AN AMERICAN MASTERPIECE

"There in a beautiful forest was a solid, high rock ledge rising beside a waterfall, and the natural thing seemed to be to cantilever the house from that rock bank over the falling water....Then came (of course) Mr. Kaufmann's love for the beautiful site. He loved the site where the house was built and liked to listen to the waterfall. So that was a prime motive in the design. I think that you can hear the waterfall when you look at the design. At least it is there, and he lives intimately with the thing he loves."

–Frank Lloyd Wright

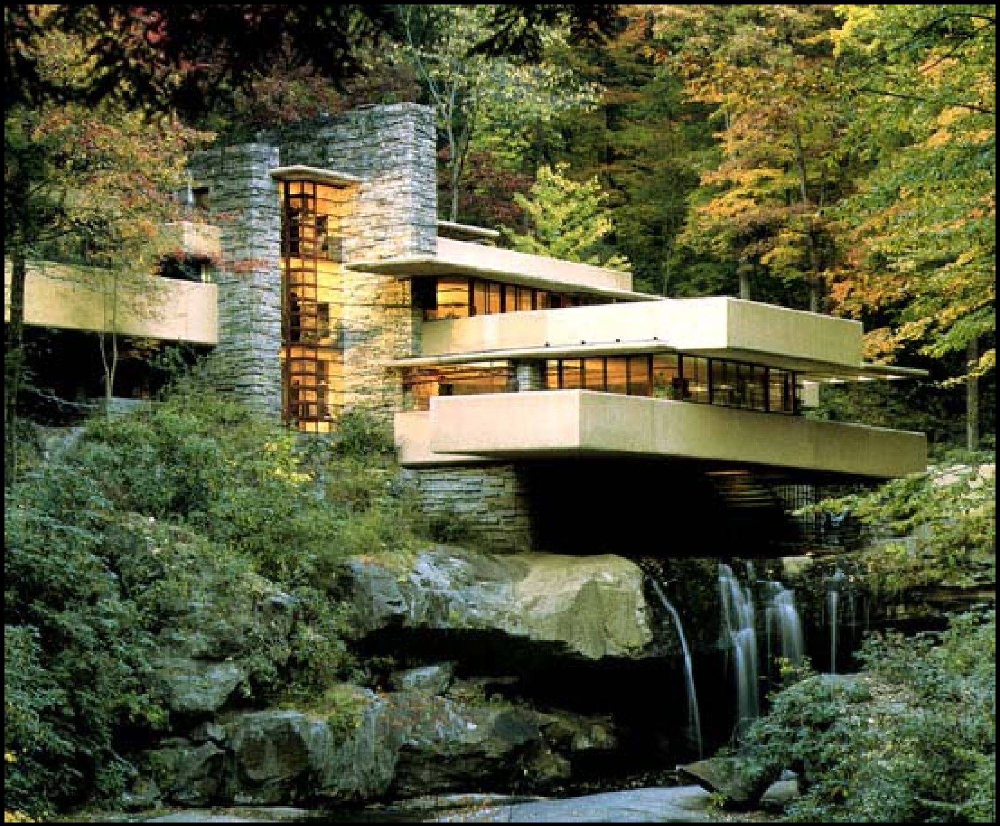
FALLINGWATER

PAST-PRESENT-FUTURE

HISTORICAL BACKGROUND

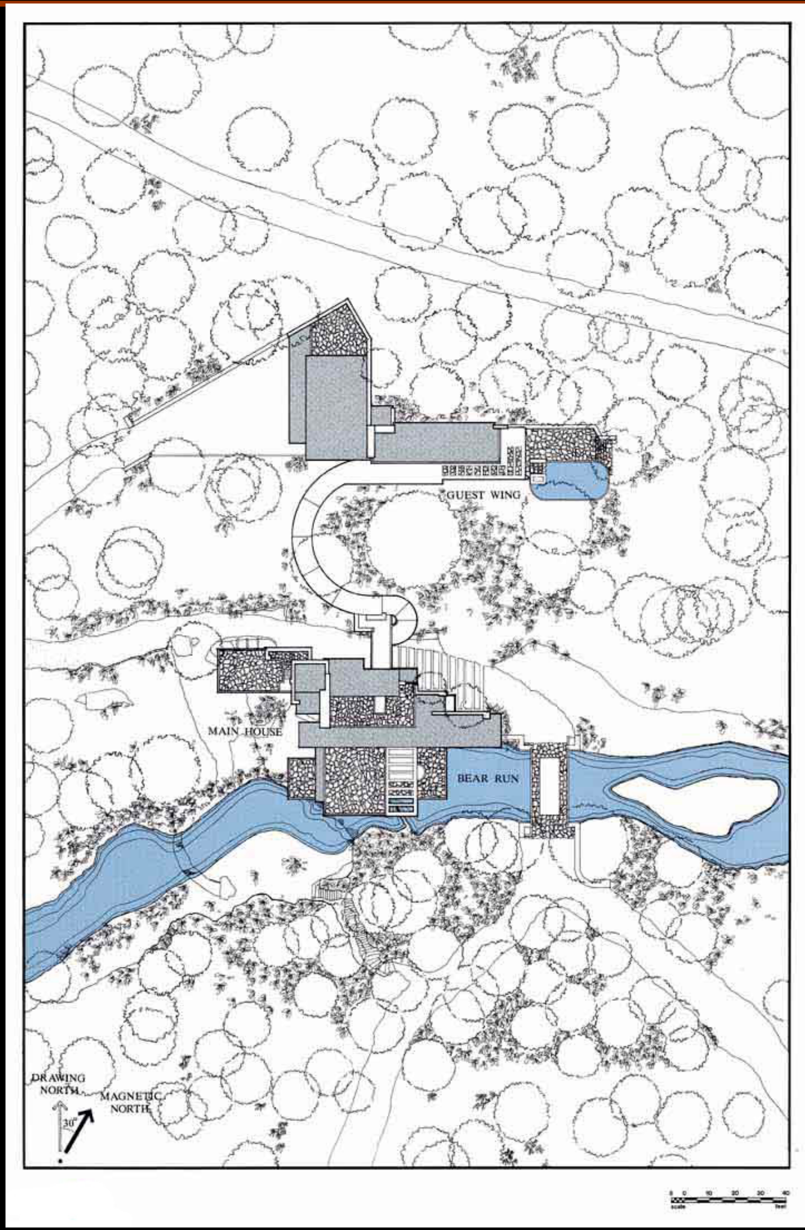
- Designed by Frank Lloyd Wright in 1935 for the Kaufmann Family as a response to the family's love for the site where a waterfall was located in a rushing mountain stream.

- Great example of Wright's concept of organic architecture.

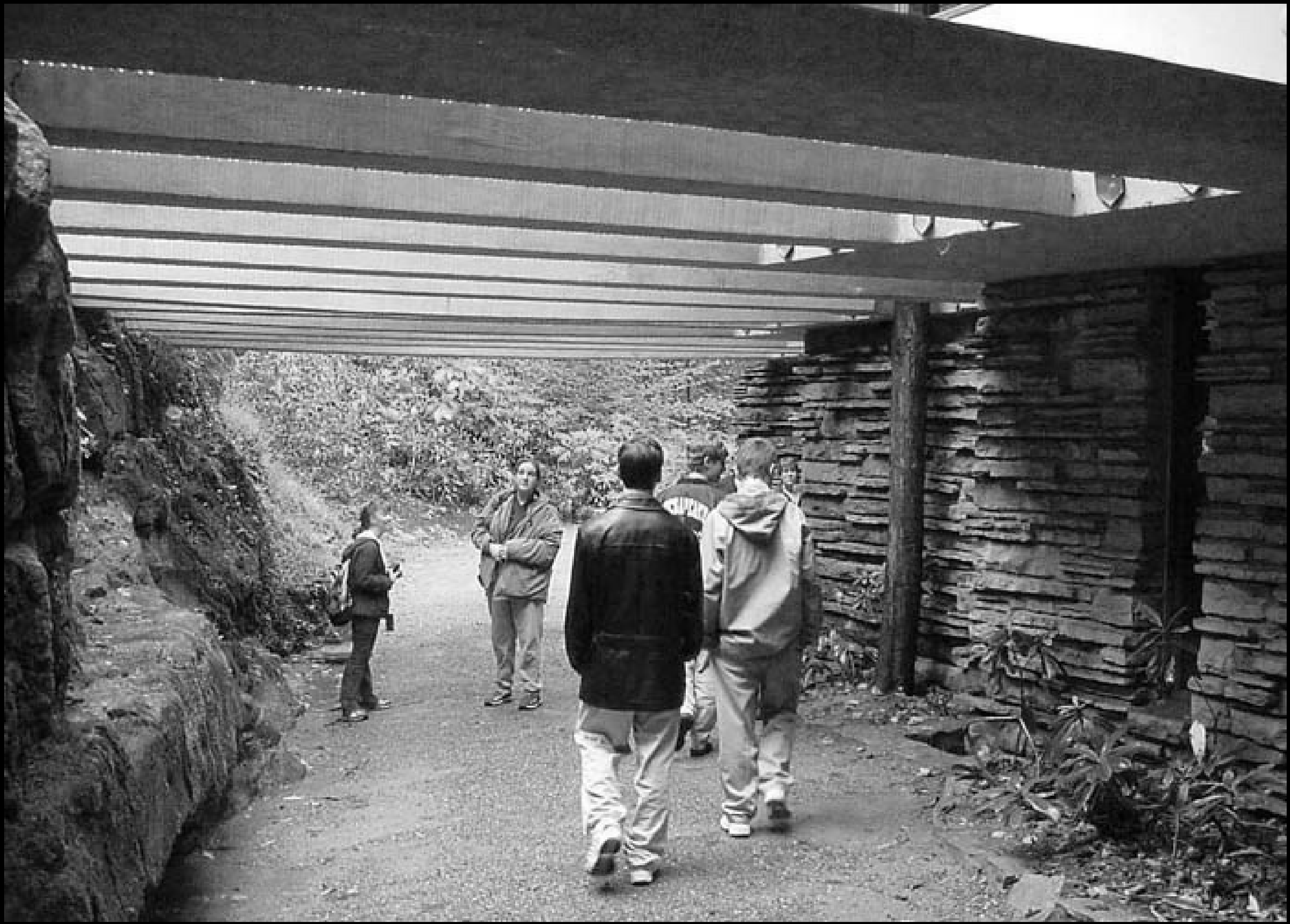


HISTORICAL BACKGROUND

- Located near Pittsburg, Pennsylvania.
- It promotes harmony between man and nature through design.
- So well integrated with its site that the structure and surroundings are fused together in an interrelated composition.



STRUCTURAL ANALYSIS



"NATURE CANTILEVERED THOSE BOULDERS OUT OVER THE FALL, I CAN CANTILEVER THE HOUSE OVER THE BOULDERS."

STRUCTURAL DESIGN

- Mimics the natural pattern established by the stream's rocky ledges by placing the house over the falls in a series of cantilevered trays.

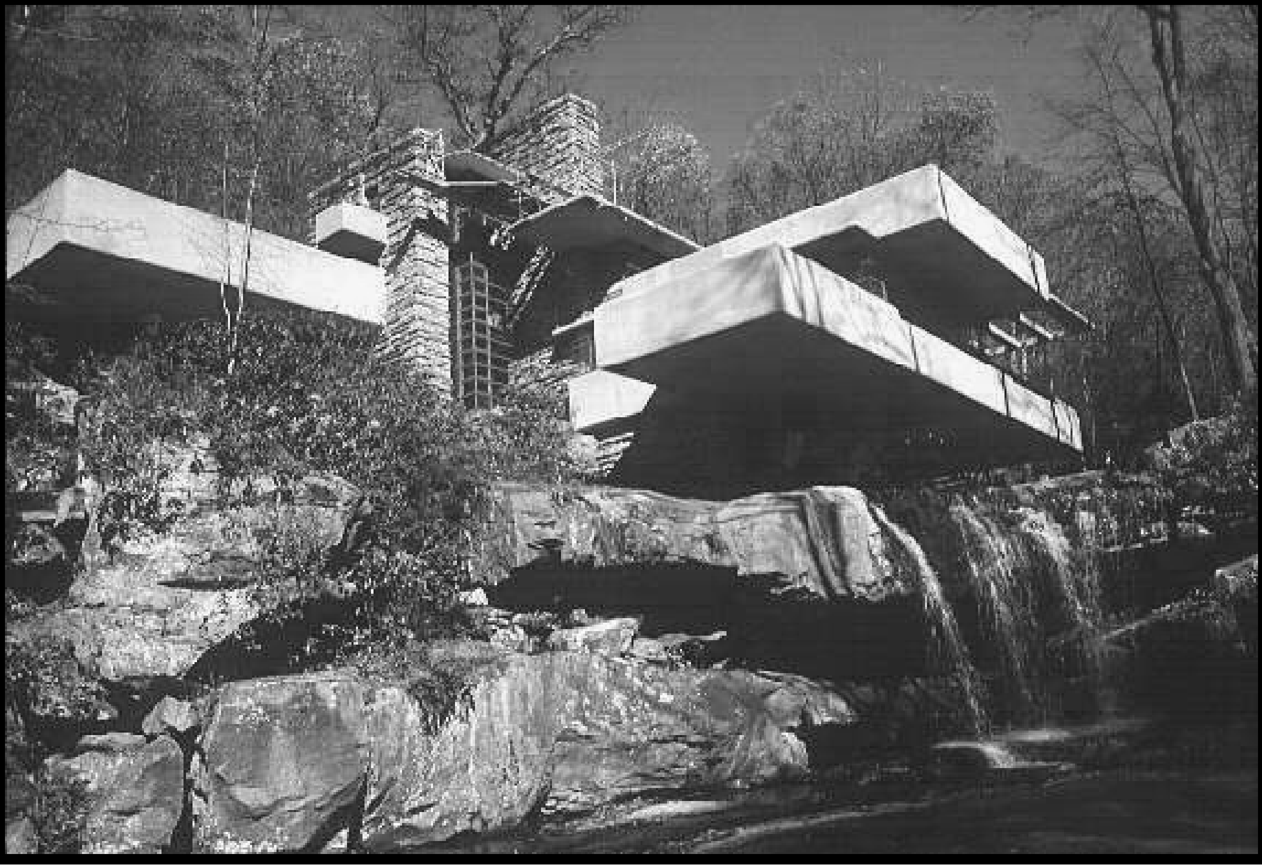
- Slabs were anchored to containment walls made out of the same sandstone found in the rock ledges.

- Structural design under the direction of the engineers: Mendel Glickman and William Peters.

- In 1963, Edgar Kaufmann, Jr. donated the house to the Western Pennsylvania Conservancy

STRUCTURAL DESIGN

- The house is anchored into the rocky mountain, its platforms jutting over the stream like rock ledges, counterweighted by the massing at the back.
- Slabs are anchored to containment walls made out of the same sandstone found in the rock ledges.



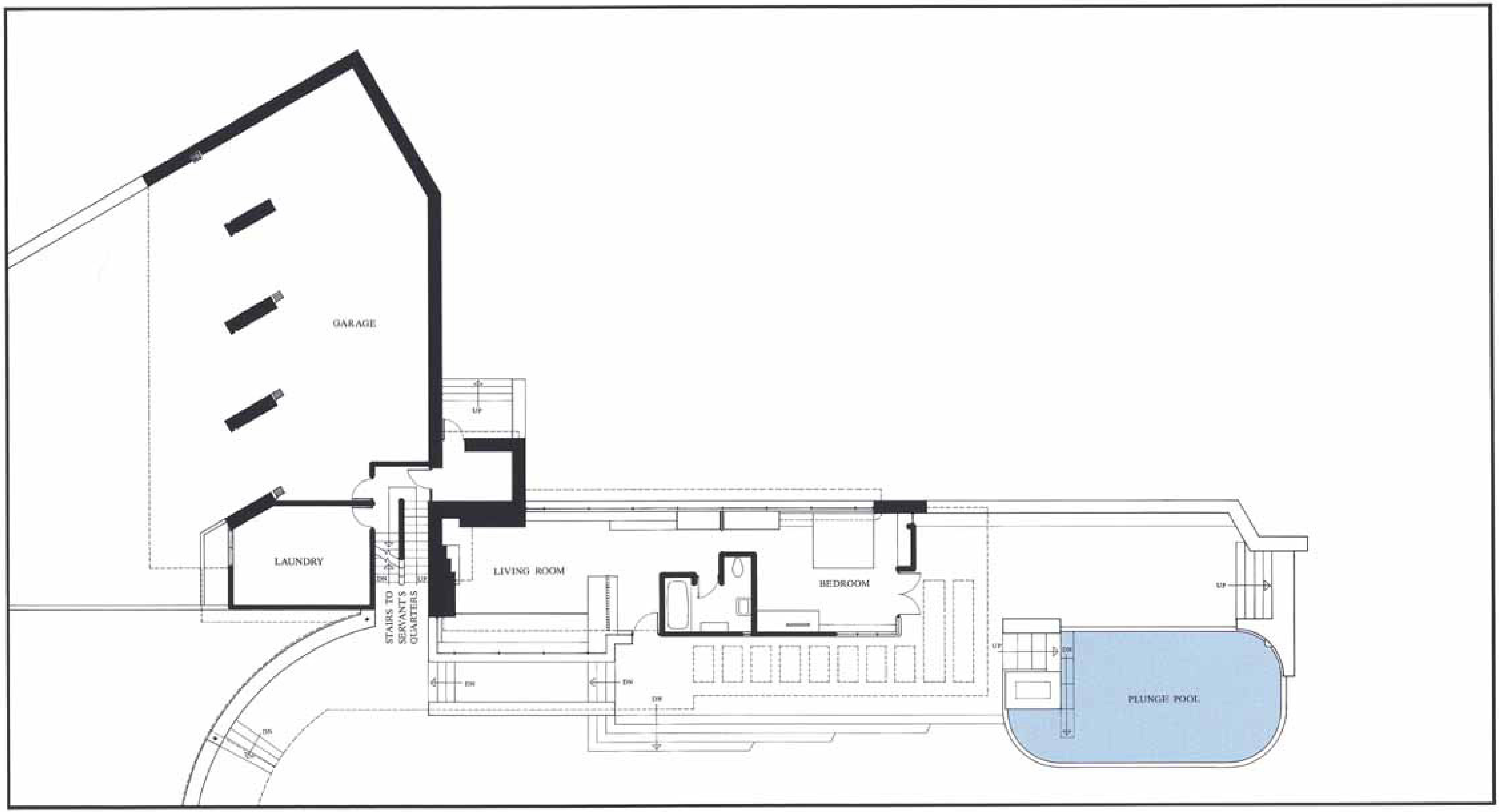
STRUCTURAL DESIGN

- Four massive concrete cantilever beams projecting 15 feet held cantilevered terraces where living room, master bedroom and adjoining terraces where located.

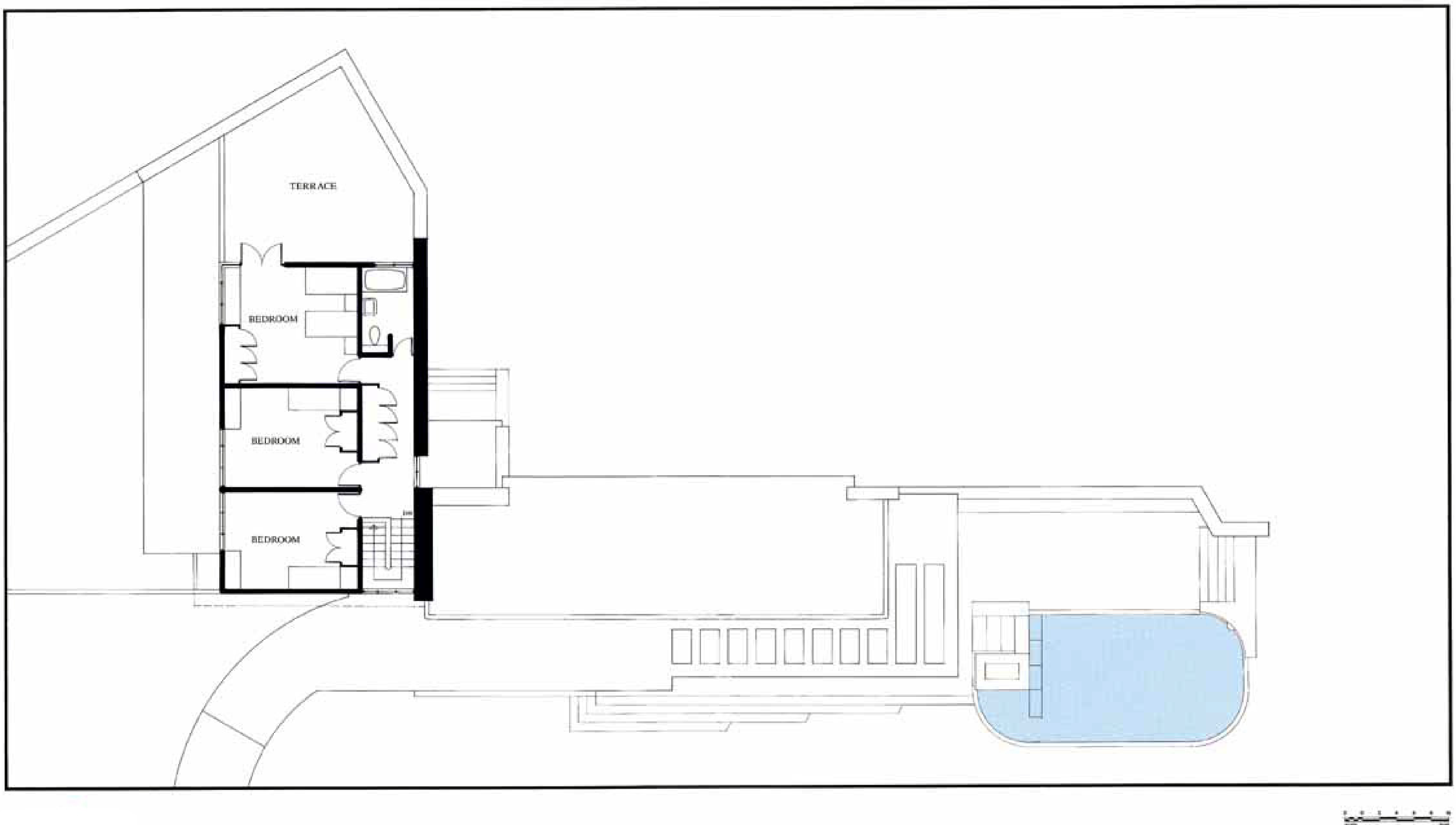
STRUCTURAL DESIGN

Window mullions which, at first were considered as non-structural elements were found to transfer loads from the upper terraces to the lower terrace.

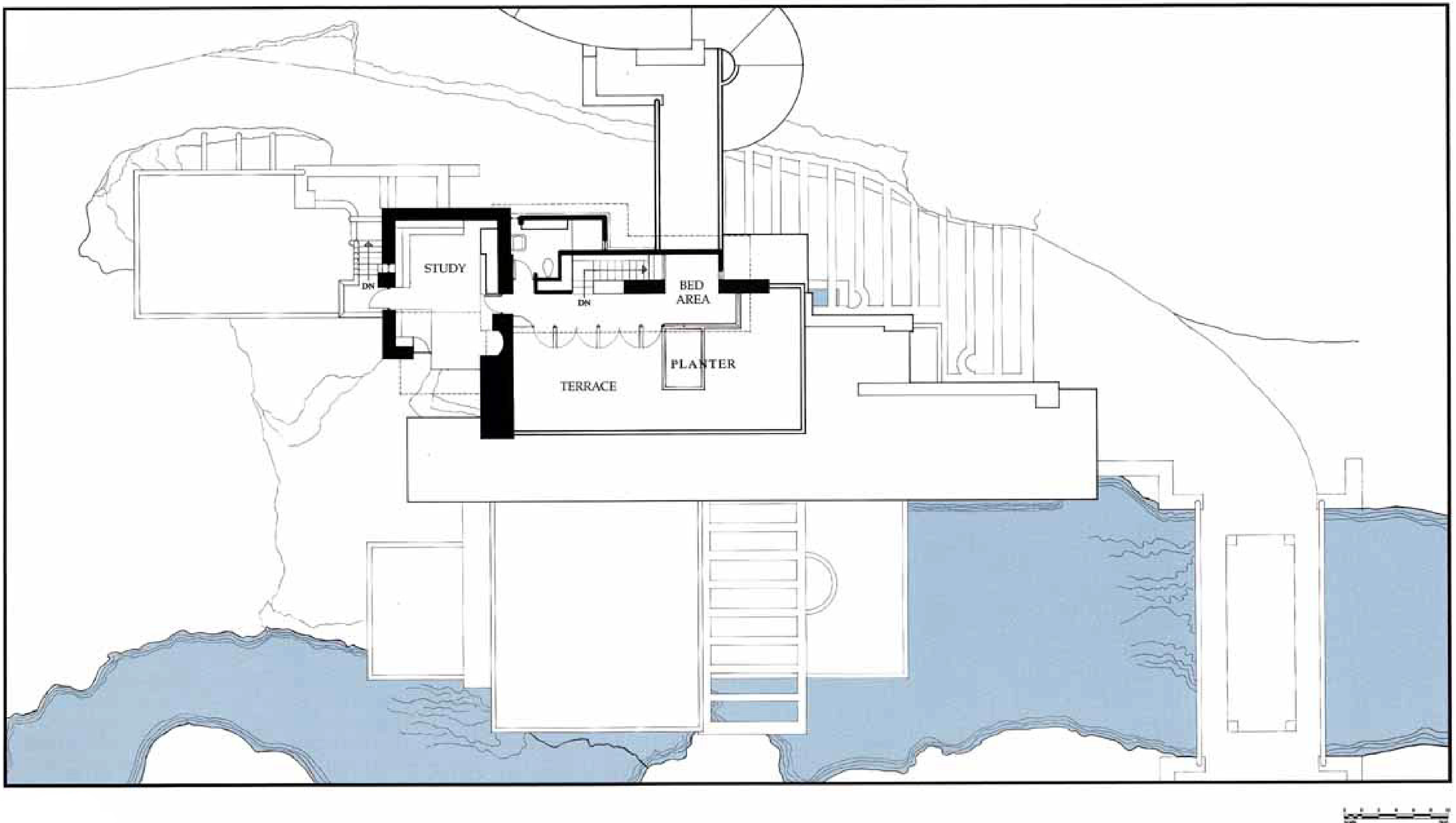
MAIN FLOOR


GARAGE
UP
LAUNDRY
LIVING ROOM
BEDROOM
STAIRS TO SERVANT'S QUARTERS
DN
UP
PLUNGE POOL

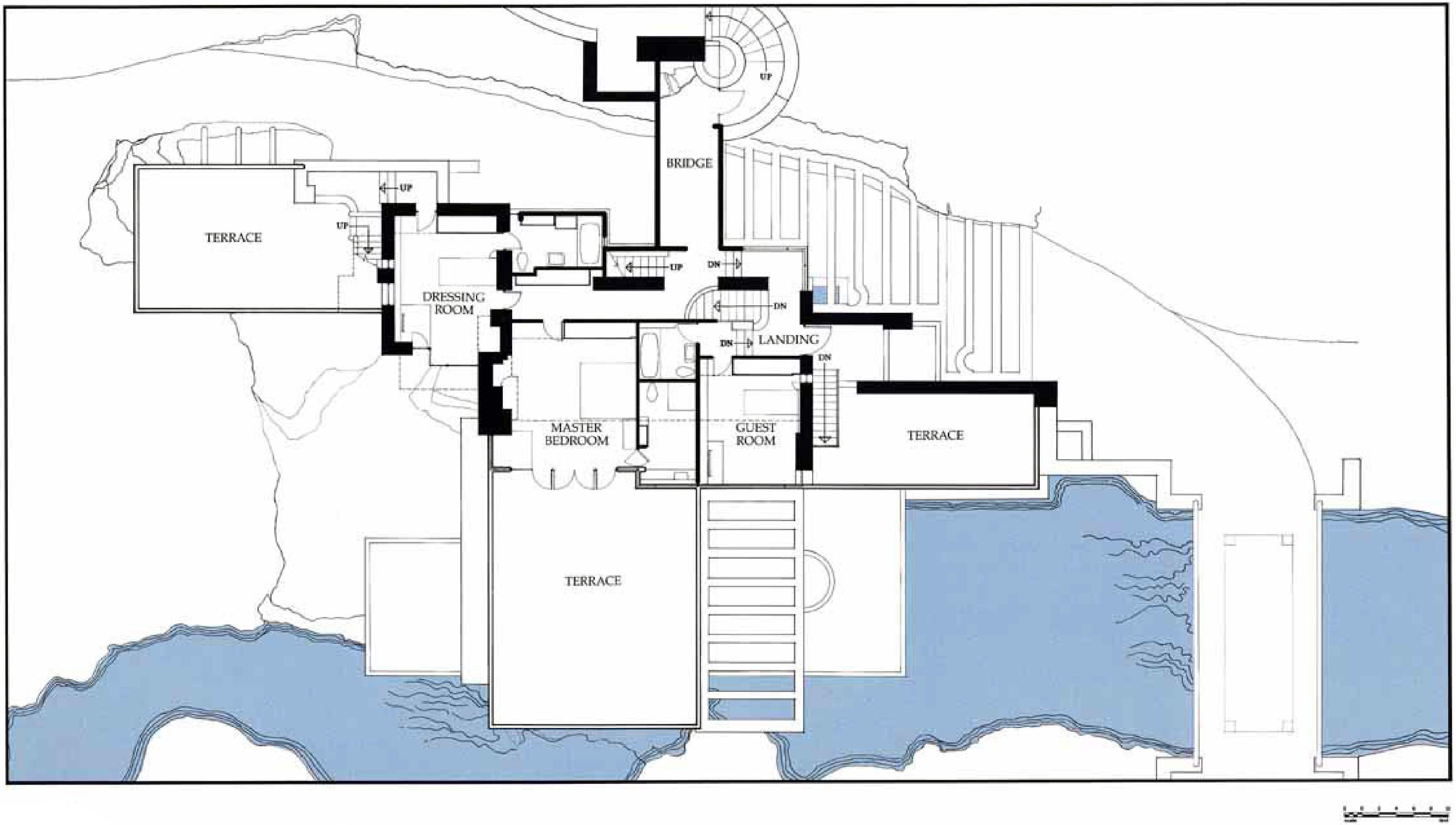
1ST FLOOR



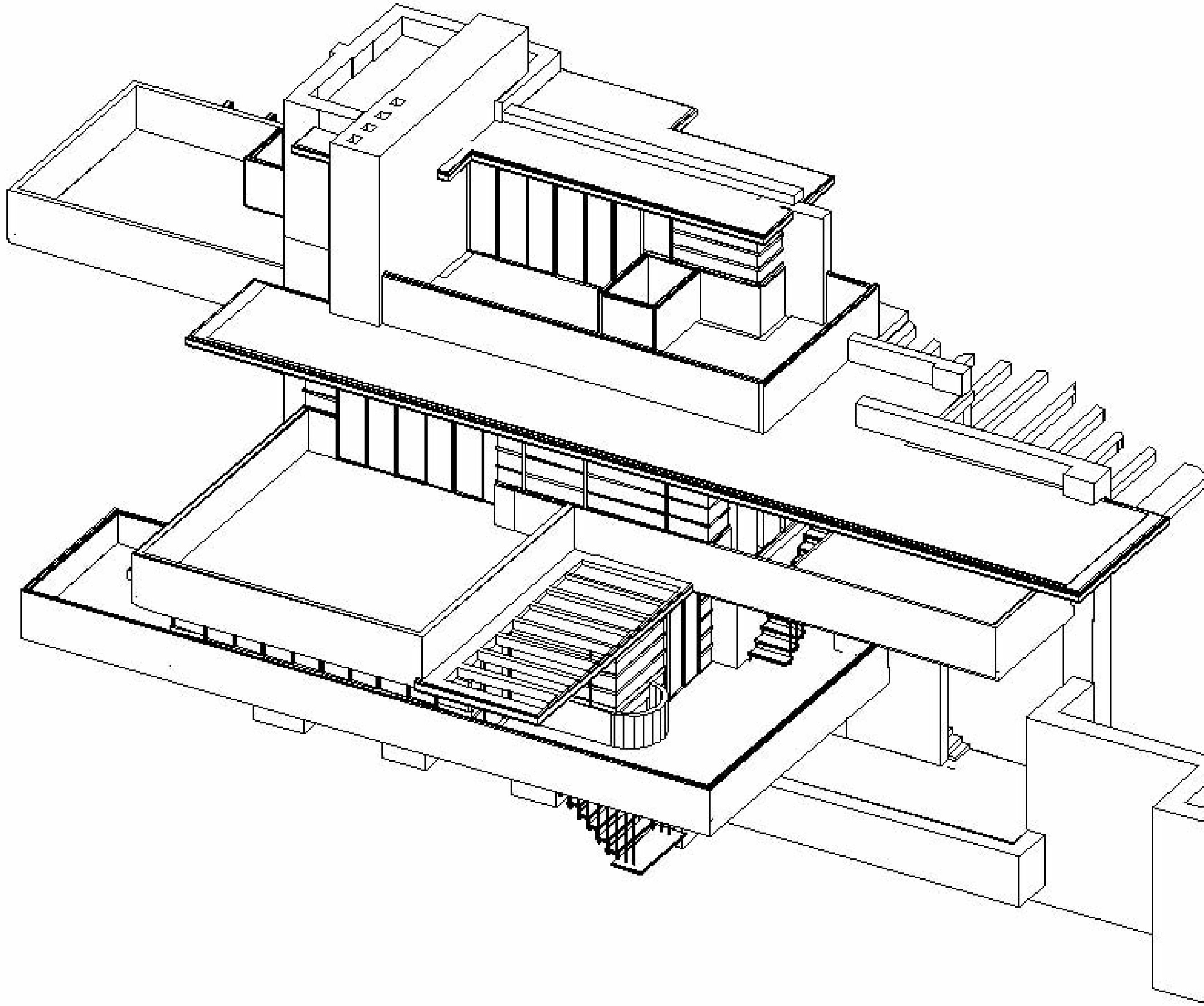
3RD FLOOR

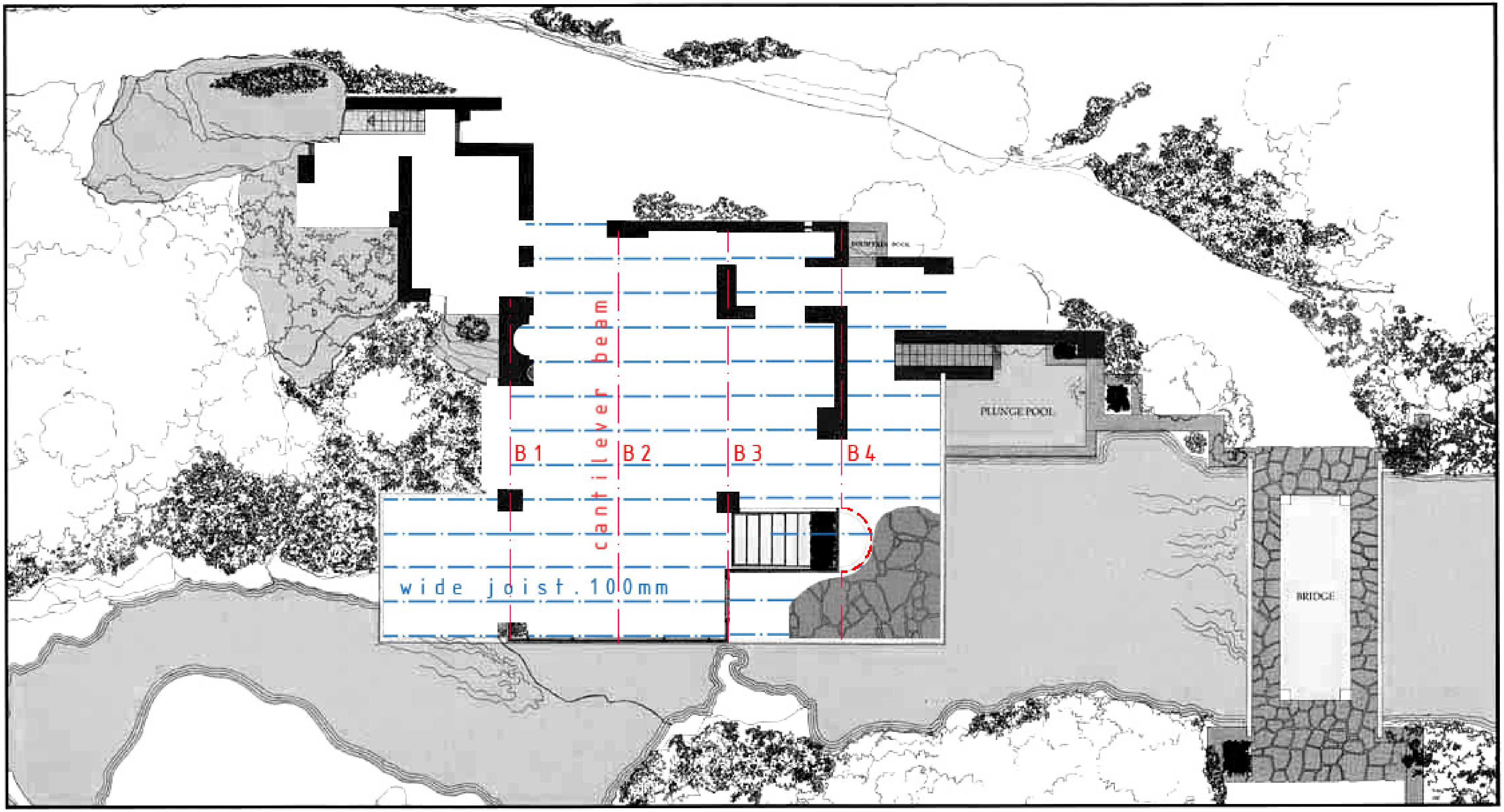


2ND FLOOR

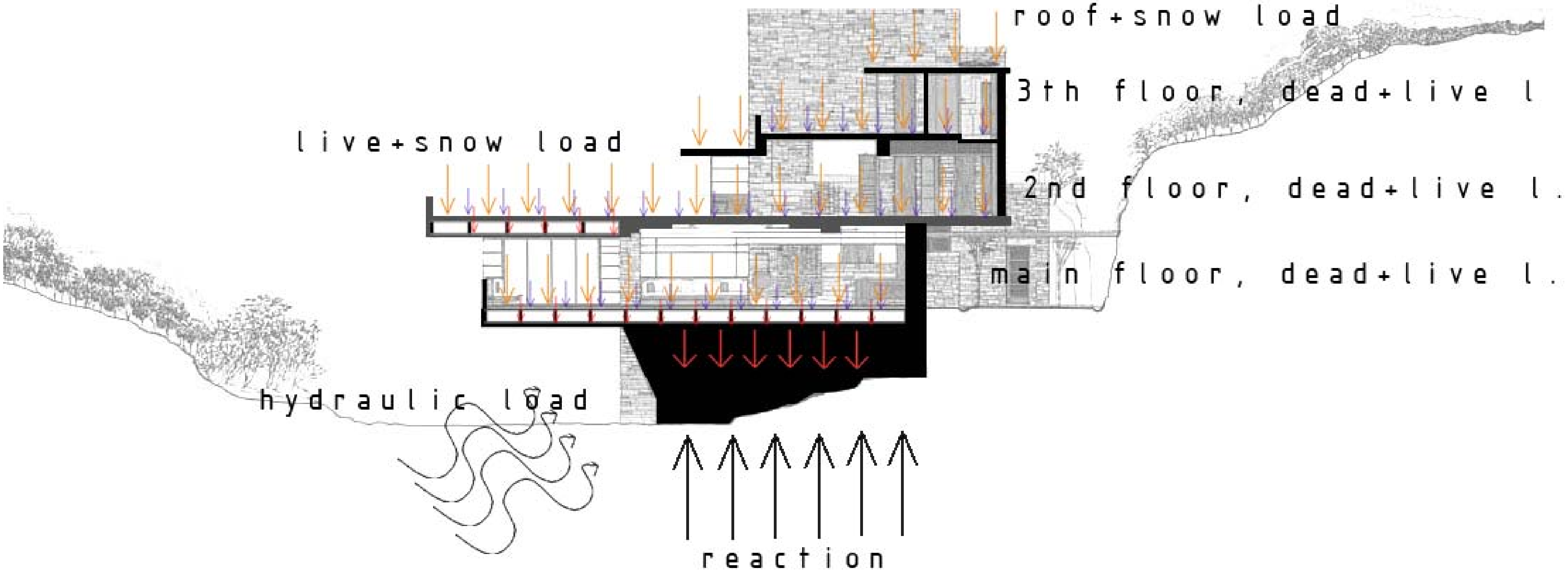


BRIDGE
UP
TERRACE
UP
UP
DRESSING ROOM
UP
DN
DN
LANDING
DN
DN
MASTER BEDROOM
GUEST ROOM
TERRACE
TERRACE





Structural Plan


roof+snow load
3th floor, dead+live l
live+snow load
2nd floor, dead+live l.
main floor, dead+live l.
hydraulic load
reaction

Numbers

Live Load **50 lb/ft2**

Floor Slab

-Concrete Slab, stone aggregate (3 inches)	36 lb/ft2
-Stone Floor (1 in)	12 lb/ft2
-Sand	8 lb/ft2
-Plywood	4 lb/ft2
-Floor Slab	+ 60 lb/ft2
	100 lb/ft2
Total	**150 lb/ft2**

Main Beam

-3 ft x 2 ft = 6 ft2

-6 ft2 x **150 lb/ft3** = 900 lb/ft

Dead Load **900 lb/ft**

Parapet

-5 ft x 0.5 ft = 2.5 ft2

-2.5 ft2 x **150 lb/ft3** = 375 lb/ft

Total **375 lb/ft**

Joists

4 in x 24 in = 96 in2/144 in2/ft2 = 0.66 ft2

0.66 ft2 x 1 ft x 150 lb/ft3 = 100 lb/ft

Total **100 lb/ft**

Parapet

375 lb/ft x 12 ft =4500 lb

Total **4500lb/ft**

Live Load

50 lb/ft2 x 12 ft = 600 lb/ft

Total **600lb/ft**

Floor Slab

60 lb/ft2 x 12 ft = 720 lb/ft

Total 720lb/ft

Joists

100 lb/ft x 12 ft = 1200 lb

(1200 lb/joist x 15 joist) / 52 ft = 346 lb/ft

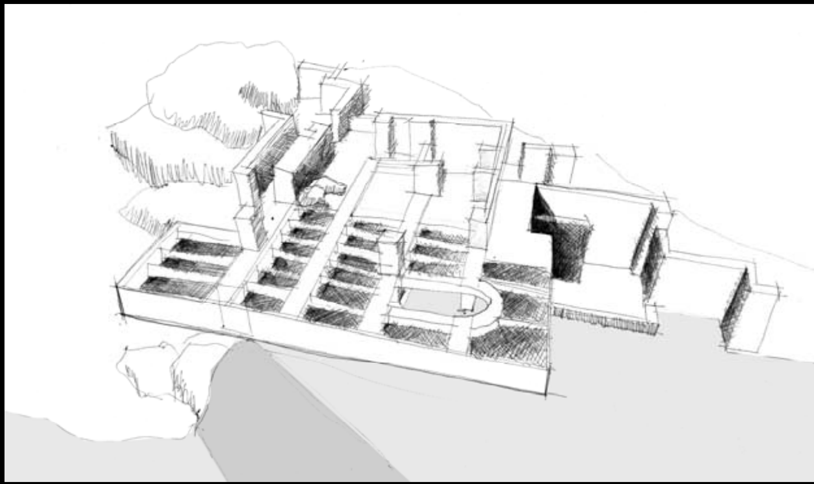
Total 346lb/ft

Beam – Parapet

375 lb/ ft x 2 = 750 lb/ft

Total 750lb/ft

Dead Load: **1816 lb/ft**



W bean 1 = Live Load + Dead Load

W bean 1 = 600 lb/ft + 1816 lb/ft = **2416 lb/ft**

Parapet

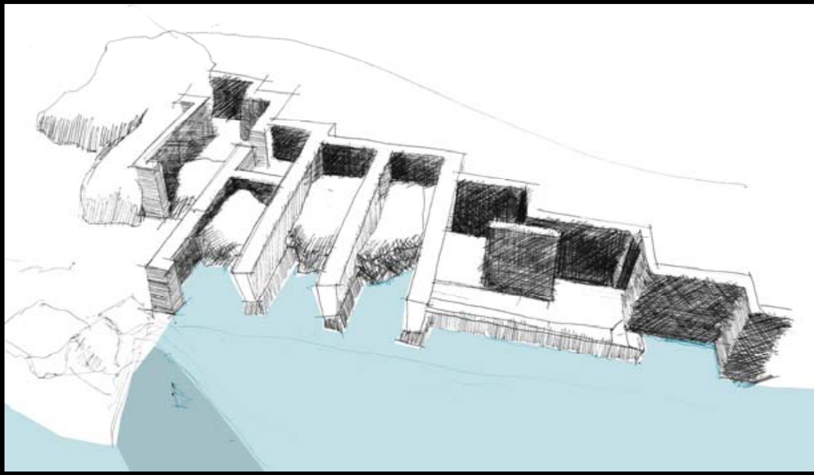
375 lb/ft x 18 ft = 6750 lb/ft

Total **6750lb/ft**

Live load

50 lb/ft2 x 18 ft = 900 lb/ft

Total **900lb/ft**



Floor Slab

60 lb/ft2 x 18 ft = 1080 lb/ft

Total 1080lb/ft

Joists

100 lb/ft x 18 ft = 1800 lb

(1800 lb/joist x 5 joist) / 15 ft = 600 lb/ft

Total 600lb/ft

Main Beam 900 lb/ft

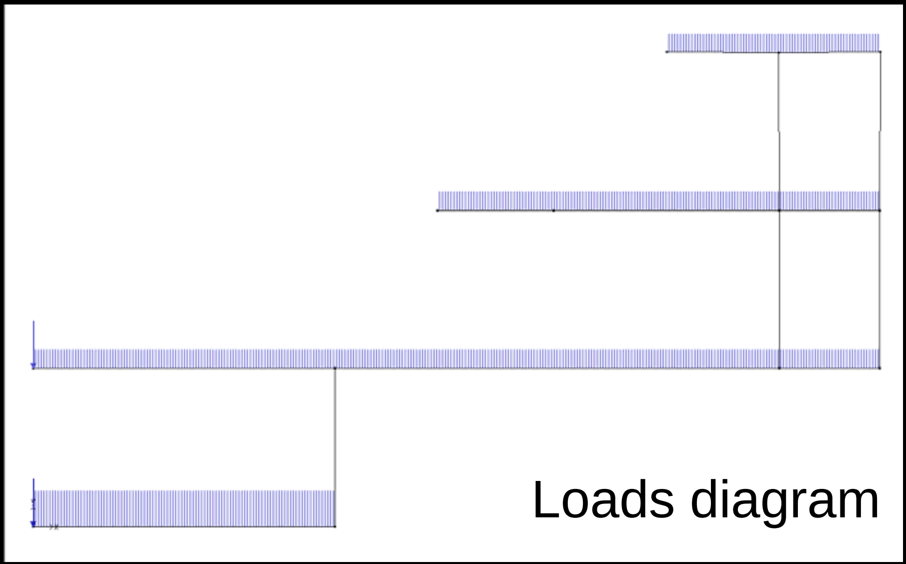
Dead Load **2580 lb/ft**

W beam 1 = Live Load + Dead Load

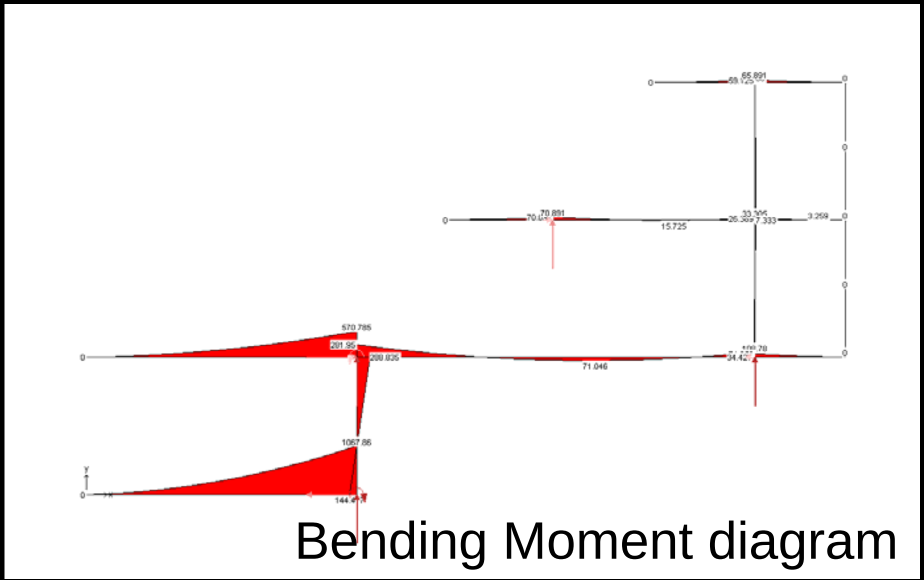
W beam 1 = 900 lb/ft + 2580 lb/ft = **3480 lb/ft**

Multi-Frame :1 case

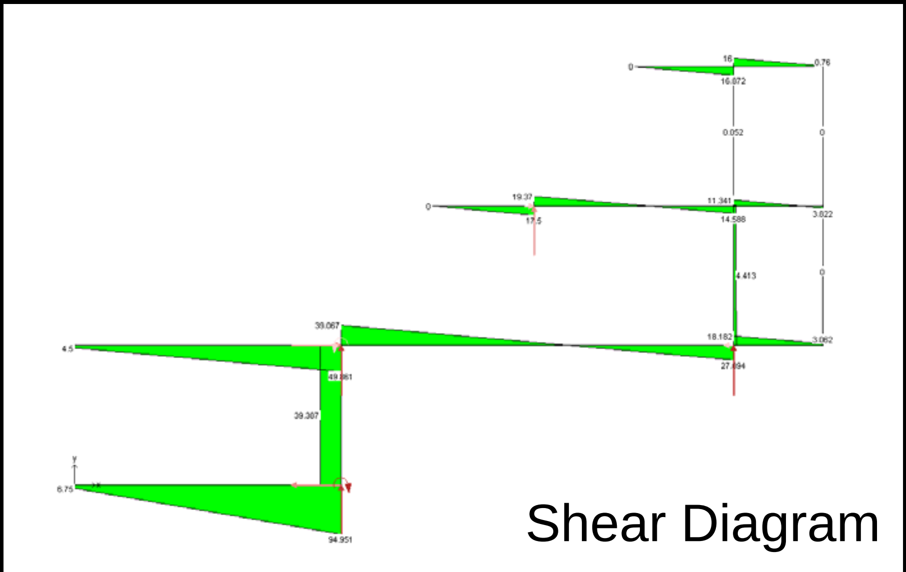
Deflection diagram



Loads diagram

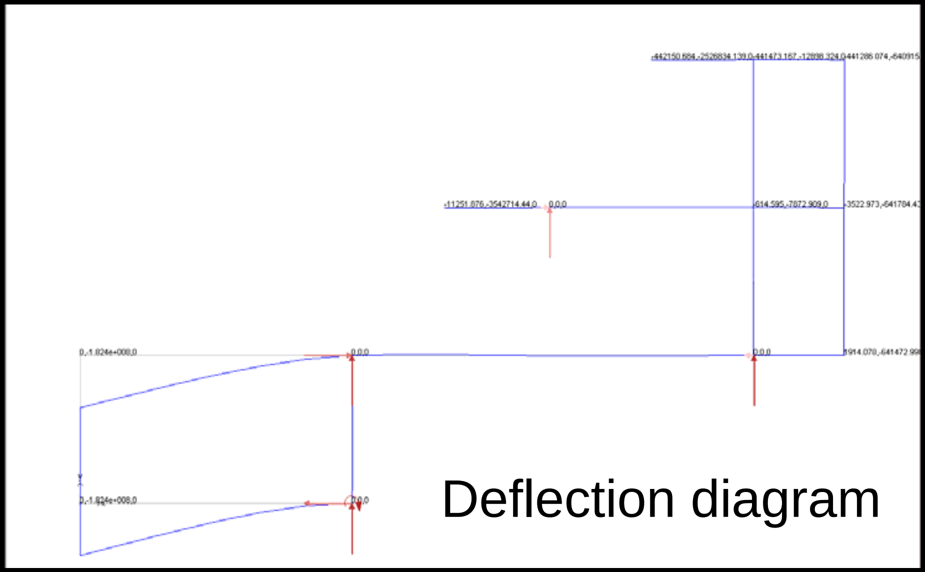


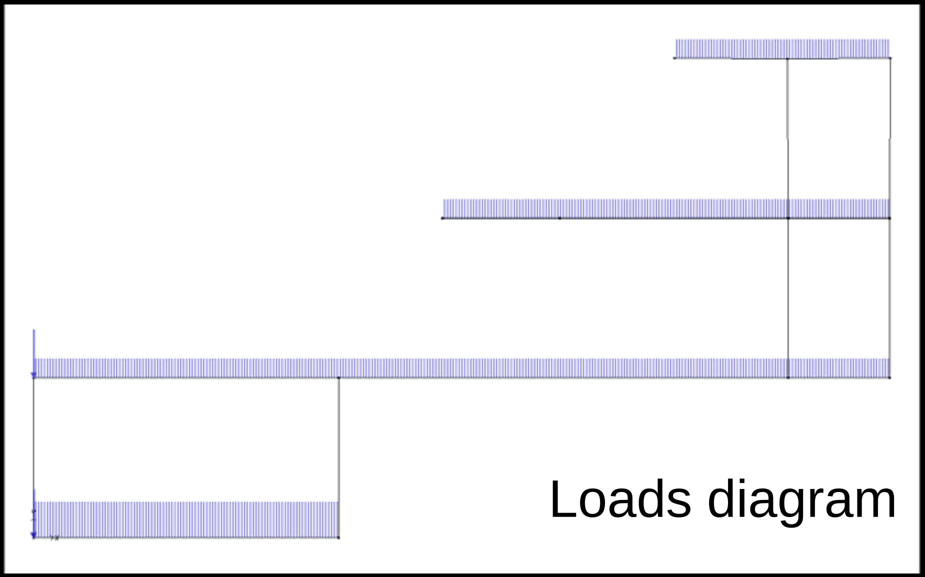
Bending Moment diagram

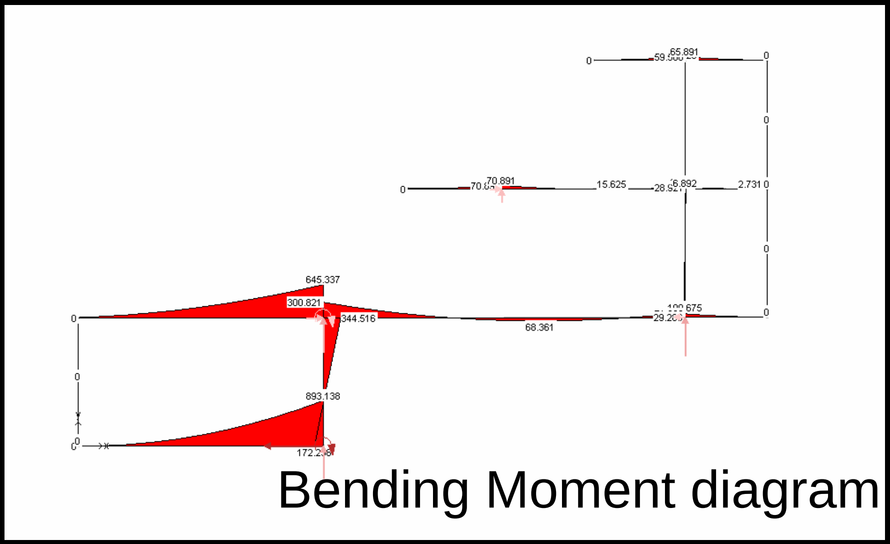


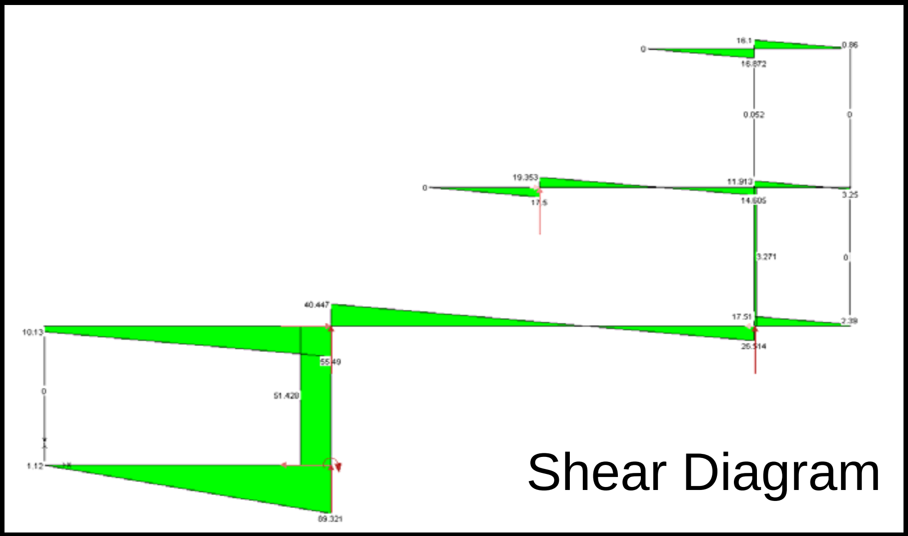
Shear Diagram

Multi-Frame: 2 case

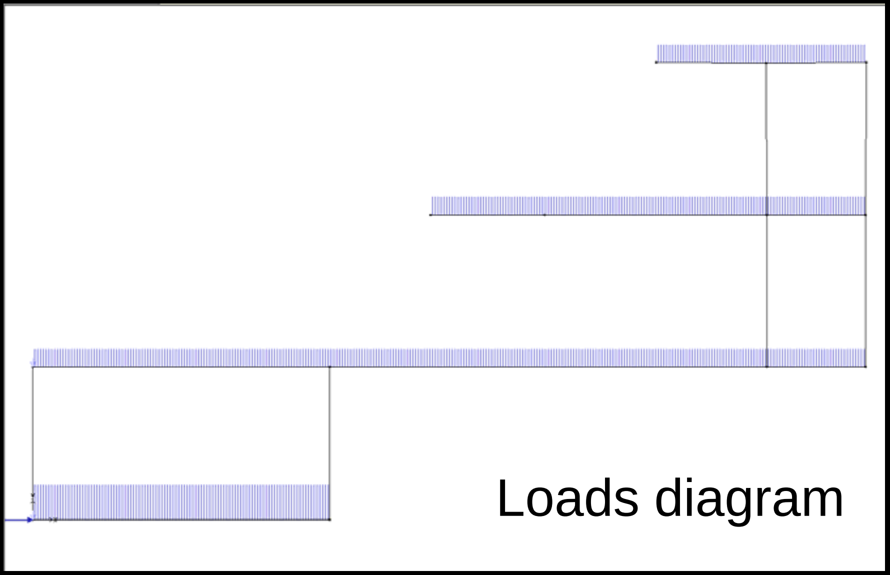


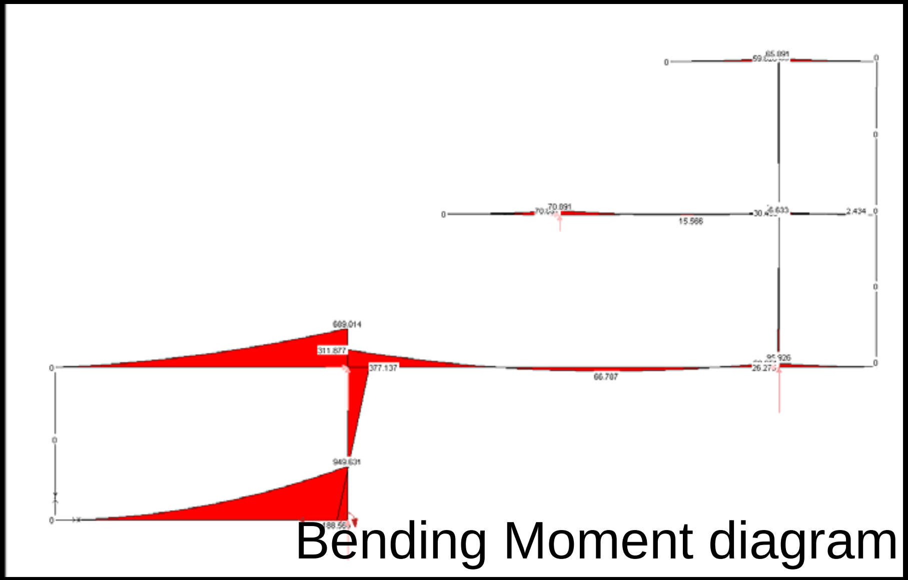


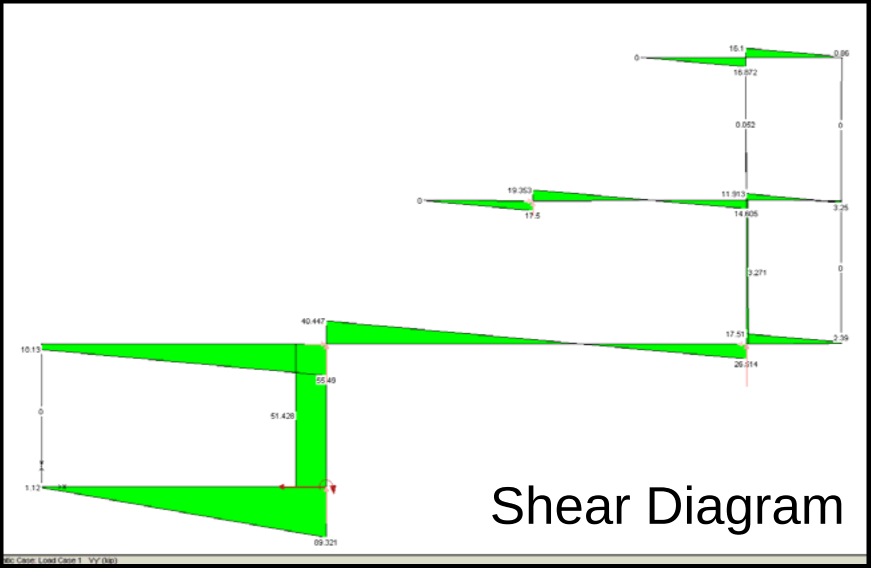




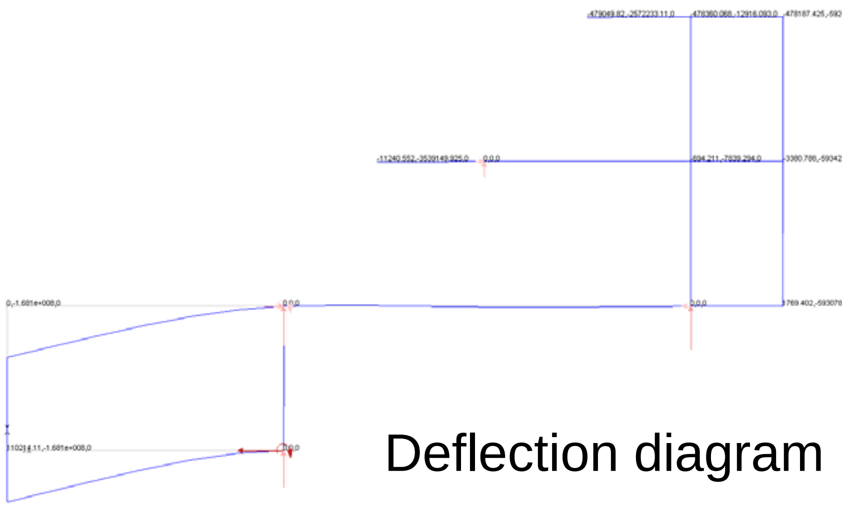
Multi-Frame: 3 case



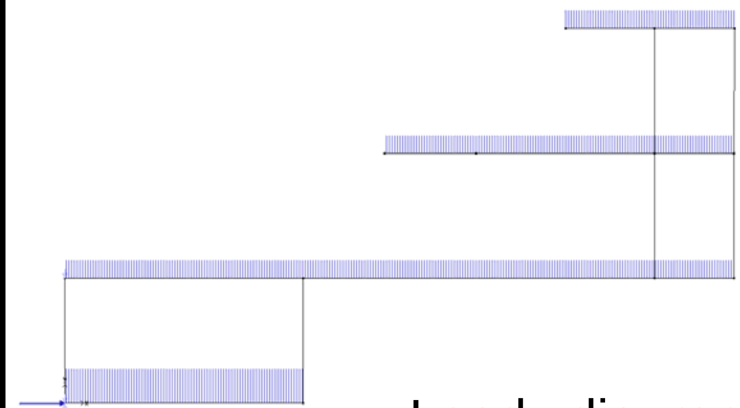




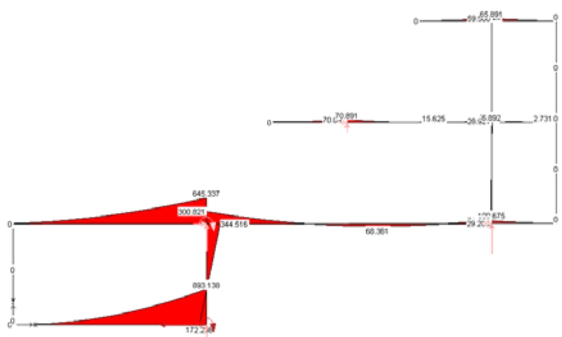
Multi-Frame: 4 case



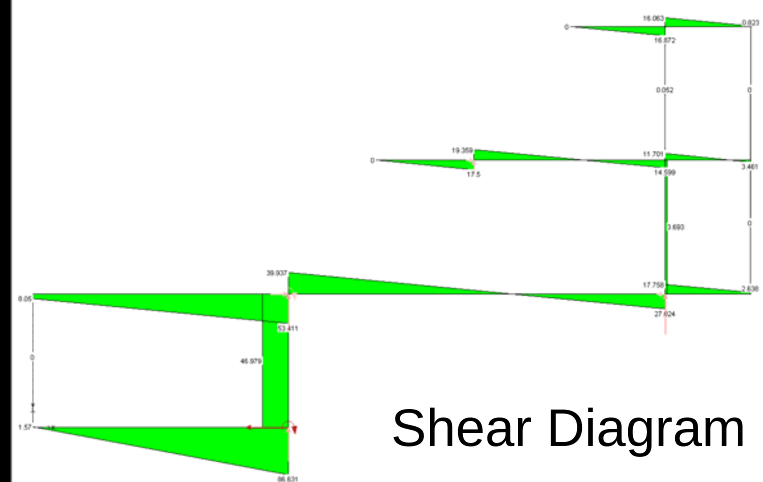
Deflection diagram



Loads diagram

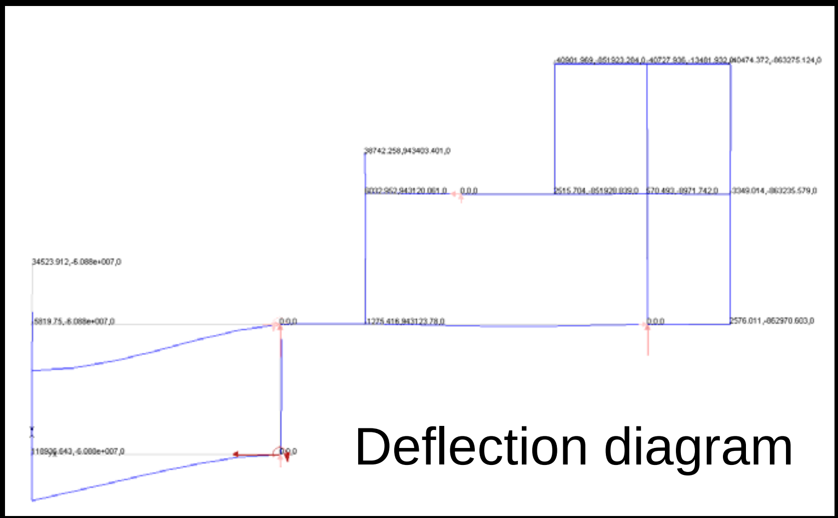


Bending Moment diagram

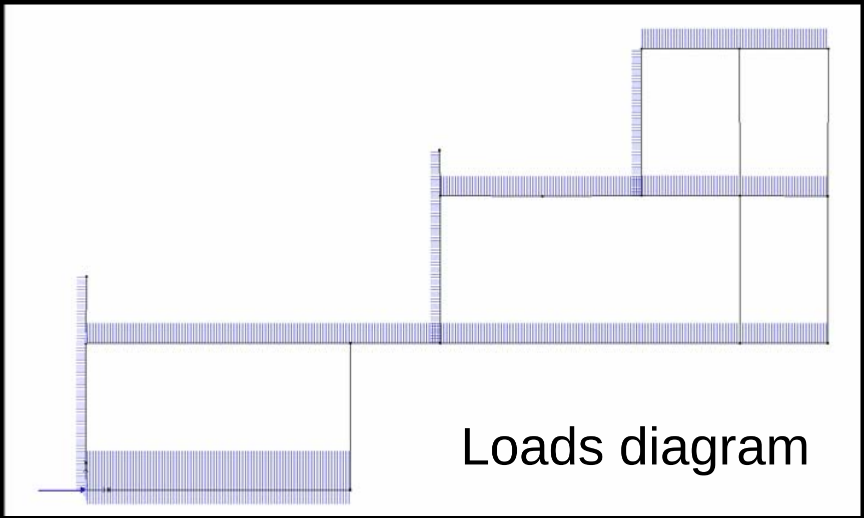


Shear Diagram

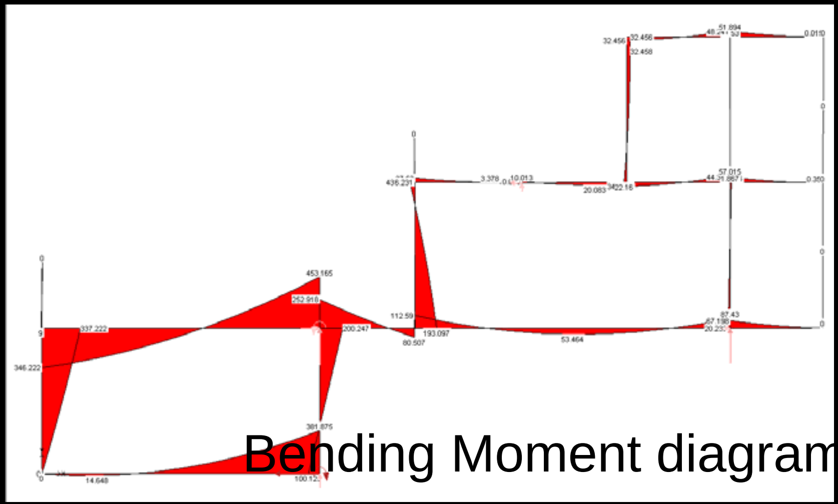
Multi-Frame: 5 case



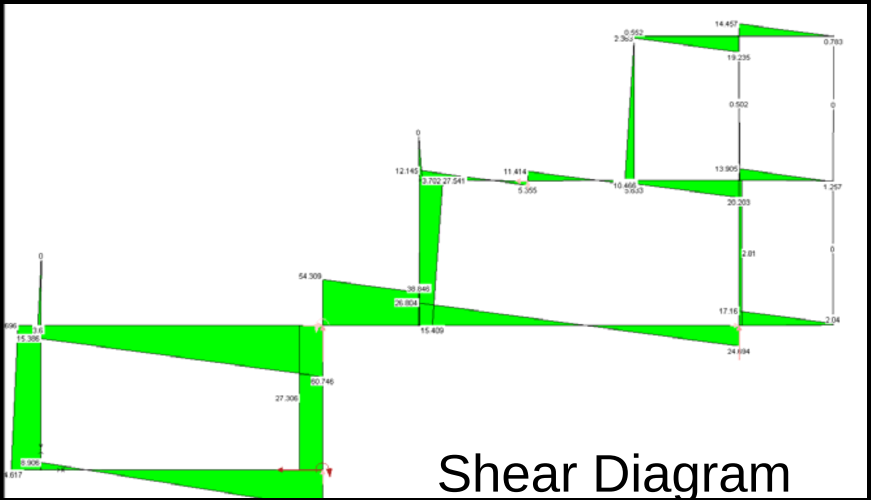
Deflection diagram



Loads diagram



Bending Moment diagram



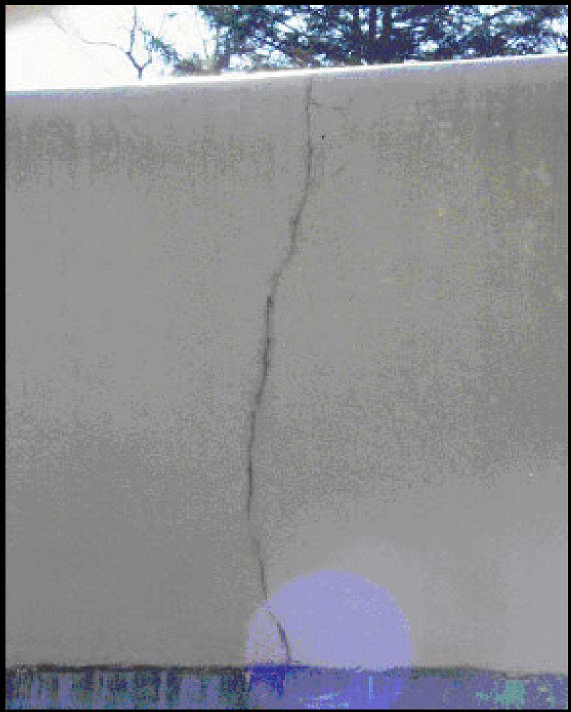
Shear Diagram

STRUCTURAL FAILURE

PROBLEMS

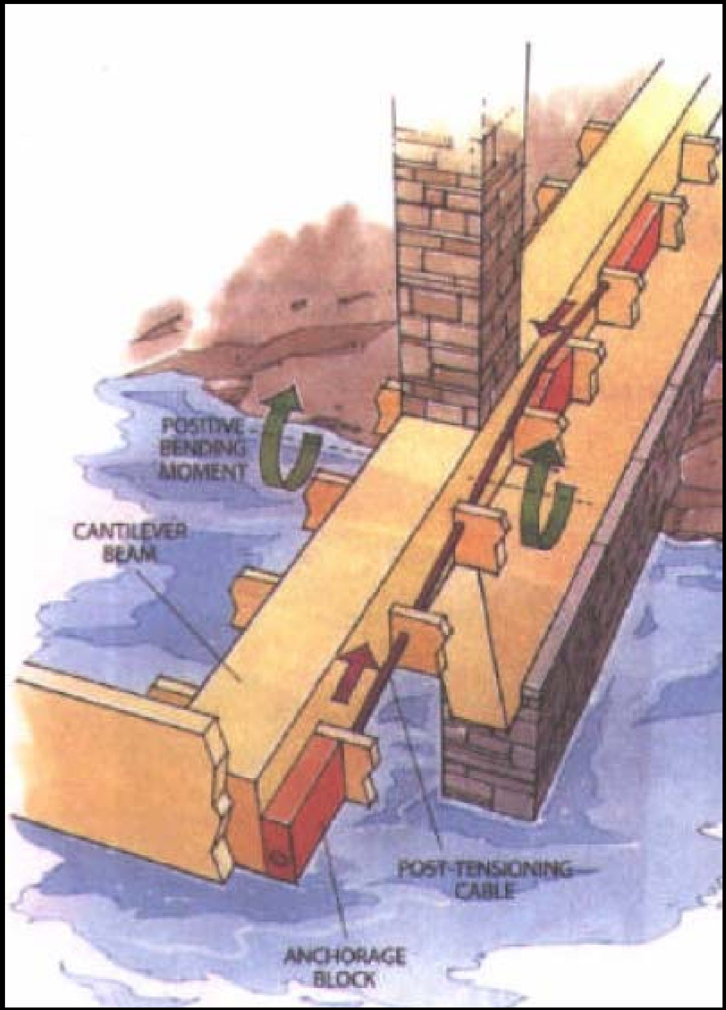
The initial deflection occurred during construction when the forms were not designed to carry the wet weight of the concrete.

The secondary problem was the lack of tensile reinforcement in the beams that carried the first and second story terrace cantilevers. The amount of steel was doubled during construction to sixteen, one inch, steel bars. This still was not enough to carry the load.



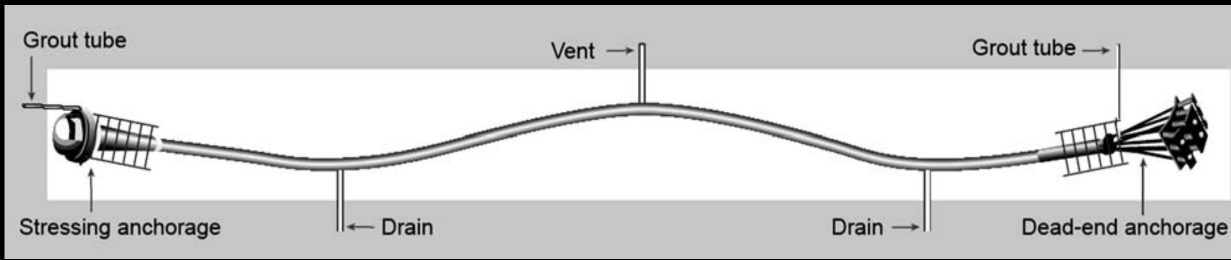
The major problem occurs in the lowest terrace with a fifteen foot cantilever. Because the tensile reinforcement was not adequate for the second story terrace, the living room window mullions transfer the weight downward to the first level terrace. The first level terrace was also insufficiently reinforced and could not support its own load plus the additional weight of the second story terrace.

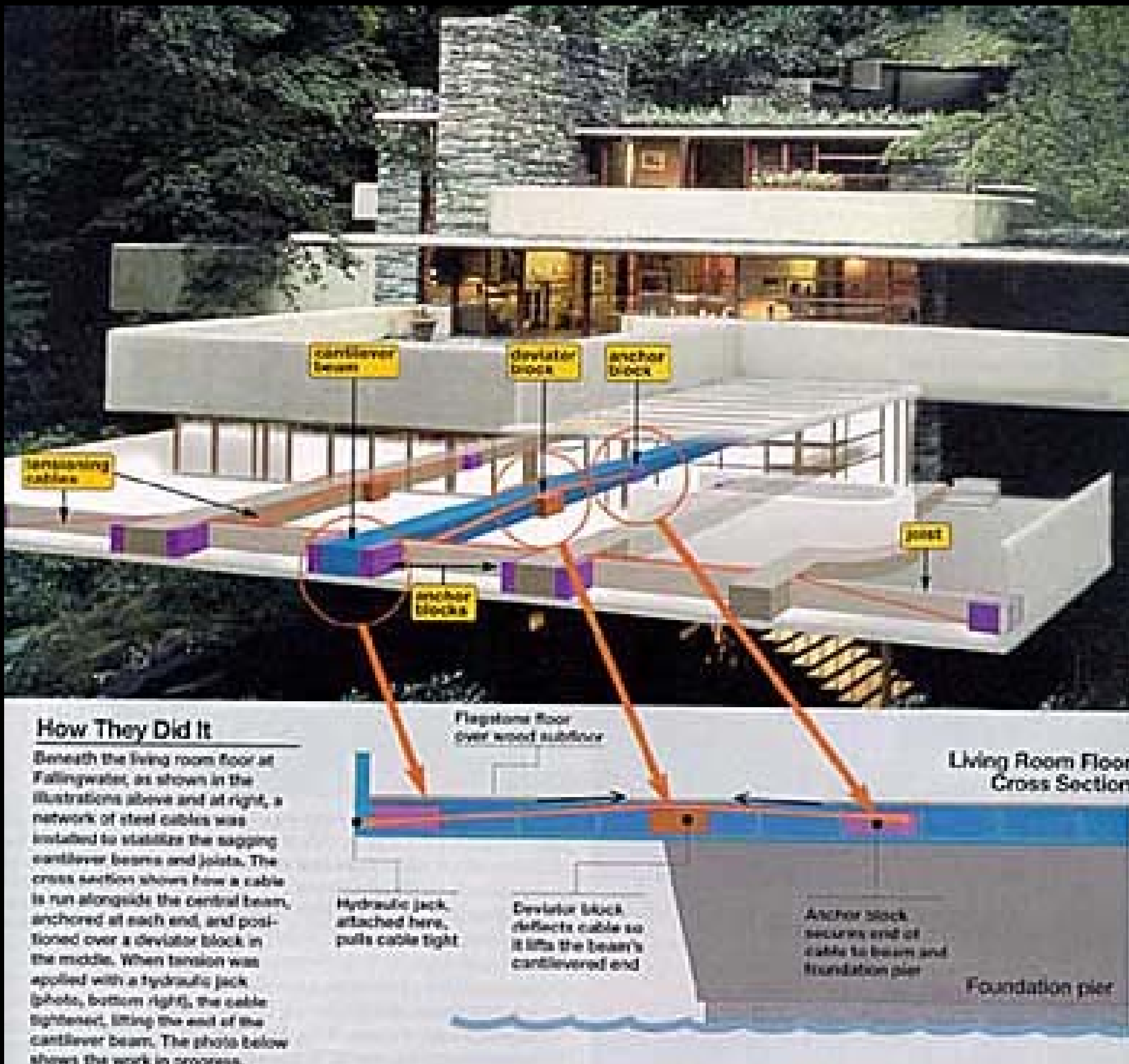
SOLUTION


POSITIVE
BENDING
MOMENT
CANTILEVER
BEAM
POST-TENSIONING
CABLE
ANCHORAGE
BLOCK

In 1999 plans were approved for the structural strengthening of the living room terrace with post-tensioning and waterproofing.

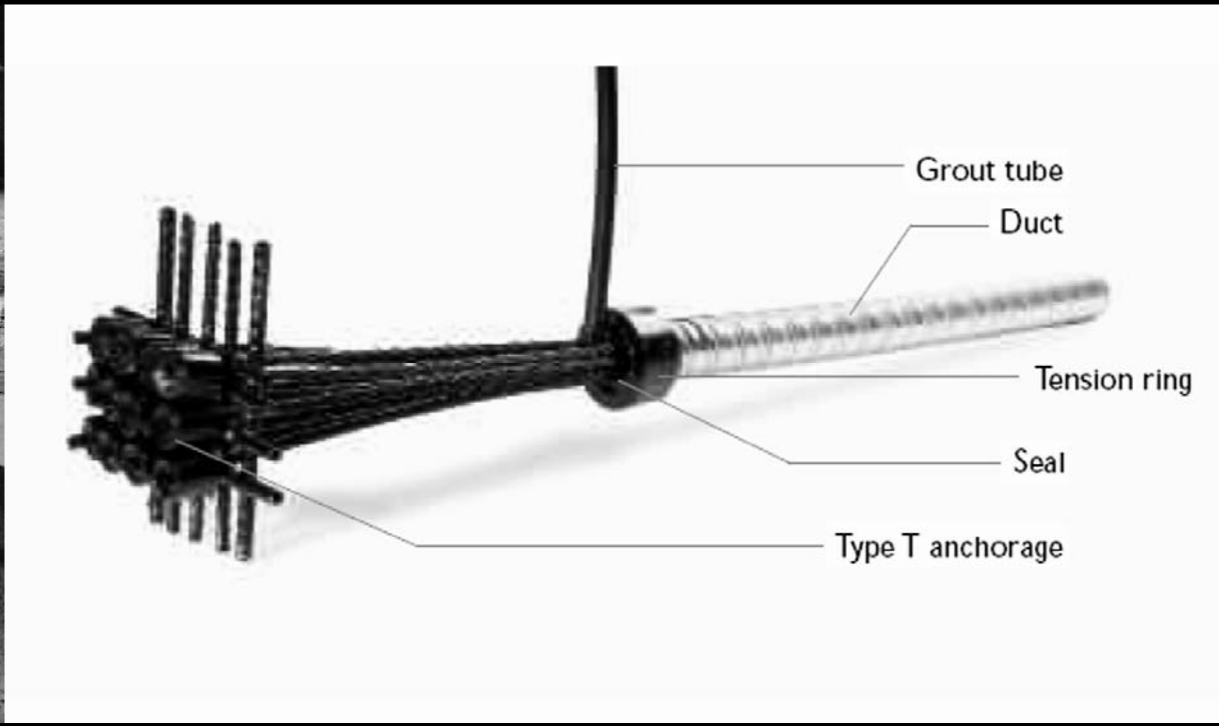
The goal was to prevent further deflection and not to raise the terrace so further structural damage was not caused to the building.





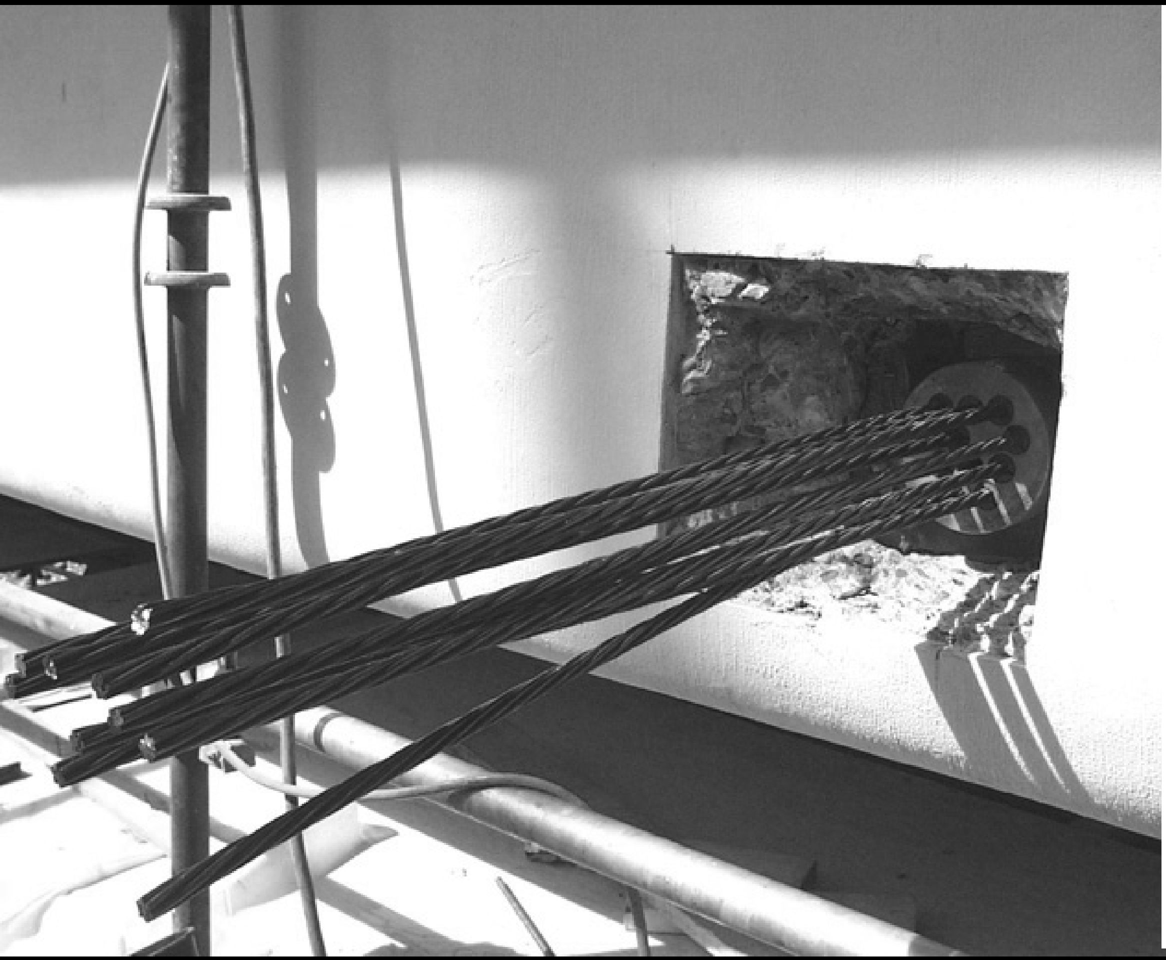
High strength cables will be placed through the main three beams of the lower terrace in a bent path so the cables will be placed at the top and bottom of the beam where they are most needed.

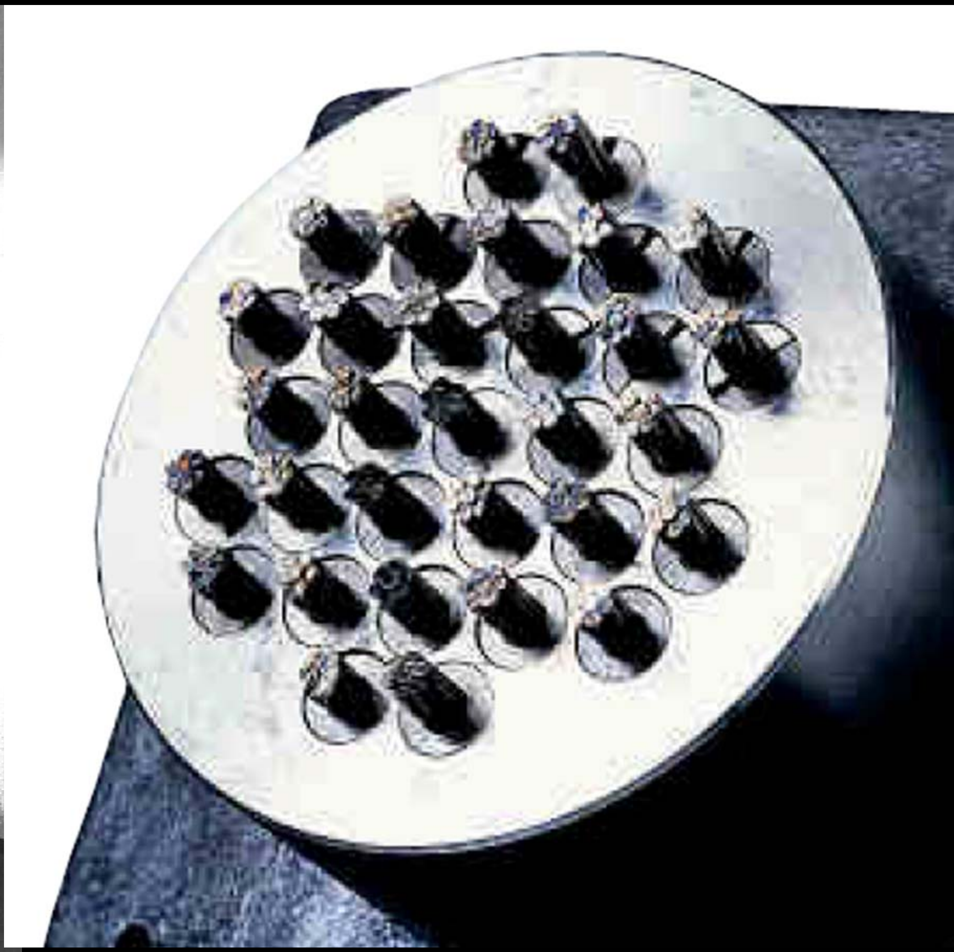
An anchoring block will be installed at one end of the beam to anchor the tensioning of the cable.



Post-tensioning jacks will be placed on the opposite end to tension the cable to 100 tons of force.

This will add 200 tons of tension to each beam.





Steel channels will be placed on both sides of the concrete joist directly above the living room window mullions to help transfer the load from the second story terrace to the living room terrace.