A Historical Review of the Techniques in Japanese Buildings for Resisting Various Loads, Focusing on Seismic Attacks

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1. Earthfast posts --- first structural members from the primitive days.

It is presumed that the time when human beings first inhabited on the land of Japan dates back to over thirty thousand years ago. The first twenty thousand years belonged to the Paleolithic age, and it is not clear whether people had dwellings or not. However, from twenty thousand years ago, when the Neolithic age came, people began to live in pit dwellings. According to the result of excavations, the topsoil was dug until about 1 meter below ground level roundly or squarely to make floor. On the floor level, four or more earthfast posts stood, the feet of which are embedded directly into the earth, and beams were laid between the tops of posts. On the other hand, many rafters were stretched slantingly from the ground just outside of the rim of pit toward the beams, thus making roofs, probably thatched. Since the size of pit dwellings in the primitive days must have been as narrow and low as one family could barely live, and, therefore, the total weight must have been so light, pit dwellings would have been quite strong enough against lateral loads, such as earthquakes and winds.

In the course of time, the first prosperous days came to Japan. In about B.C. 3,500~2,600, huge raised-floor buildings, presumably watchtowers, came to exist. According to the result of recent excavations, people obtained the technique of cutting trees as big as nearly 1 meter in diameter with stone axe. Such huge trees were processed and erected as earthfast posts. Big timbers must have been used as structural members in every parts of huge raised-floor buildings, accordingly, buildings became very heavy but strong against lateral loads.

Earthfast posts were strong enough against lateral loads, insofar the bottom of posts was well stationed on solid soil and the surroundings of posts were well refilled with soil or stone and tamped down. The only disadvantage of earthfast posts was that the feet of posts were apt to rot in the humid condition as Japan. The lifespan of buildings are presumed as short as several decades.

In addition to these two types of building, pit and raised-floor, there existed the third type, namely ground-floor buildings. Earthsast posts were used also for the ground-floor buildings.

Coming down to the later period, in about B.C. fourth century, ironware was introduced in Japan together with the technique of rice cultivation. In spite of these great changes of culture, three types of buildings, namely pit, ground-floor and raised-floor, continued. At the same time, the technique of earthfast posts still survived. From around the third century A.D., Japan launched to have relations directly with the countries in Asian Continent such as China and three kingdoms in the Korean Peninsula. Consequently, many powerful families appeared and big tumuli were constructed. Also, it is presumed that the style of huge palace building must have been introduced. Nevertheless, no outstanding new architectural techniques were introduced. Posts were still earthfast ones.

2. Posts standing on foundation stones.

In the 6th century, Buddhism was introduced from Korean peninsula. Japan groped to communicate with China (Sui Dynasty). In the 7th century, the advanced political, administrative systems as well as all kinds of cultures were imported from China (Tang Dynasty). Many Buddhist temples were established, and the style and structure were greatly changed. Posts were set up on foundation stones which were placed on podia, some bays between posts were filled with thick clay walls, on the posts complicated bracket compounds were set up, and roofs were covered with tiles.

Why Chinese architecture had the formation composed of posts on foundation stones and clay walls? This question is too difficult to answer, but if I add some hypotheses, the history of development could be explained as follows. In the very ancient times, Chinese buildings had earthfast posts, but, the history different from Japan was that there were hidden foundation stones at the bottom of posts. The result of excavations of ancient sites dating back to B.C. 16~11th centuries shows the trace of this technique. However, in the course of time, foundation stones raised up toward the surface of podia. On the contrary, Japan did not have the technique of foundation stones to support posts. It is presumed that Japan was pleased to accept this Chinese technique as a new, advanced and fashionable technique, hoping that ever-lasting buildings could be made by applying the technique of posts with foundation stones.

Nevertheless, posts standing on foundation stones do not have any power of resistance against lateral loads. If posts incline and the vertical line from the center of upper loads comes down out of the base of post, this post can not stand any more and will fall down, or if upper loads are not heavy enough, posts will slide form foundation stones. To cope with this shortcoming, Chinese invented to set up very thick and strong wall between posts, which was sometimes made of brick or tile. This structural system composed of posts standing on the foundation stones and thick walls would have been safe enough in China where big earthquakes are rare.

Japan accepted this Chinese structural system. A good example of this system can be found at the Golden Hall of Horyu-ji (Buddhist temple), which was built in the latter half of 7th century. Here, the bays surrounding the inner sanctuary (5 bays x 4 bays) are closed with thick walls and solid wooden doors. Furthermore, it is worthwhile noting that the walls are equally six in number along both longitudinal and transverse directions. This layout of posts and walls shows how effective it is in order to resist against seismic attacks. It can be presumed that the layout may be the origin of the fortunate history of the Golden Hall which has been kept intact for about 1,300 years.

The inner sanctuary of Golden hall, Horyu-ji is a successful example, but at the outer bays of the same hall more open bays with doors and windows were preferred. Consequently, horizontal members, named nageshi, are put above and below the doors and windows. A pair of nageshi was set so as to pinch posts from both sides and was fixed by nails. It is presumed that nageshi might have been invented by Japanese carpenters. However, frankly speaking, the effect of nageshi against seismic attacks would be rather small.

The structural system composed of posts with foundation stones and solid walls prevailed among Buddhist temple buildings and main palace buildings, but in many places earthfast posts system also survived. For example, the five-storied pagoda of Horyu-ji (late 7th century) had an earthfast central post standing on a foundation stone placed underground. It is presumed that the traditional Chinese technique would have been reminded. In Nara Palace site (8th century), the results of excavations show that almost all emperor's residence buildings and governmental office buildings had the system of earthfast posts. Moreover, vernacular houses in the countryside had earthfast posts until 10-11th centuries.

3. Revision of posts and walls system.

Japanese people preferred more open and light building. For this end, posts gradually became slender and thin board panel was preferred to thick clay wall. As mentioned before, nageshi was used, but the effect was so small. Therefore, the strength of building became rather weak. In the 12th century, aristocrats competed to establish new Buddhist temples, but during the next century many of them disappeared, among which a considerable number of buildings were fallen down by the attack of earthquakes and winds.
After the inner-war days in the 11-12th centuries, a new feudal warrior's government (shogunate) was established. Then, two architectural styles were introduced from China and contributed for the development of Japanese architectural techniques. The first technique was nuki (penetrating tie) system. It is the system that square holes are dug on the surfaces of confronting two posts and horizontal tie bars are inserted into these holes and tightened with wedges. At first nuki was inserted separately in each bay, but later, from 14th century on, nuki was long enough to penetrate two bays or more.
The second technique was sujikai (diagonal brace).. Sujikai system was once applied in the 13th century, but has not prevailed or survived, because it sometimes caused clacks on the surface of clay wall. Clay wall was also used together with nuki, but soon became thinner. Therefore, if a wall was deformed, clacks came out and wall itself would gradually clash from the peripheral parts toward the central part. So to say clay wall had the role of buffer.

4. People's philosophy to the damage caused by earthquake

The system, composed of posts, nuki and thin wall has continued until the end of the pre-modern times, namely 19th century. Yet, Buddhist temple buildings were rather strong against lateral loads because of their comparatively thick members and complicated, tough construction. On the contrary, vernacular buildings were much poorer and subject to serious damage by lateral loads.
If we see a world map of seismic distribution, we can understand that Japan is located on a belt of serious earthquakes. Japan experienced many earthquakes as strong as around M8. But more serious phenomenon is that in Japan earthquakes occur almost everyday, if up to insensible ones are counted. Buildings suffer from vibration, and every time slight deformations and damages may be left and accumulated. Eventually, after several centuries, a strong earthquake will destroy buildings.
Because of the lack of effective preventive measures, to stop gradual looseness, Japan discovered the unique way of periodical repair. First, the parts easily subject to damage, such as roof tiles and clay walls, should be repaired from time to time. Secondary, about every 200 years buildings should be tightened again and/or partially dismantled and reassembled if necessary. Finally, every 300-400 years major repair woks, including complete dismantlement, necessary replacement of members, and reassembly should be carried out.
Vernacular houses were very weak to seismic attacks. Therefore, common people despaired of the damage caused by earthquakes, by saying "An earthquake is caused by the struggle of huge catfish underground.

5. The modernization of Japan and the improvement of structural dynamics

In 1868 Japan opened her window to the world and began to step forward to the way of modern country. Following European policy, a university was established and the first graduates appeared in 1879. But, in those days, all energies were devoted to learn European architecture and science, and no interest was paid toward the improvement of Japanese timber buildings.

In 1891, a big earthquake which is supposed as strong as M 8.0 occurred in the central area of Japan which caused the damages of 140 thousand completely destroyed houses and over 80 thousand half destroyed ones. Then, the first on-the-spot survey was systematically carried out in Japan. In 1919, the government enacted the Law for Buildings in Urban Districts, but most of provisions were written for the purpose of city planning and only one article was provided for the architectural structure that the competent Ministry can establish regulations when necessary.
Japan was struck by a big earthquake in 1923 which destroyed Tokyo. Its size was as big as M 7.9 and the number of completely or half destroyed houses reached to 100 thousand, but the damage increased not by direct seismic attacks but by the fire caused just after the earthquake. Besides, a tunami of 12m high attacked the seashore.
The Law for Buildings in Urban Districts was repealed and the Building Standard Law was newly enacted in 1950. The Building Standard Law is active still now. According to this Law, big wooden buildings, such as temples cannot be constructed in town districts.

6. The history of the protection of cultural property buildings.

In Japan, the Law for the Preservation of Ancient Shrines ad Temples which was the first law for the protection of cultural property was enacted in 1897. This law was succeeded by the Law for the Preservation of National Treasures in 1929, and in 1950 the Law for the Protection of Cultural Properties was enacted. It is very interesting that the these two laws, one for the development of towns and buildings and the other for the protection of cultural property, were enacted in the same year, 1925, and it was decided to prescribe in the Article 3 of the Building Standard Law that “cultural property buildings shall be excluded from the application of this Law”. It was understandable that cultural property buildings should be free from the restrictions of the Building Standard Law, because of not only the need to keep their cultural value but also the consensus among scholars that cultural property buildings would be strong and tough enough to resist against seismic attacks. The number of designated buildings as cultural property was then about 1,100, and almost all of them were shrines and temples, which had rather thick members and complicated structures. Among them only one building fell down by the shock of earthquake in 1923. This anecdote may prove the fact that cultural property buildings were strong enough.

7. New policy for the protection of cultural property

With the enactment of the Law for the Protection of Cultural Properties, the objective of the law changed from preservation to protection. The Law prescribes that the word “protection” means “preservation and utilization”. In order to utilize cultural property for our present days, they should be actively used, either for the proper usage, for the sake of tourism, or for any secondary purposes, such as museum. Consequently, cultural property buildings must be reinforced for keeping the security of the people visiting them.
Secondly, the targets of cultural property building expanded. Before 1950, all designated properties were either Buddhist temples and Shinto shrines, castles, mansions and other monumental buildings, but after 1950 many vernacular buildings and so-called western style buildings in the early modern period have been designated as cultural property, which are far week against loads from outside, including seismic attacks.
Therefore, the thoughts to reinforce cultural property buildings were gradually claimed as the policy of government and also as the ethics of conservation architects.
Reinforcement works have been carried out in the first place taking the opportunity of repair works of vernacular buildings. In these works main structures must be strictly preserved to keep authenticity. Conservation architects and structural engineers discussed carefully and reached consensus. The idea of reinforcement was that the small clay walls between lintels and ceiling should have been strengthened by inserting hard

board panels, and, if the width of bay between two posts was so wide, a steel framework should have been constructed as subsidiary support preferably in hidden or shadowy places. In this case, the principles for the reinforcement of ordinary scale buildings given by the Ministry of Land, Infrastructure and transport Japan were fully referred. The lateral load caused by an earthquake was fixed as 0.2 of vertical loads (self load + superimposed load +snow load etc.) and the angle of inclination of posts at the time of earthquake was less than 1/30 radian. These restrictions seem rather classical.
The surface of reinforced wall can be plastered by traditional material and the steel frameworks may be recognized as temporary structures, therefore, it is believed that the essential points of authenticity are not violated.
By the big earthquake which attacked Kobe in 1995, a western-style two-storied house was completely clashed. At the restoration work of this building, a huge earthquake exemption apparatus was constructed in the basement. By adding this kind of equipment, the cycle of seismic waves can be made longer, probably until 4 sec. As the proper cycle of timber structures may be 1-2 sec. the sympathetic vibration between building and earthquake can be avoided. The earthquake exemption apparatus is of course hidden underground. However, there is some criticism that such a equipment is so exaggerated for a small light timber structure.

8. Recent anti-seismic ideas

Recently Japan was attacked by several strong earthquakes. Owing to the improvement of seismograph, the waves of three big earthquakes of different types have been exactly observed by meteorological observatories. Among them the three types of earthquakes, namely a deep ocean type (1968, M7.9), a intermediate type (1978, M7.4), and a just above epicenter type(1995, M7.3) were representative.
In 2000, the Ministry of Land, Infrastructure and Transport Japan issued a notice, saying that an imaginary seismic wave which includes three waves mentioned above shall be applied as the basis of structural analysis of skyscrapers. Furthermore, the Ministry requested some special magnification of seismic force, when a building is built on the alluvial. Thus, the control by the competent authority became more and more severe, but at the same time, the advantageous points to be applicable to timber structures have been found. For example, the modulus of lateral load can be reduced when the condition of sympathetic vibration is clear, and the angle of allowable inclination of posts can be moderated until 1/15 radian, instead of 1/30 radian.
Quite recently, the special project team, headed by Prof. Suzuki of the Kyoto University invented a new method, by applying above-mentioned condition for the reinforcement work of the Hall Dedicated to the Founder in Higashi-Hongan-ji in Kyoto. Owing to their energetic study, we could apply a considerably simple anti-seismic method. However, a lot of experiments and much financial resources must be needed. Therefore, it would be difficult to apply this new system to all reinforcement works of cultural property buildings.

9. Conclusion

Now that cultural property must be preserved and at the same time, should be utilized, buildings should be accessed by people as easily and safely as possible. Consequently, cultural property buildings should receive earthquake-proof reinforcement. However, some methods applied so far are not necessarily suitable for cultural property. Fortunately, as the advance of seismology is quite striking and speedy, I hope more simple, suitable and effective measures will be invented near future.