FRANK LLOYD WRIGHT'S IMPERIAL HOTEL: A SEISMIC RE-EVALUATION

Robert King Reitherman[I]

SUMMARY

A technical reassessment of the story of the Imperial Hotel and the 1923 Great Kanto earthquake is overdue, and some of the following topics have not previously been scrutinized thoroughly: seismic separation joints, "waiter's tray" box system, short pile foundation system, cavity wall construction, vertical distribution of material, fire-following-earthquake preventive measures, masonry anchorage details, structural/non-structural isolation. With our hindsight, some of the building's aseismic features may now seem of dubious validity, but the Imperial Hotel remains a rare example of a designer's thorough attempt to integrate architecture and engineering into a comprehensive aseismic design strategy.

HOTEL STANDS UNDAMAGED AS MONUMENT OF YOUR GENIUS. HUNDREDS OF HOMELESS PROVIDED BY PERFECTLY MAINTAINED SERVICE.
CONGRATULATIONS.
OKURA

This dramatic radio telegram from Tokyo by Baron Okura, the key financial promoter of the just completed Imperial Hotel, was the first word to reach the U.S. concerning the September 1, 1923 Great Kanto earthquake: the Imperial Hotel earthquake legend had just sprung to life full grown. As one of Wright's biographers has noted, "The publication of this message in the newspapers was the start of the widely believed and printed myth that the Imperial Hotel was the only building in Tokyo to withstand the earthquake. This however, was far from the truth." (1)

If one were to choose the building whose performance in the 1923 earthquake had the greatest influence on architectural historians and journalists and therefore the mass audience, it would no doubt be the Imperial Hotel. But if one were to look at the structural performance which was most noted and discussed among engineers, or to single out the examples which had the greatest effect on both the development of the state-of-the-art of seismic design and on the evolution of the modern aseismic building code, then the Tokyo buildings designed by Dr. Tachu Naito would be the obvious choice.

The family tree of our contemporary seismic state-of-the-art can be traced back through Naito (and Suyehiro, Sano, Imamura, Omori, Milne, and others in Japan) and to Italy and elsewhere in the latter half of the nineteenth century, but Wright is not part of this lineage. The Imperial Hotel case stands outside this evolutionary history.

I. Research Associate, Building Systems Development, Inc., San Francisco. California.

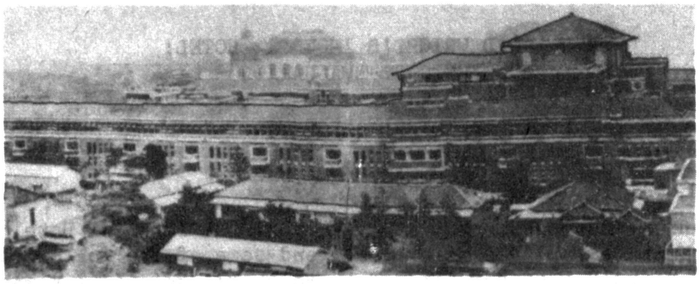

Fig. 1 Imperial Hotel, Tokyo. View following the earthquake showing the Hotel (as well as an insurance firm's brick building beyond).
photo: Clay Products Institute Of California

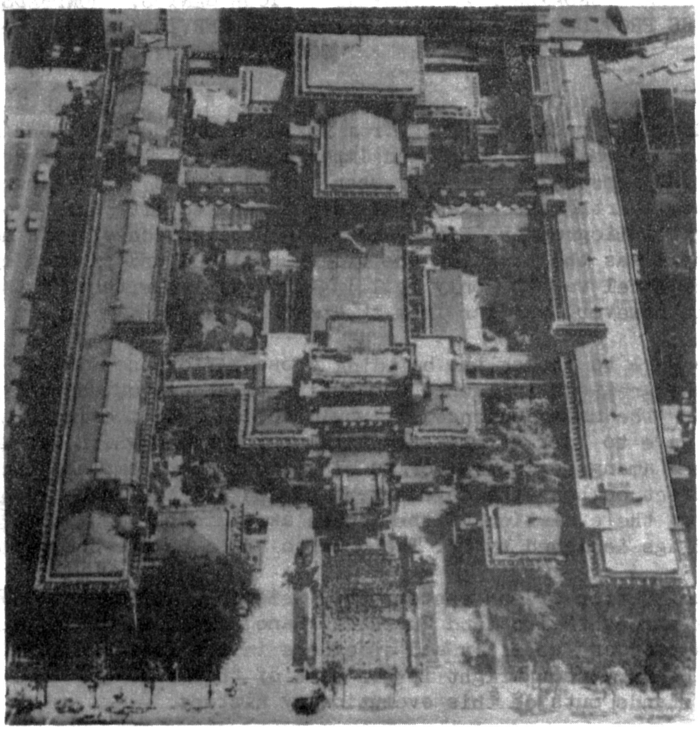

Fig. 2 Imperial Hotel, Tokyo. Aerial view of the building in the 1960's, prior to demolition to make way for the new high rise hotel on the same site.
photo: Architectural Forum

Extent Of Damage. The Imperial Hotel experienced some non-structural and structural damage in the 1923 earthquake: the dining room floor bulged and required cutting and shimming of concrete columns to re-level it, and fans, kitchen equipment, lights, partitions, and other similar non-structural items were damaged. The insurance companies' damage rating system used a five point scale. The Imperial Hotel was listed in the category of second-best performance, or light damage. There were other large buildings which were rated in the first category. (2) The Tokyo Building Inspection Department's estimates, which included fire as well as earthquake damage, list about 19% of the city's brick buildings in the undamaged category, and a little over 20% of the steel and reinforced concrete buildings in this category. (3) Typical, second-hand contemporary press accounts that the building "withstood the earth stresses far better than other large buildings in Tokyo" were thus in error, and the recently made statement that "Frank Lloyd Wright's finest hour was when his Imperial Hotel in Tokyo stood while others fell" might be more accurately re-phrased to say "while some others fell, (and while some others performed better)." Imamura's contemporary intensity map of Tokyo placed the Imperial Hotel in the second most intense category out of four levels of shaking. A good deal of Tokyo was within this category or the highest level of intensity. While these basic facts may not be surprising to Japanese readers, there is a considerable amount of misconception in other countries. The building's structural performance, under these circumstances, might be termed good, but not outstanding. If settlement had not occurred, (and it is settlement which the contemporary reports blame for the structural damage to concrete columns and floors) the building would apparently have performed quite well.

Foundation System. Many people have heard that the building's foundation system somehow isolated the building from the earthquake's vibrations, and that this was responsible for good performance. The foundation system was certainly quite novel: nine inch diameter tapering concrete piles only eight feet long were set about every two feet along the length of the walls, in pairs or threes side by side. About eight feet of soft surface soil overlaid about 75 feet of softer alluvium and ground water extended to within about two feet of the surface. "Because of the wave movements, deep foundations like long piles would oscillate and rock the structure... That mud seemed a merciful provision - a good cushion to relieve the terrible shocks. Why not float the building upon it? - a battleship floats on salt water." (4) Julius Hoto, the project's Japanese structural engineer, agreed. "These piles tying the heavy superstructure of the taller buildings to the solid earth below, transmitted the full intensity of shocks." (5) Hoto's and Wright's attraction to the idea of a "monolithic mass resting on a soft flexible cushion" is perhaps not itself theoretically invalid, however it does lead to the related problems of providing adequate vertical support to prevent settlement and of making an entire building truly act monolithically. The "soft story" concept as applied to soil materials is as dubious and problematic as its application to the ground story of a building. It is likely that the underlying mud, rather than being "a merciful provision - a good cushion," was rather an amplifier of the ground motion. However, at the same time that it would have increased the amplitude, it would have affected the frequency content of the motions, filtering out the short frequency and transmitting a predominantly long period motion to the surface. The Imperial Hotel was demolished in 1968, amid worldwide but ineffectual protests. Probably the prime reason for the economic obsolescence of the hotel was its low-rise, low density design and its high-priced, central Tokyo location. A reporter also noted that the owners, the Inumaru's had cited the fact that "the structure was impossible to repair, and was slowly sinking into the mud." (6) The central 7-story portion of the complex settled two feet in the earthquake. From 1955-1965 it sank five inches. Total settlement at the rear of the central section in the 45 year life of the structure was three feet - eight inches. (7) Settlement was definitely a major problem. In Bradshaw's opinion, "When one sifts through the 'waiter carrying trays,' 'the earth waves,' 'cheese foundation,' etc., one finds that what the man did was drive piles. It's as simple as that... [another] misconception is that the choice of foundations [very shallow piles] was even a wise one." (8) The dining room floor structure was damaged because of this settlement. Although soil/structure interaction and local geological effects are subjects about which we will no doubt learn much more in the future, at this point it appears ironically likely that the design feature which Wright and other have primarily credited with the success of the Imperial Hotel's 1923 performance, the short pile foundation system, was in fact the probable primary cause of the damage experienced in 1923 from the earthquake and in subsequent years due to ongoing settlement. Taller buildings in Tokyo, which used deep pile foundations (and which probably tuned in more to the ground motion due to their height) suffered less damage, indicating that the usual foundation design method was a sound approach.

"The Waiter's Tray." Wright stated: "... a construction was needed where floors would not be carried between walls, because subterranean disturbances might move the walls and drop the floors. Why not then carry the floors as a waiter carries his tray on upraised arm and fingers at the center - balancing the load. All supports centered under the floor slabs like that instead of resting the slabs on the walls at their edges as is usually the case? This meant the cantilever, as I had found by now..." (9) Floors spanned transversely over a pair of columns in the middle, which straddled the double-loaded corridor, and the floors were supported by bearing walls at the exterior. Hoto thought that the Imperial Hotel's cantilever design appeared "new by virtue of the originality of architectural design" not by its structural behavior. Wright was addressing a major recurring problem in masonry design: how to connect floors to walls. Wright's reasoning that extending the slabs continuously over the wall, rather than "leaving them to grasp at the sides of walls" was at least theoretically valid, but this leaves several practical issues concerning chords, wall-floor shear transfer, and bond beam function left unanswered. Some old masonry school buildings in Tokyo were described by Milne twenty years earlier to have had wood roofs which "floated" upon the walls, to allow seismic movement. These approaches, however, have been universally rejected by mainstream seismic design since then, which has emphasized tying the parts together.

Bearing Wall Construction And Masonry Anchors. The bearing walls were composed of an exterior wythe of solid bricks, an interior wythe of hollow patterned bricks, and a solidly filled cavity of concrete. Was the concrete reinforced? In a letter to John Freeman in 1931 Wright specifically said that there was no steel reinforcement in the concrete, while according to Hoto, the walls were built by "layering up an outer and inner shell of brick, filling in between, as the work progressed, with concrete and laying reinforcimg steel into this concrete, thus making exceedingly strong monolithic walls." (10) It is symptomatic of this building's story that there are conflicting reports concerning such a basic point. As Shinjiro Kirishiki notes in his attempted reconstruction of the financial, construction process and other aspects of the building, many records have been lost either in the 1923 earthquake and fire, or in the bombings of 1945 (in which the Hotel was partially burned), and "several points still remain vague." (11) According to Berg, "... A construction feature that received less comment [than the short pile foundation] from the architect but which seems to me to have been a greater contributor to the success of the structure, was the exterior wall construction. The walls consisted of a double shell of brick, each shell just a single brick in thickness, but with the void space between them carefully filled with poured concrete. In principle this is not greatly different from the filled-cavity masonry walls required in California schools today." (12) Wright had also written that because the lava stone used as trim was "so easily worked I could hollow it out and use it for forms into which the concrete slabs, cantilevers, or walls were cast and the steel reinforcement be tied into the material from beneath and all cast solidly together with the concrete. Wherever there was a chance for a flaked off piece, copper was used in connection with it to insure it." (13) Since the Imperial Hotel was perhaps the most profusely ornamented masonry building in Tokyo, the good performance of appendages is notable. Reportedly only 2 pieces of garden sculpture fell down.

Reinforced Concrete Frame Design. Hoto stated that although he designed the reinforced concrete slabs and transverse frames for Wright in conformance with the code then in effect in Chicago, "he tells me now that, in building, my computations were disregarded and that much lighter sections were everywhere substituted, making in effect a design which eliminates all the strength usually provided for the live loads. In this connection, the writer would like to comment that this reduction was entirely logical..." (14) Since early code provisions dealing with reinforced concrete for vertical loads were sometimes unduly conservative, Hoto may have been right concerning the prudence of Wright's downward adjustment of his calculations, especially since the construction supervision was apparently quite thorough. It makes the story of the Imperial Hotel even more surprising, however, since the architect disregarded his structural engineer's calculations for concrete member design, used an innovative foundation system, and otherwise took responsibility for the building's structure. The Imperial Hotel illustrates both strengths and weaknesses of the strong-willed master designer or masterbuilder approach to architecture. Contemporary team design has obvious advantages, but perhaps it is not generally recognized that it too has weaknesses: often the team approach leads to merely "satisfactory" or "unobjectionable" compromises rather than to superior innovative solutions derived from a strong-minded adherence to first principles.

Configuration. The vertical arrangement of the building's exterior is an interesting example of the complementary interaction of architecture and engineering. "The outside walls were spread wide, thick and heavy at the base, growing thinner and lighter toward the top. Whereas Tokyo buildings were all top-heavy, the center of gravity was kept low against the swinging quake movements and the wall slopes were made an aesthetic feature of the design." (15) The walls were perforated with small windows in the first two stories, while the more abundant openings in the third story reduce the material and turn the walls into closely spaced piers.

"Flexibility." Wright wrote that "we solved the problem of the menace of the quake by concluding that rigidity couldn't be the answer, and that flexibility and resiliency must be the answer... Why fight the quake? Why not sympathize with it and out wit it?" (16) When Wright advocated "flexibility" he wasn't actually taking the opposite side of the debate from Tachu Naito, who was the prime spokesman for the "rigidity" argument in the twenties and thirties. Wright's method of creating a "flexible structure instead of a foolish rigid one" was to "divide the buildings into parts. Where the parts were necessarily more than sixty feet long, joint these parts, clear through floors, walls, footings, and all, and manage the joints in the design." (17) He called the result a "jointed monolith." What is immediately apparent today is that this was an early and thorough use of the seismic separation joint, though this seems not to have been subsequently appreciated. Thus the 500'-long wings did not have to try to act like 500'-long structures. The complex plan (from a seismic viewpoint), with eight major and at least four minor re-entrant corners, was thus merely a concatenation of simple, symmetrical, small rectangles, mostly three stories (plus basement) tall, about 35' x 60' in plan. Their height/depth ratio of the component structures was close to one, and the shear walls of the perimeter, along with the rigid diaphragms, and with some rigidity added by the interior columns and numerous longitudinal and transverse partitions must have created a stiff, rather than "flexible" structure, in the usual seismic use of the word. The fundamental periods were probably less than one-quarter second. Wright's use of light weight copper sheet rather than the traditional Japanese tile lightened the roof by a factor of about ten. The use of a light roof further reduced the period of the structure. (Wright had another purpose in mind: "Roof tiles of Japanese buildings have murdered countless thousands of Japanese in upheavals, so a light hand-worked copper roof was planned. Why kill more?") (18) The stiffness probably decreased the amount of non-structural damage, and also probably decreased the dynamic response of the building to the ground motion which, as discussed earlier could probably be characterized as long period.

Structural/Non-Structural Interaction. Mechanical/electrical riser members hung free of the structure in vertical shafts, and runs were laid in covered concrete trenches in the basement rather than buried. "Earthquakes had always torn piping and wiring apart where laid in the structure and had flooded or charged the building," Wright wrote. Lead pipes were used and pipe turns were accommodated with sweeping curves rather than small radius right angle bends. "Thus any disturbance might flex and rattle but not break the pipes or wiring." (19) Except of the underwriting industry's concern with the seismic aspects of fire sprinkler plumbing design around the time of World War II, Wright's serious attention to this architectural/engineering problem remained a rare example in American practice up until at least the 1964 Alaska earthquake, (and thorough examination of the non-structural problem remains the exception, not the rule even today, especially on the part of architects).

Entrance Court Pool. The reflecting pool in the entrance court, which stored roof-collected rain water, functioned as an emergency water supply *for bucket brigades following the earthquake when the conflagration swept* Tokyo and Yokohama. Fires reached to the very edge of the Imperial Hotel grounds on three sides, but it was not damaged. Surviving the trial by fire was probably more of an accomplishment than surviving the trial by earthquake. Windows were wetted down as the fire approached the vicinity. The pool had an everyday aesthetic role to play as well. In fact, since Wright often used a pool in an entrance court, as in the case of the Coonley House of 1912, one might argue that the pool would have been part of the design even if it had no emergency function to fulfill.

Conclusions. Though beyond the scope of this paper, it should be briefly noted that this same building was a forerunner in the development of radiant heating, forced air ventilation, and indirect lighting, and even though there is thus a long list of interesting seismic and non-seismic technical innovations involved in the story of the Hotel, it achieved fame and landmark status primarily on the basis of its aesthetic character. While American architect Louis Sullivan's contemporary writings on the Imperial Hotel contain inaccuracies, he was quite perceptive in calling the work "thought-built." Although Wright's accounts sometimes sacrifice engineering accuracy to poetic license, his statement that "the plans were made so that all architectural features were practical necessities" is more than simply self-publicizing rhetoric. Whether practicalities are antecedently considered and then used to determine the aesthetic aspects, or whether practicalities are fitted into pre-conceived design concepts, is perhaps of minor significance. The important question is whether or not the two sets of concerns are thoroughly integrated. Some of the innovative seismic design aspects for which the building is known, such as the foundation system and "waiter's tray" floor system, may now seem flawed, while other features never given much attention at the time or subsequently are now state-of-the-art: the use of seismic separation joints, structural/non-structural interaction, multi-hazard design to protect against fire as well as earthquake, filled cavity bearing wall construction, appendage anchorage, vertical mass and resistance proportions. It is generally true that a great building, upon closer inspection, is great for a variety of reasons, and perhaps it is also true that upon closer inspection the particular facts are almost never as simple as they at first appeared.

ACKNOWLEDGEMENTS

Portions of this research were conducted as part of "Building Configuration And Seismic Design," a National Science Foundation - funded study by Building Systems Development; and Charles Scawthorn, Christopher Arnold, and Eric Elsesser, were quite helpful in reviewing the manuscript and suggesting sources.

REFERENCES

1. Farr, F., 1961. Frank Lloyd Wright. p. 169

2. Bradshaw, R., January 1961, letter to the editor, Architectural Record, p. 10.

3. Clay Products Institute Of California, 1929, Earthquakes And Building Construction, p. 32.

4. Wright, F.L., 1955, An American Architecture, p. 150.

5. Hoto, J., "Imperial Hotel," Architectural Record, p. 121.

6. Dunhill, P., May 1968, "Requiem For A Masterpiece," Architectural Forum, p. 73.

7. Kirishiki, S., January-February 1968, "The Story Of The Imperial Hotel, Tokyo," Japan Architect, p. 137.

8. Bradshaw, R., January 1961, letter to the editor, Architectural Record, p. 10.

9. Wright, F.L., 1955, An American Architecture, p. 150.

10. Hoto, J., "Imperial Hotel," Architectural Record, p. 121.

11. Kirishiki, S., January-February 1968, "The Story Of The Imperial Hotel, Tokyo," Japan Architect, p. 137.

12. Berg, G., 1976, "Historical Review Of Earthquakes, Damage, And Building Codes," in William E. Saul and Alain H. Peyrot, editors, Methods Of Structural Analysis, American Society Of Civil Engineers, p. 392.

13. Wright, F.L. 1965, The Work Of Frank Lloyd Wright, p. 135.

14. Hoto, J., "Imperial Hotel," Architectural Record, p. 122.

15. Wright, F.L., 1955, An American Architecture, p. 152.

16. Ibid, p. 149-159.

17. Ibid, p. 152.

18. Ibid, p. 152

19. Ibid, p. 155. In regard to this and other issues discussed above, see also Freeman, J., 1932, Earthquake Damage And Earthquake Insurance, Chapter IX.