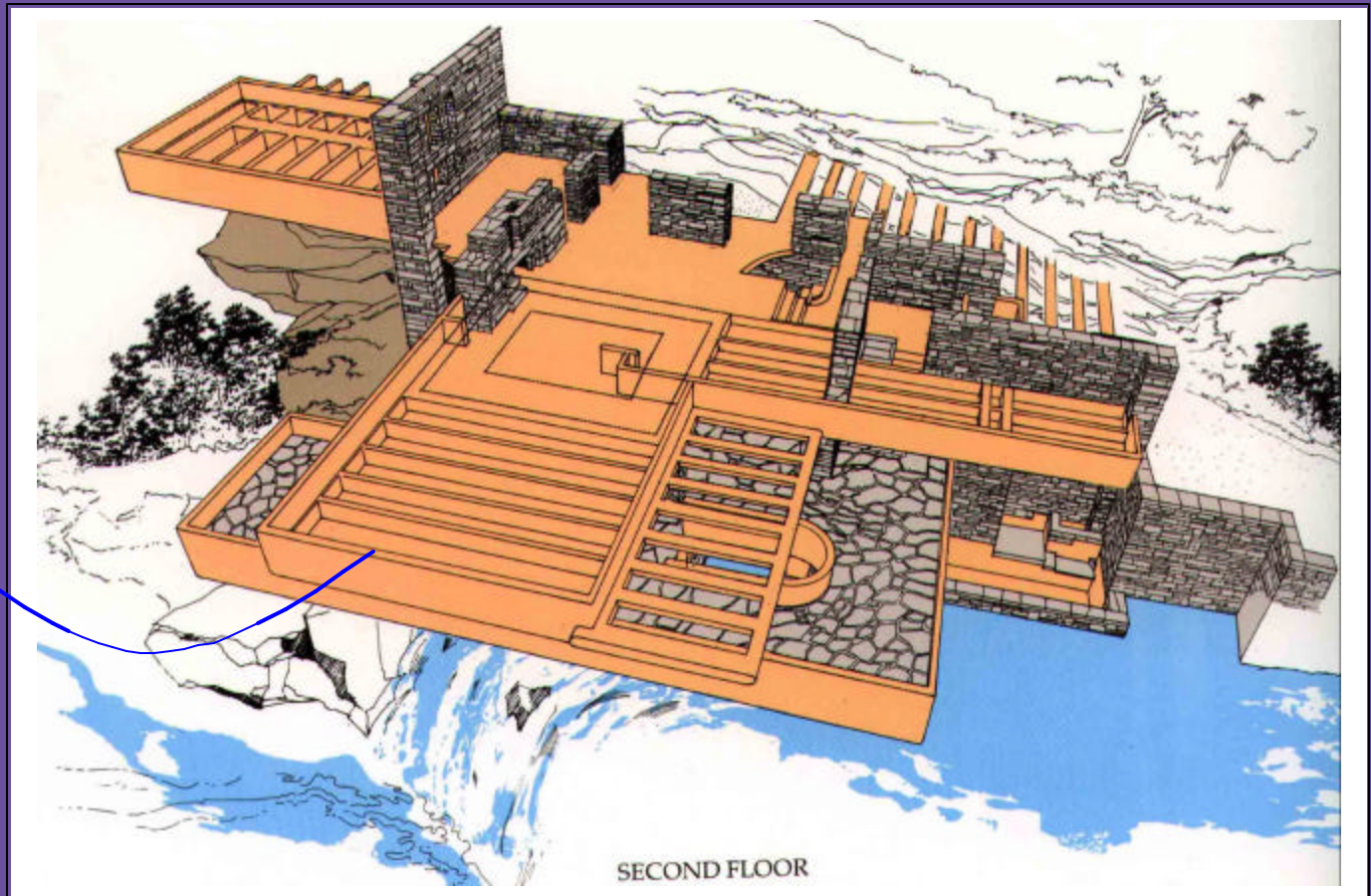
Natural Boulders

Stone bearing walls

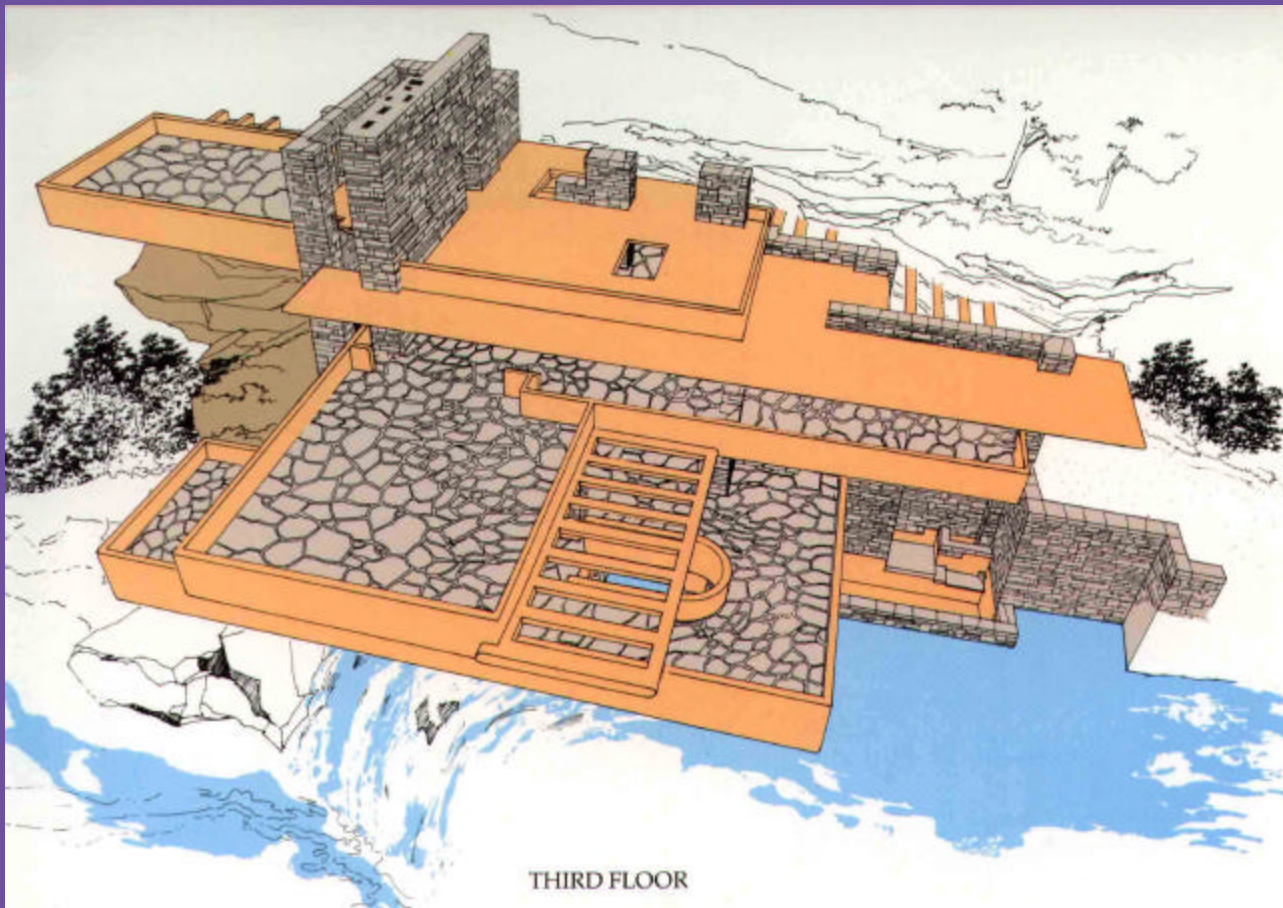
Main Terrace: Each bolster supports supports a horizontal reinforced concrete beam that extends 15 feet beyond the bolster. The beams are connected to one another by concrete joists, each 4 inches wide. Together the beams and joists create a rectilinear grid.



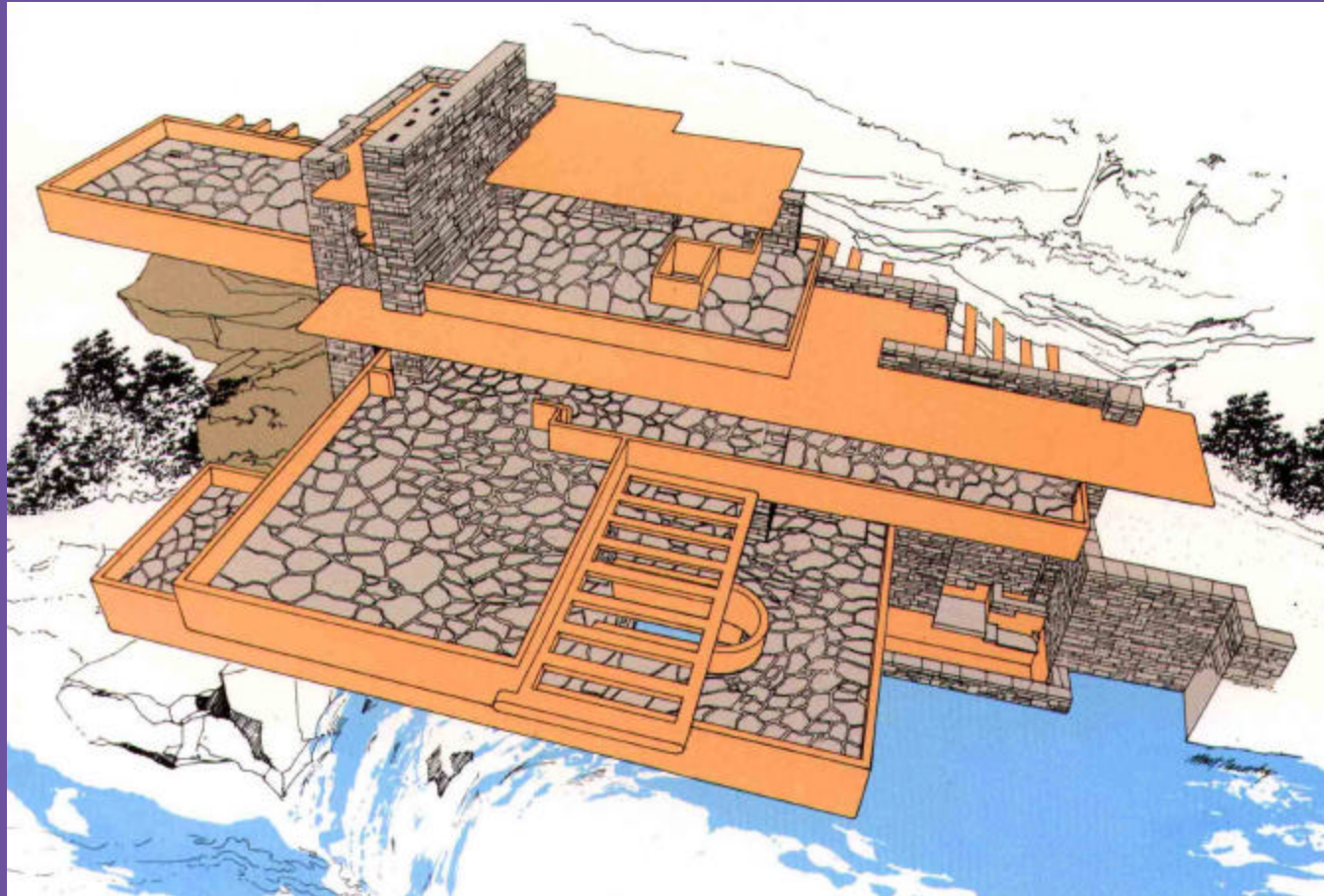
Master Bedroom Terrace: The master bedroom terrace extends an extra 6 feet beyond the first floor terrace. Beside the concrete floor joists and the structural parapets, it is supported by 4 steel window mullions embedded in the first floor parapet.



Third Floor: Kaufmann Jr.'s Study and later sleeping area



Roof:



Structural Problems:

- Analysis shows Deflections still growing
- Engineers increased the # of 1” steel bars from 8 to 16
- Wright angered, claimed the extra load of the added steel was the problem
- Later analysis showed that if they hadn’t doubled the steel, beams would have certainly failed
- When wood framework was removed, 1st floor concrete terrace sagged 45 mils instantly and grown up to 8” in 70 years.
- These cantilevered beams also carry forces from the 2nd floor terrace
- Some say it is due to the flaw in construction. They should have sloped the terrace upward so that it would sag into the horizontal position after settlement

“oh my god, I forgot the negative reinforcement!”

- Glickman, Fallingwater’s Structural engineer forgot the negative reinforcement
- He was referring to the reinforcement for negative bending moment, which causes compression in the lower part of each cantilever beam and tension in the upper part
- Any beam made of reinforced concrete, the concrete resists the compression on the beam and the steel bars resist the tension
- after workers removed the framework from the concrete of the master bedroom terrace, two major cracks appeared in the terraces parapet

Solutions:

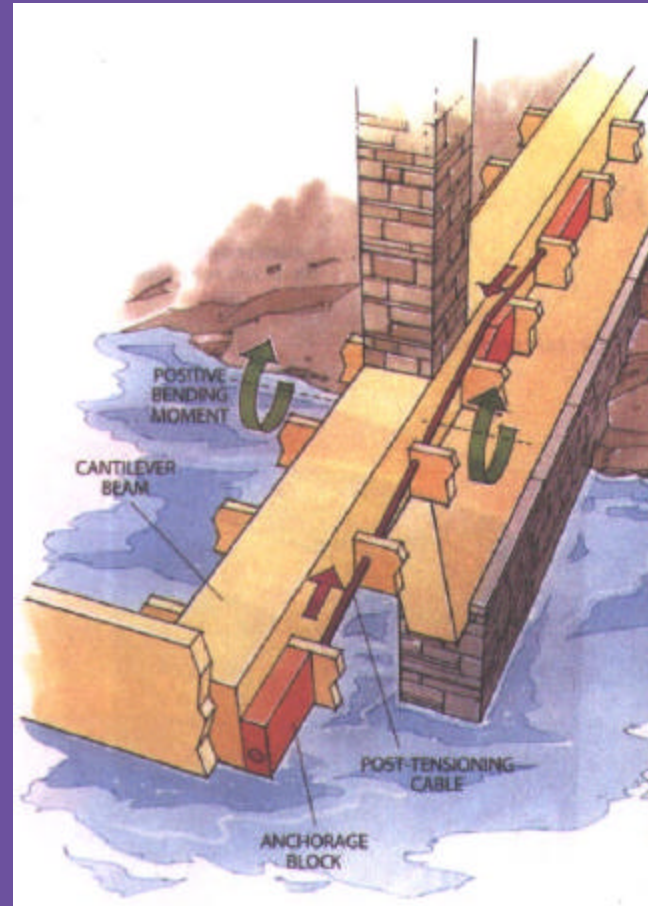
- Leaving the shoring in place which looked ugly
- Providing supplemental steel framing
- Augmenting the steel by using bonded steel plating, which would have eventually interfered with the floor height.
- Fiber reinforcing at the top surface, which could not provide sufficient added capacity
- Using high-strength post-tensioning. This was chosen

Steel Shoring:



Post-tensioning:

- For safety the house was first shored
- It doesn't change the outside appearance
- Steel cable was passed thru drilled joists & attached to a concrete block at the end.
- Anchored at north end & post tensioned at the south end with a hydraulic jack to create the needed positive moment



Structural calculation:

- Existing concrete strength of 5000 psi
- Yield strength of existing steel 41,000 psi.
- The stress in the reinforcing bars of the terrace's parapet are 1,195 megapascals, or more than four times the steel's yield strength.
- Stresses of 288 megapascals in the steel of the main cantilever beam and 30 megapascals in the concrete. These stresses are at critical level and they are just about the yield strengths of the material

References:

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- * All the contents of this "course project" (including photos) have been obtained from the above references. I have not added anything to the body of knowledge. This is merely an exercise to understand Fallingwater through what I learned in Arch631.