Just How Good Is Wood?

Wooden buildings constructed with traditional techniques show remarkable seismic resistance. **Kawai Naohito** of the Department of Structural Engineering at the Building Research Institute explains what we might learn from these buildings based on the results of tests being conducted in Japan.

Japan has a long history of constructing buildings with wood. Many wooden buildings such as Buddhist temples and Shinto shrines are still standing, including the Golden Hall of the Horyu-ji temple, the oldest extant wooden building in the world. Five-storied pagodas of around 30 meters in height, sometimes exceeding 50 meters, are also counted among them. Farmhouses have also been built in wood since time immemorial with the Hakogike house, allegedly built in the Middle Ages, still standing.

The five-story pagoda at Itsukushima-jinja shrine on the island of Miyajima, Hiroshima Prefecture

Hakogike house in Kobe, Hyogo Prefecture

Even today, temples and shrine buildings are often constructed in wood, and about 85% of detached houses are built in wood. Compared to buildings constructed with other materials, wooden buildings have gained recognition from the environmental perspective in recent years as the perception is that carbon dioxide emissions at the time of construction are low, and that they are effective in terms of energy conservation and carbon dioxide reduction. The traditional wooden buildings were sustainable structures, part of a cycle of forest cultivation and building production that made effective use of locally harvested wood, soil and other materials. From the viewpoint of the environment, one might say that they provide one model.

Another attractive point is that building a frame using timber and logs for posts and beams creates spaces with few walls that feel both approachable and expansive. In addition, in contrast to the modern industrialized production techniques, the value of manual production methods and the face to face connection between the builder and the one living in the house seem to be undergoing a reevaluation as something that is desirable for modern society with its economic priorities.

The History of Seismic Damage

In ancient times, earthquakes were natural calamities beyond human understanding, and little thought was given to constructing quake-resistant buildings. Before the emergence of engineering concepts, buildings seem to have been extremely fragile in the face of natural disasters. In Japan, where every year brings a risk of strong winds such as typhoons, there was some consideration of the wind in itself. Major earthquakes, on the other hand, occur with a frequency of once in several hundred years, and it is believed that the accumulation and transmission of techniques to resist earthquakes has gone beyond the potential time interval.

If we exclude the five-story pagodas, there are countless examples of the destruction of temples, shrines and private homes by severe earthquake damage. As an example of a five-story pagoda toppling over in the wind, there is the destruction of the five-story pagoda at Shitenno-ji by typhoon Muroto in 1934.

With regard to seismic resistance in traditional wooden buildings, the first scientific survey of earthquake damage was probably carried out after the Nobi earthquake in 1891. The seismic survey of the seismic resistance of residential dwellings was undertaken by Josiah Conder, a British architect working and living in Japan. He identified issues such as the lack of diagonal bracing in the walls, the lack of foundations, and heavy roofs.

Since then, wooden homes have sustained damage through repeated earthquake damage, and there have been advances in researching the seismic resistance of wooden buildings. At the time of the change from so-called traditional construction to new wood construction backed up by engineering, the attention focused on the weight of the walls. The Building Standard Law formulated in 1950 required the installation of diagonal braces in the walls, and that the sum of the value obtained by multiplying the factors (quantifying the seismic effect) of the length of the walls in all directions on every floor to be more than the reference value for the floor space. Today, the regulations on earthquake resistance for wooden buildings have changed in terms of numbers, but the way of thinking remains.

Seismic Resistance in Traditional Wooden Homes

In recent years, the scientific view has again come to focus on seismic resistance in traditional wooden buildings.


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Damage to wooden buildings in the Nobi earthquake of 1891, centered on Gifu and Aichi prefectures

For the past ten years or so, a lot of research has evaluated the seismic performance of traditional wooden structures in practice, attempting to leverage the results in modern design.

Originally, there were no engineering designs for traditional wooden buildings, but they were built based on traditional techniques handed down and backed up by the experience of the carpenter. Extremely advanced engineering judgment and analytical techniques are required to turn this into engineering models for analysis. Since this has been difficult in the past, there are aspects that have been left out of the standards, but thanks to modern advances in seismic engineering, the engineering approach has now become feasible.

Conceivable quake-resistant elements in traditional wooden buildings include the effectiveness of clay walls as shear walls, resistant posts that bend because partition walls are attached to the posts (a construction technique whereby the posts are simply placed on top of a stone) that reduces seismic input, and the self-reliance of large posts such as the ones in ancient temple construction.

The photographs show aspects of vibration tests conducted by the Building Research Institute on open frames featuring clay walls only in the upper section. The situation varies depending on the thickness of the logs or whether the plinths are fixed or not. If the diameter of the posts is a fairly thick 150 mm, the clay wall is destroyed, but if the diameter is a fairly thin 135 mm, the posts snap. Also, if the posts are simply placed on top of the stone without fixing in place, the plinths slide on top of the stone resulting in little damage to the frame.

Among the research projects funded by the Government, there are also those that carry out vibration testing on full-size traditional wooden houses. The photographs show the results of applying huge seismic motion to observe the state of destruction after confirming adequate performance at the standard of assumed seismic motion. In this regard, the graph shows an example of the analytical model and the results of analysis undertaken at the Building Research Institute using the Distinct Element Method. Using a 3-D model based on testing of components such as the clay wall and the connecting parts, it is possible to predict seismic response with considerable accuracy.

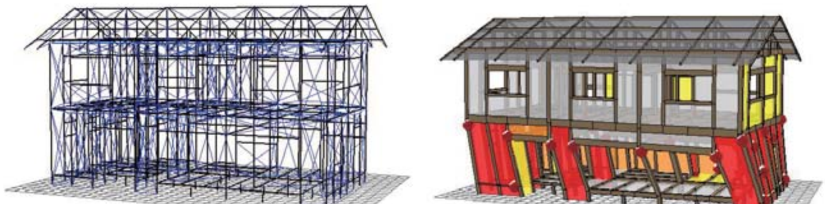
Through research projects that include empirical testing, we are discovering the potential for seismic design in traditional wooden buildings based on the flexing resistance in clay walls and posts.

Seismic testing of a frame consisting of posts and a partition wall. (Building Research Institute, 2008, 2009.)

Test situation: When the logs are thick, the wall in the upper section is destroyed.

When the circumference of the post is a size thinner, the post snaps. If the plinth slides, however, there is little damage.

Vibration testing of a two-story full-size wooden home. (Research project by the Ministry of Land, Infrastructure, Transport and Tourism, 2008.)



Example of analytical model and analytical results. The colors show degree of damage, from red (most damaged) through orange to yellow (least damaged). The gray areas suffered no damage. The red circles show where the supporting pillars are damaged. (Nakagawa Takafumi, Building Research Institute.)

Seismic Resistance of the Five-Story Pagoda

At first glance, the five-story pagoda looks like an unstable structure, but there is no historical record of a pagoda having been destroyed by an earthquake. There are many examples of pagodas escaping destruction even in major earthquakes with other buildings collapsing and sustaining major damage. The illustration is a record of damage to a five-story pagoda in the Great Ansei earthquake of 1855. The top is bent, but the pagoda escaped destruction, in marked contrast to the collapsed buildings in the surroundings.

About a hundred years ago, the seismic resistance of the five-story pagodas was treated as a seismic engineering riddle with a variety of theories put forward. They included emerging engineering concepts that have actually been put to use today, such as the potential for high-rise buildings to withstand earthquakes, or the mass damper technology for controlling vibrations by placing a weight at the top of a building and inserting a damper.

Research such as vibration measurements, manpower excitation and strong motion observation has been carried out on pagodas to find an engineering explanation for the seismic resistance of the five-story pagoda. So far, these measurements have been done on the twenty-two extant five-story pagodas built before the Edo period (1603–1867). In recent years, we have also carried out vibration testing, not on full-size pagodas, but on mockups scaled down to one fifth the size of a five-story pagoda (6.4 meters). In terms of normal seismic motion, it is clear that replicating the type of oscillation where all stories incline in the same direction is difficult, and that there is no major variation even if the shape of the central pillar of the pagoda is changed.

On the basis of this research, the reason five-story pagodas seldom collapse in earthquakes is that they sway slowly because of the height of the pagoda itself, which is about 30 meters. As a result, the foremost reason is that in normal seismic motion where many components sway minimally, resonance is not easily induced.

Seismic damage to a five-story pagoda. (From the archives *Ansei kenmonshi*, 1856)

Vibration testing of a mockup of a five-story pagoda. (Forum for Wood Architecture and the National Research Institute for Earth Science and Disaster Prevention, 2004.)

There is something about traditional wooden buildings in Japan that attracts people and makes them feel safe, an appeal that is not found in contemporary buildings. However, while it may be true that they are attractive, we cannot close our eyes to problems with seismic resistance. It is the role of us who live in the present day to accumulate objective data and to identify what is good about traditional wooden buildings through engineering appraisals, and to transmit the ancient knowledge to the future.

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