IMPERIAL HOTEL

Tokyo, Japan

A Case Study of ARCH 685 for ARCH 631 given by Keith Wilson - Summer 2003

Reasons for the Imperial Hotel as a Case Study :

- Survived the great Kanto earthquake of 1923 while many other buildings perished.
- A rare example of a designer's thorough attempt to integrate architecture and engineering into a comprehensive seismic design strategy.
- Created the beginnings of many features for seismic design in buildings which are state-of-the-art today.
- The building was also a forerunner in the development of radiant heating, forced air ventilation, and indirect lighting.
- A famed and landmark status building

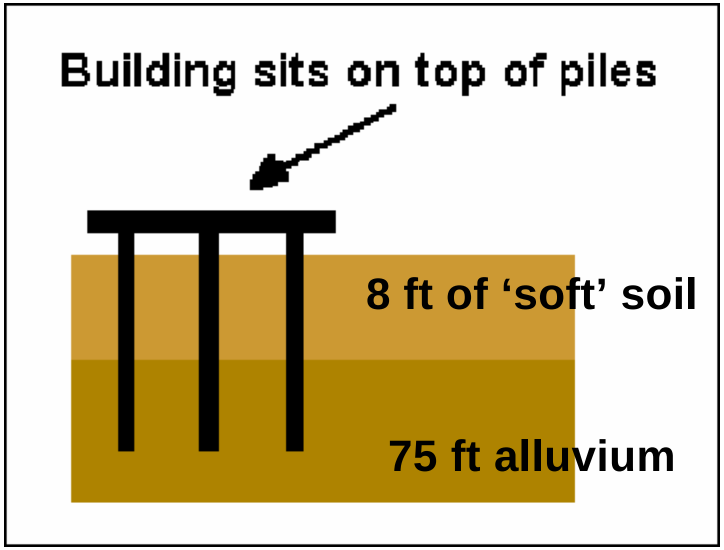
The Designer of the Imperial Hotel :

Frank Lloyd Wright

- The Imperial Hotel was designed by great American architect Frank Lloyd Wright.
- The hotel was first commissioned by FLW in 1915 and construction was finished in 1922.
- One of the main driving forces of the design was how the building was to withstand the dreaded “temblor” as well as the fire that ensues.
- “The terror of the temblor never left me while I planned the building nor while, for more than four years, I worked upon it.” - FLW

The Design of the Foundation :

- The general method of resisting earthquakes in foundation design during the time the Imperial was built was thought to be along the lines of a rigid structure; generally, the more rigid the better.



General foundation design before the Imperial

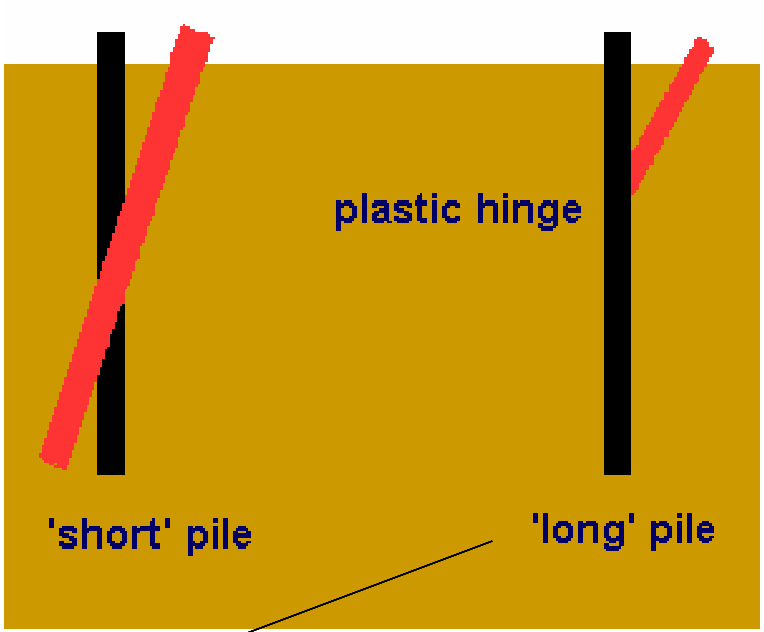
The Design of the Foundation :

- The general method of resisting earthquakes in foundation design during the time the Imperial was built was thought to be along the lines of a rigid structure; generally, the more rigid the better.

- The soil of the site consisted of a top layer of soft soil at a depth of about 8 feet. Below that was softer alluvium soil and ground water to a depth of about 75 feet. Because of this, the method of using long piles was a common foundation design.

- The long piles were used to transfer the load of the building down directly to the solid earth.

- The problem with long piles during an earthquake is that they create a plastic hinge (a point where the pile can no longer take the bending moment and so begins to yield.)



General foundation design before the Imperial

(Red shows the failure)

The Design of the Foundation :

- FLW and Julius Hoto (the Structural Engineer) both believed that because of the wave movements through the earth and based on the soil type, deep foundations like long piles would oscillate and rock the structure. Therefore the foundation should be short and shallow.

- The main theory was that the deep level of mud that underlies the surface soil would act like a good "cushion" to relieve terrible shocks. It was believed that the building should float upon it as a "battleship floats on salt water".

- The solution that they came up with for transferring the load is quite novel:
  - Nine inch diameter tapering concrete piles
  - Only eight feet in length
  - Set about every two feet along the length of the walls in pairs or threes side by side

- The piles were friction piles. The building was computed pound for pound and distributed equally so that it was uniformly loaded. Here is a typical calculation for the lateral load for one pile:

Typical tapering concrete pile

Cu = 100psf
Assume ?c = 145 pcf
Assume ?s= 100 pcf
L = 8'-0"
pile d = 0'-9"
e = 1'-0"

- Based on Chart for Ultimate Lateral Resistance Hu / Cu d² :
Hult / Cu d² ~ 23 when e = 1'-0
Working Load Value for H =
12,938 / 2 = **6,469 lbs**

fc = equating horizontal forces
fc = Hult / 9Cu d² =
12,938/9(1,000)(.75)= 1.92 ft

Mult = Maximum Resisting Moment =

Mult = Hult[e+1.5d+fc/2] =

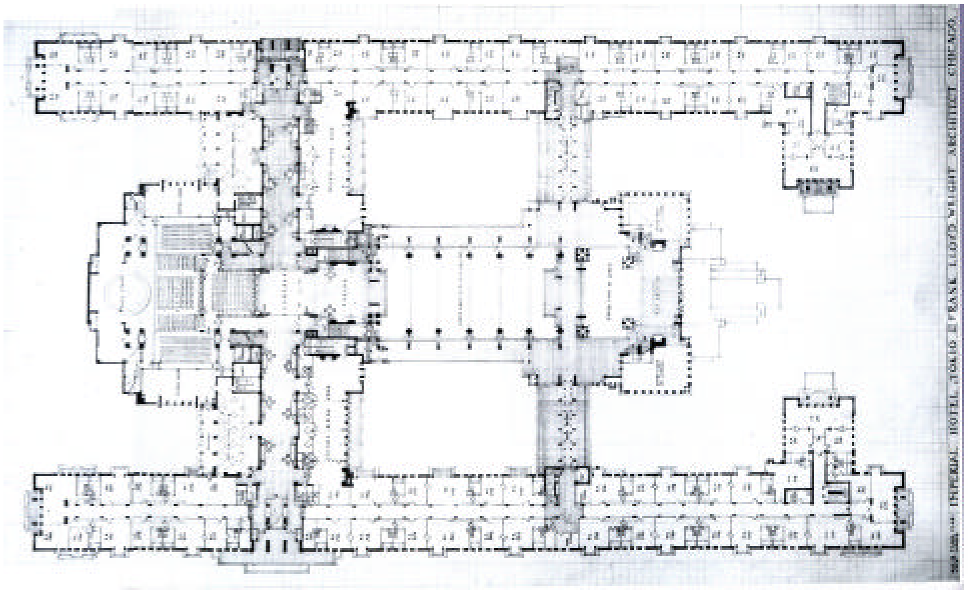
(12,938)[1+1.125+.96]=
39,914 Ft-lb

Working Load Value for M =

39,914/2 = **19,957 Ft-lbs**

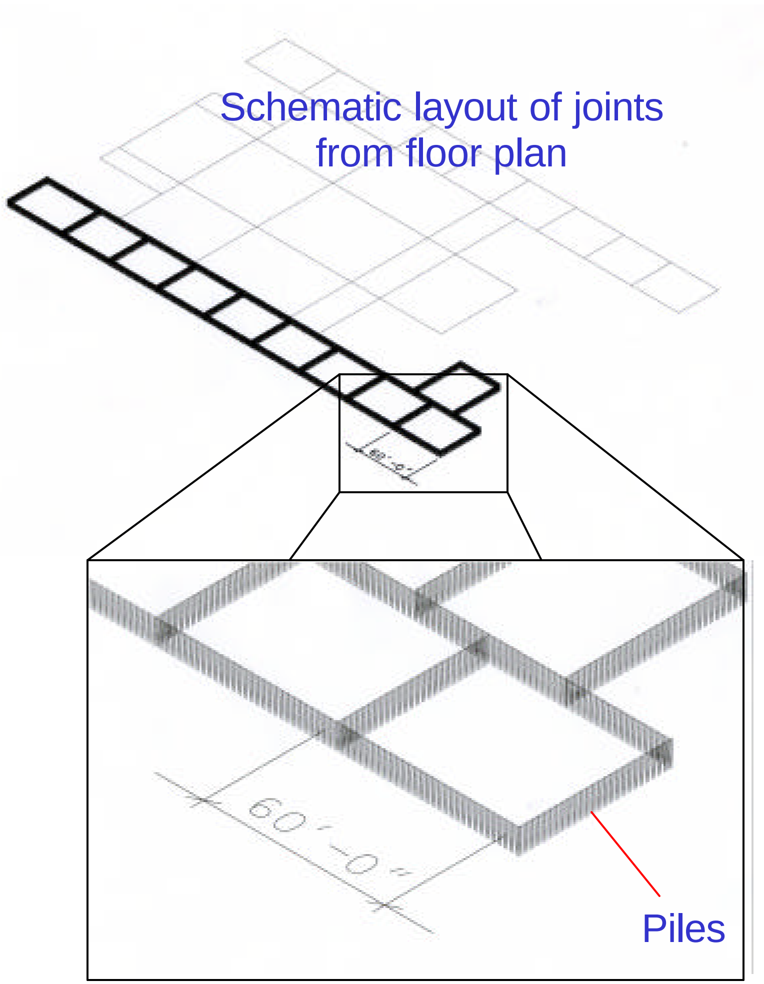
Flexure :

"Why fight with the quake? Why not sympathize with it and outwit it?" –FLW



Main Floor Plan of the Imperial

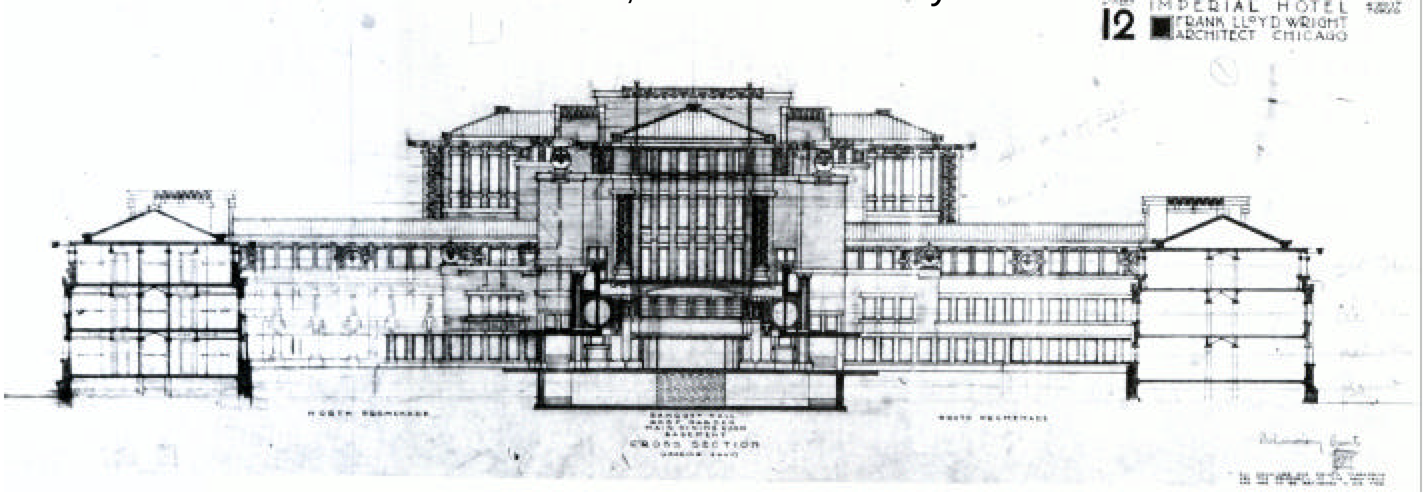
- To make the flexible structure instead of the "foolish rigid one", FLW divide the building into parts. The parts that were necessarily more than 60 feet long were jointed clear through the floors, walls, lootings and all.
- Where ever part met part were through joints as well. Through careful calculation of a uniform load, the building became able to "ride" the waves of the temblor.



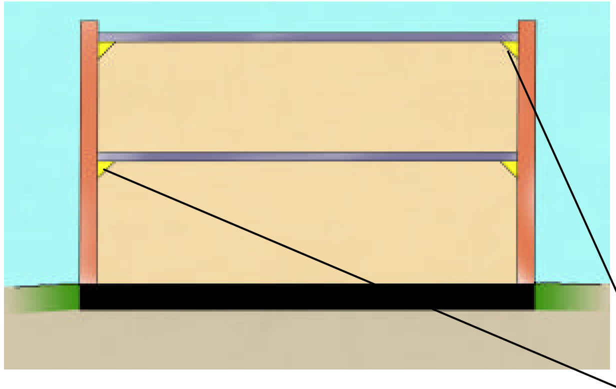
Close up of Schematic

“The Waiter’s Tray” :

“A good construction was needed where floors would not be carried between walls, because subterranean disturbances might move the walls and drop the floors. Why not carry the floors as waiter carries his tray on upraised arm and fingers at the center- *balancing* the load. This meant the cantilever, as I had found by now.” - FLW



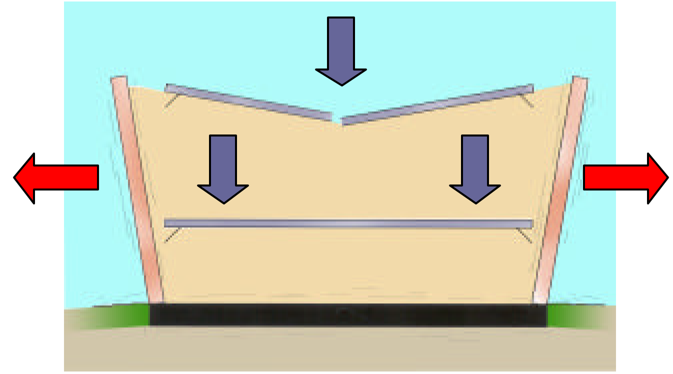
Cross Section of the Imperial



- What Wright was saying was instead of supporting the floors at their edges, which was common practice, support the floors from their center.

Schematic of wall with floors connected at edges into wall

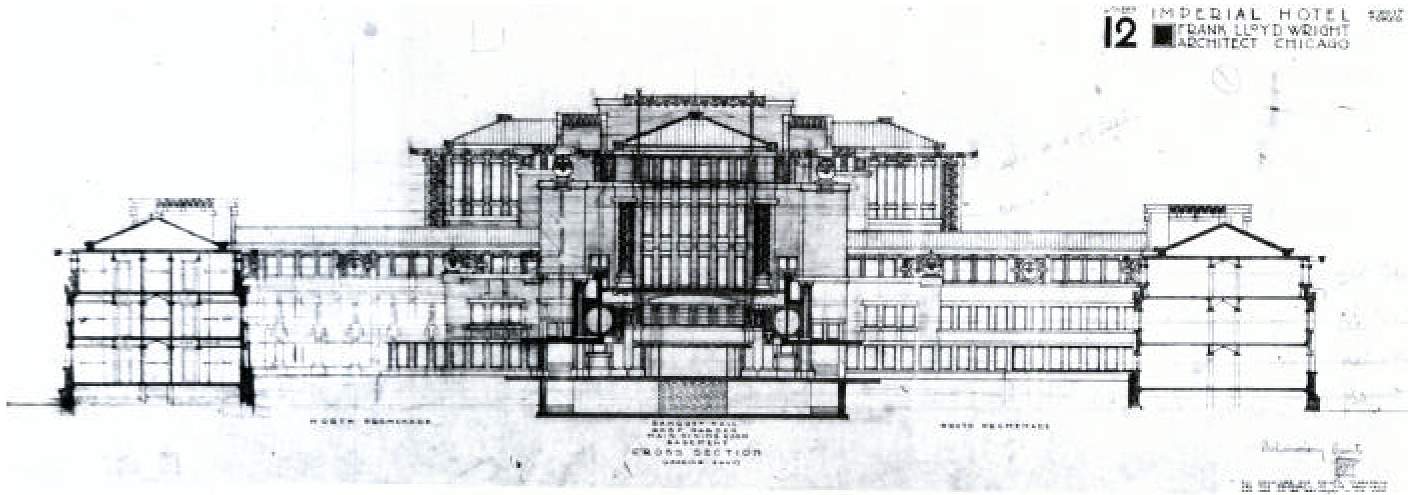
Connections



Disturbances may move the walls and drop the floors

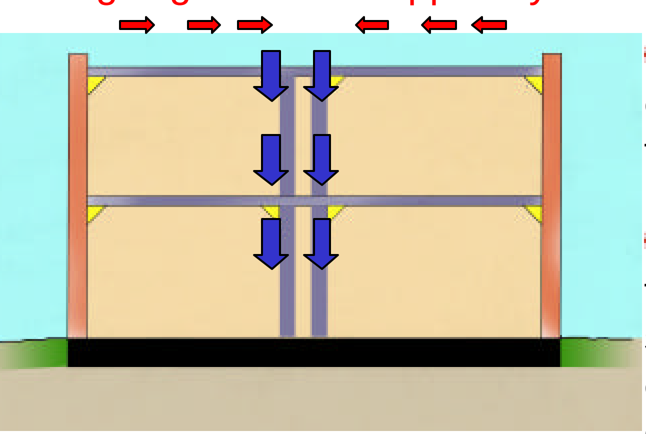
“The Waiter’s Tray” :

“A good construction was needed where floors would not be carried between walls, because subterranean disturbances might move the walls and drop the floors. Why not carry the floors as waiter carries his tray on upraised arm and fingers at the center- *balancing* the load. This meant the cantilever, as I had found by now.” - FLW



Cross Section of the Imperial

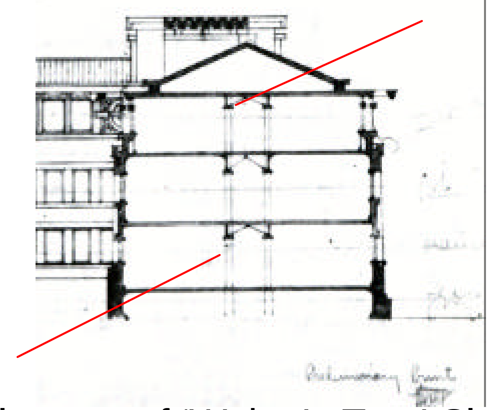
oads going to center support system



Schematic of Cantilever Slab

- And so concrete cantilever slabs continuous across the building from side to side became the structure for the Imperial Hotel at Tokyo.
- All of the slabs were in conformance with the Chicago code, but FLW disregarded it since early code provisions of reinforced concrete were sometimes unduly conservative. FLW called for much lighter sections to be used and the structural engineer notes that was “entirely logical”.

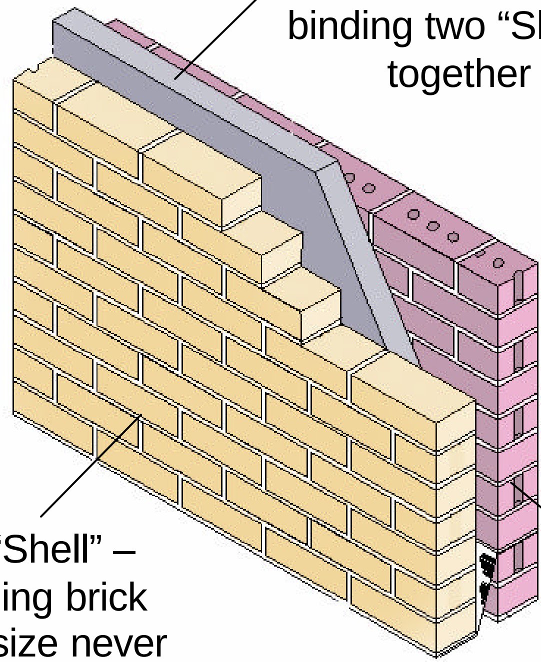
Columns anc connections supporting th floor slabs



Close up of ‘Waiter’s Tray’ Slab

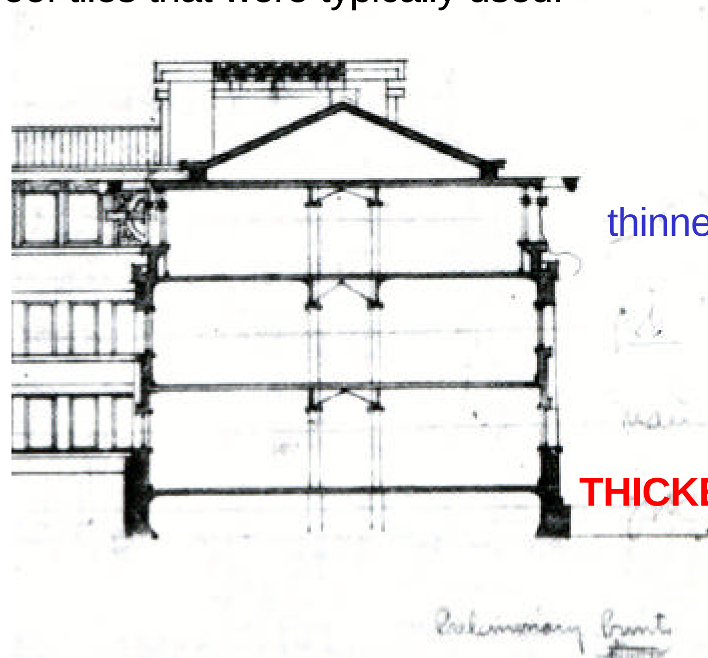
Exterior Wall Construction :

- The exterior wall structure was load-bearing masonry.
- The outer walls were spread wide, thick and heavy at the base growing thinner and lighter toward the top.
- In doing so, the center of gravity was kept low against the swinging movements, and the slopes made an aesthetic feature of the design.
- In addition to keeping a low center of gravity, the roof was topped with light hand-worked green copper instead of the heavy roof tiles that were typically used.



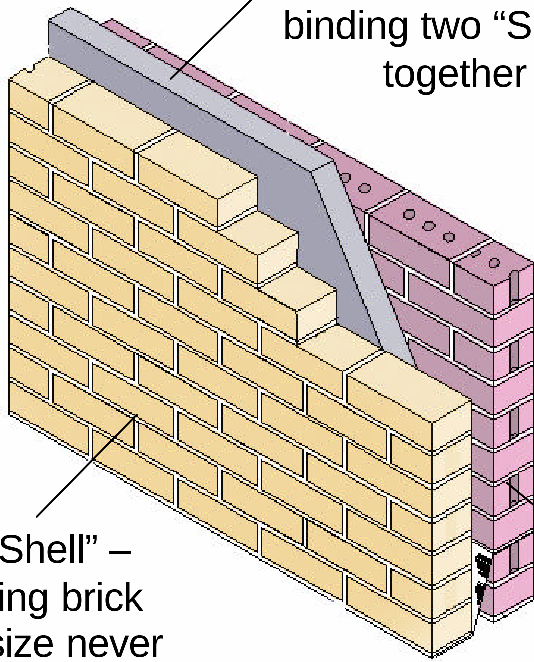
Typical Exterior Wall Construction

- The whole structure was set up as a double shell - two shells, an exterior of slim cunning bricks and an interior of fluted hollow brick. These shells were poured solid with concrete to bind them together.



Cross section showing exterior walls growing thinner toward top

Exterior Wall Construction :



Typical Exterior Wall Construction

- The exterior wall structure was load-bearing masonry.
- The outer walls were spread wide, thick and heavy at the base growing thinner and lighter toward the top.
- In doing so, the center of gravity was kept low against the swinging movements, and the slopes made an aesthetic feature of the design.
- In addition to keeping a low center of gravity, the roof was topped with light hand-worked green copper instead of the heavy roof tiles that were typically used.

- The whole structure was set up as a double shell - two shells, an exterior of slim cunning bricks and an interior of fluted hollow brick. These shells were poured solid with concrete to bind them together.

Detail of exterior wall and brick

Piping, Wiring, and Water :

- Earthquakes had always torn piping and wiring apart where laid in the structure and had flooded or charged the building.
- In the Imperial, all piping and wiring were laid free of construction in covered concrete trenches in the ground of the basements, independent of even the foundations.

- Mains and all pipes were of lead with wiped joints. The pipe bends sweeping from the trenches to be hung free in vertical pipes shafts, from which the curved pipe branches were again taken off, curved, to the stacks of bathrooms.
- Thus, any disturbance might flex and rattle but not break the pipes or wiring.

- An immense pool as an architectural feature served also as a reservoir to use in case of fire that generally would follow a temblor. It was connected to the water system of the hotel and conserved the roof water.

Pool at entrance of the Imperial

"When the earthquake is violent, fire finishes the terrible work." - FLW

The Great Kanto Earthquake

- On 1 September 1923, a little over only one year after the Imperial's completion, the test of the hotel's structure came, as one of the worst earthquakes in history hit the Kanto plain destroying Tokyo, Yokohama and the surroundings.
- Over 140,000 people fell victim to this earthquake and the fires it caused.
- Although many other buildings did not, **the Imperial survived**. Through innovation and careful consideration of the structure, the hotel stood firm among the rubble of its surroundings. The hotel served as a shelter for many homeless Japanese.
- In came the cablegram from the owner of the Imperial Hotel to Wright:

FRANK LLOYDE WRIGHT
OLIVE HILL STUDIO RESIDENCE B 1645 VERMONT AVE. HOLLYWOOD CALIF. FOLLOWING WIRELESS RECEIVED FROM TOKIO TODAY HOTEL STANDS UNDAMAGED AS MONUMENT OF YOUR GENIUS HUNDREDS OF HOMELESS PROVIDED BY PERFECTLY MAINTAINED SERVICE CONGRATULATIONS
SIGNED OKURA IMPEHO

Bibliography :

ウエスタン・ユニオン・テレグラム

カリフォルニア州ロスアンジェルス市サウス・スプリング局，1923年9月13日午後6時受信。

フランク・ロイド・ライト

カリフォルニア州ハリウッド，ヴァーモント通1645，オリーヴ・ヒル・スタディオ・レジデンスB

「ホンジツトウキョウヨリイカノデンシンヲジュシンセリ。ホテルハムキズニテキカノサイノウノキネンヒトナレリ。ヤドナキタスウノヒトビトハソレニテテアツキカンゴヲウク。オメデトウ。テイコクホテル，オークラ」

Bibliography :

- Futagawa, Yukio. Frank Lloyd Wright The Imperial Hotel, Tokyo, Japan. 1915-1922. Tokyo, Japan: A.D.A. Edita 1980.
- Hoto, Julius. “Imperial Hotel, Tokyo, Japan.” Architectural Record Jan-June 1924: 118-123.
- Reitherman, Robert King. “Frank Lloyd Wright’s Imperial Hotel: A Seismic Re-evaluation.” NISEE – National Information Service for Earthquake Engineering. <http://nisee.berkeley.edu/kanto/kanto.html>
- James, Charles. “The 1923 Earthquake and Fire.” NISEE – National Information Service for Earthquake Engineering. <http://nisee.berkeley.edu/kanto/tokyo.html>
- Kengelbacher, August. “Great Kanto Earthquake 1923.” Schauwecker’s Guide to Japan. <http://www.japan-guide.com/a/earthquake/>
- Watson, James. “Seismic Foundation Design.” Department of Civil Engineering Earthquake Engineering. Sept. 2003. <http://www.cen.bris.ac.uk/civil/students/eqteach97/design2.htm>