# Fire Safety Measures Enabling Construction of Large Wooden Buildings (Part I)

To create a large-scale wooden structure, it is important not only to ensure the safe evacuation of occupants in the event of a fire, but also to take fire safety measures to prevent the fire from spreading and minimize damage to neighboring structures due to collapse, scattering of embers and other hazards. Through activities such as full-scale fire testing on three-story wooden school buildings, the Building Research Institute has been advancing research into ways to improve fire safety in large wooden buildings.

### Promoting the Use of Wooden Construction

In recent years, there has been heightened interest in the use of wooden materials and wooden buildings. Until now, wooden building materials have primarily been used for the construction of detached homes in Japan. The Building Standards Law has imposed strict restrictions on large wooden buildings from the viewpoint of fire safety.

During the Edo period (1603–1867), Edo (now Tokyo) suffered several major fires, including the Great Fire of Meireki in 1657. While countermeasures such as the widening of roads and the creation of fire barrier zones were taken in response, major fires broke out repeatedly, in excess of a hundred times. Large fires continued to cause major damage throughout Japan during the Meiji (1868–1912) and Taisho (1912–1926) periods. During the Great Kanto Earthquake of 1923 in particular, some 76,000 people died and around 430,000 homes burned down in the major fires that followed. For this reason, restricting wooden buildings and the fireproofing of cities came to be regarded as the best fire safety measures. When a fire breaks out after an earthquake, fire-fighting operations cannot be relied upon. Accordingly, in terms of fire-resistive performance in Japan, large buildings are required to remain standing even after being subject to the heat of a fire, based on the assumption that no fire-fighting operations would be forthcoming in such an event.

Photo 1: An eight-story wooden apartment building in Sweden

Many major cities overseas have also experienced large fires. Notable among them is the Great Fire of London (1666), in which 85% of the city, which comprised tightly packed wooden buildings between three and five stories high, burned down. The fire is also famous for the subsequent ban on wooden buildings that was issued and the use of brick masonry for rebuilding.

In this way, while large wooden buildings have traditionally been restricted, the building of medium-rise and large-scale structures such as apartment buildings, schools and office buildings for which the use of wooden materials and members has posed difficulties until now is an effective way to increase the use of wooden building materials in the field of building construction.

Beginning in the 1990s, progress was made in the development of technologies related to wooden structures and fire safety in Europe. At the same time, fire safety standards underwent revision, and today the construction of medium-rise wooden buildings is possible. One such example is the construction of the wooden apartment building depicted in **Photo 1**. Even in Japan, regulations governing performance were established in fire safety standards in response to the revised Building

Photo 2: A three-story wooden school building constructed for full-scale fire testing purposes

Standards Law in 2000, and this has expanded the scope of use for wooden building materials by enabling the adoption of fire-resistive wooden constructions. Even so, the technical hurdles are still high, and fire-resistive wooden construction has not yet been widely adopted.

Amid these circumstances, the Act for Promotion of Use of Wood in Public Buildings was enacted in October 2010, and the Ministry of Land, Infrastructure, Transport and Tourism indicated its intention to revise regulations after conducting the necessary research regarding fire safety of three-story wooden school buildings. At present, the Building Standards Law requires that three-story school buildings should be fire-resistive buildings and made from a reinforced concrete structure or similar. As pointed out above, the establishment of performance-based regulations in fire safety standards has enabled wooden fire-resistive structures, but as will be discussed below, using wooden building materials in a visible way is difficult. Given this, research is underway to utilize wooden building materials and members in a visible way while ensuring adequate safety against fires even for buildings made of a wooden construction (**Photo 2**).

## Ensuring the Fire-Resistive Performance of Wooden Buildings

In terms of the fire safety performance required of buildings, generally speaking the larger the building, the higher the fire-resistive performance demanded in members such as posts and beams. As wooden building materials are regarded as being susceptible to fire, it has traditionally only been possible to construct small buildings using wood. Measures generally used to enhance fire-resistive performance even when wooden building materials are used include the fire protection membrane covering technique, where the wood is covered with gypsum board, and a burning marginal layer design (**Figure 1**).

By covering the wood with a noncombustible material, the fire protection membrane covering technique can moderate temperature rises in wooden building materials, making it harder for them to burn. However, as the wood is obscured with a covering material, the surface of the wood is not visible.

On the other hand, the burning marginal layer design utilizes properties to slow the speed at which burning progresses to the inside of wooden building materials by burning and charring the surface of the wood. Therefore, only members with a cross section equal to this thickness that will burn (burning marginal layer) are required. The surface of the wood can be shown, allowing the sense of wooden construction to be expressed.

Overseas, the use of fire protection membrane coverings in a way that does not show the wooden building materials is common, but in Japan, there is a strong interest in showing the wooden building materials and displaying that a building is of wooden construction if one is to use wooden building materials in the first place.

## Fire-Resistive Performance of New Wooden Members

Until around 1990, even wooden buildings in the West were limited in size to about two stories high, but today it is possible to construct buildings more than five stories high. These kinds of wooden buildings make judicious use of a new kind of wooden member known as Cross-Laminated Timber Panels, or CLTs (**Figure 2**). These are panels with a relatively thick cross section bonded at right angles to the grain.

While constructing a building using

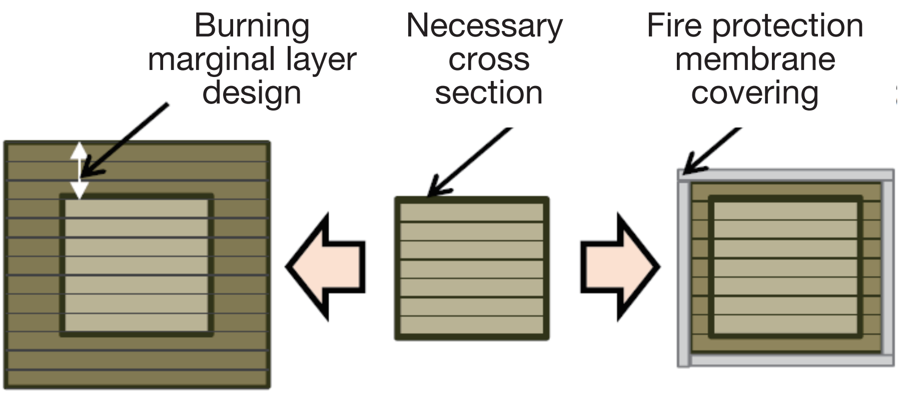


Figure 1: Concepts of Burning Marginal Layer Design and Fire Protection Membrane Covering

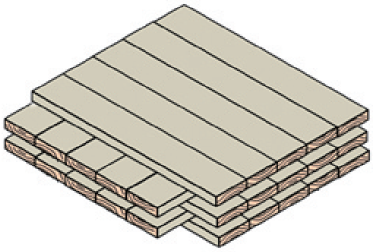

Figure 2: CLT Panel Configuration

Photo 3: CLT panels immediately after a heating test

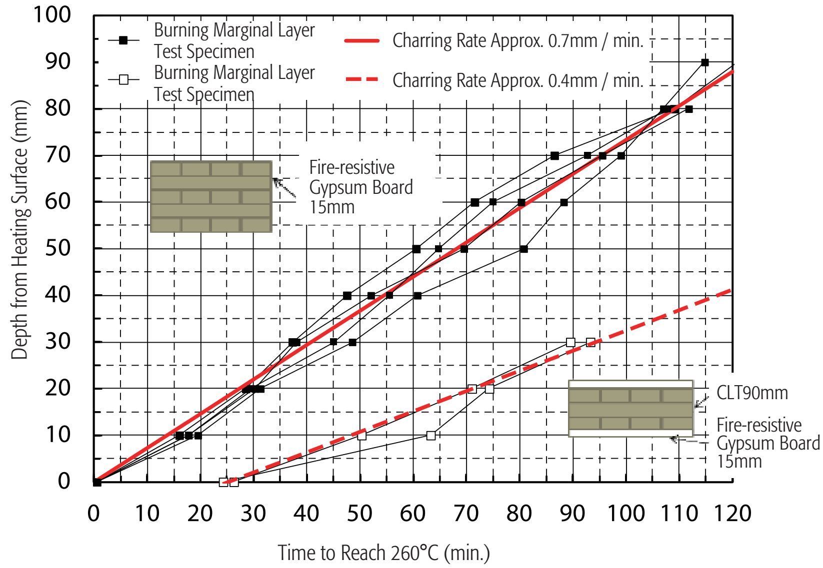


Figure 3: Charring Rates of Various CLT Panels

CLT panels still poses difficulties in Japan, there is a demand for CLT panels to be made easy to use. Given this, like the burning marginal layer design used in buildings that utilize large-cross section laminated materials (heavy timber) for posts and beams, we are advancing consideration to enable the application of burning marginal layer designs in wall and floor CLT panels.

We created wall test specimens that combined CLT panels with different properties such as covering method and tree species, and conducted heating tests to ascertain its fire-resistive performance. The results of the tests showed that for cedar-based CLT wall panels (without any fire protection covering), the charring rate was approximately 0.7 mm per minute, which represents a similar charring rate to heavy timber. In addition, for cedar-based CLT wall panels with a 15-mm fire-resistive gypsum board as fire protection covering, our results showed that not only was the charring start time of the wood components delayed for between twenty and thirty minutes, but also that if the fire protection covering did not drop off, the charring rate was reduced to approximately 0.4 mm per minute (**Photo 3**, **Figure 3**).

Based on these experimental results, CLT panels are assumed to exhibit a similar charring rate to that applied to heavy timber, and the application of a burning marginal layer design is thought to be possible. In addition, if the fire protection covering not falling off is established as a condition, the dimensions of the burning marginal layer could also be reduced and a more rational fire-resistive performance could be ensured.

## Charring Properties of Combined Members

With a burning marginal layer design for posts and beams, first and foremost members with a large cross section are used, but it is often difficult to secure large-cross section members when it comes to structural large-section glued laminated timber. If a burning marginal layer design can be applied in a similar fashion by combined members with a

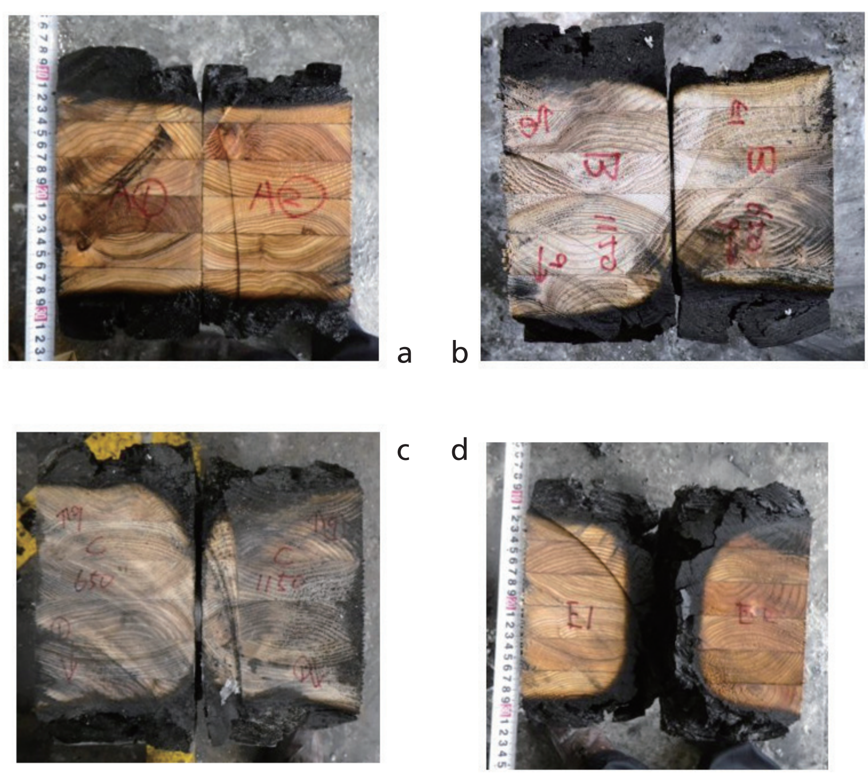


Photo 4: Charring properties of combined members (Gaps a: 0 mm, b: 3 mm, c: 5 mm, d: 20 mm)

Photo 5: Fire behavior in wooden interior finish spaces (left, when heated at 100 kW; right, at the end of the test)

medium cross section which are available on the market, there would be greater freedom in terms of design and construction. Given this, we ascertained the charring properties of combined members made up of medium-cross section members by means of heating tests.

With the combined sections, heat penetrates the gaps between members and charring advances. As test specimens we combined two laminated posts of cedar (120 mm x 240 mm) and conducted heating tests by varying the gap between members by between 0 mm and 20 mm. The results, as shown in **Photo 4**, clearly indicate that when the gap between members is greater than 5 mm, charring of the gap portion advances all the way in. Since burning up is limited when the gaps produced due to the drying of the wood, construction work errors or other factors is up to around 5 mm, this is not regarded as likely to cause significant problems in terms of fire safety.

Through these tests, it became evident that by combining medium-cross section members in this way, a similar burning marginal layer design to large-cross section laminated wood can be applied.

### Fire Behavior in Wooden Interior Finish Spaces

When wooden materials are used for interiors, as interior wooden materials burn together with combustibles stored inside a room, the heat release rate is greater and the time until flashover is reached is shorter, increasing the fire risks. The Building Standards Law restricts the wall and ceiling finishing in the habitable rooms of special buildings to flame-retardant wood and other flame retardant materials, but this prevents the creation of interiors that show the wooden materials. Given this, we conducted tests to recreate the fire behavior during the early stages of a fire using a space utilizing wooden materials for the interior.

**Photo 5** depicts such a space with a quasi-noncombustible material used in the ceiling and wooden materials used in the walls. When the space was heated using a gas burner at 100 kW for ten minutes, the tip of the flames reach the ceiling, but since the ceiling does not burn, it barely spreads laterally. Thereafter, when the space was heated with a burner at 300 kW for a further ten minutes, the wooden wall materials burned to the extent that the fire spread laterally underneath the ceiling, but the fire died down without spreading further.

In this way, we found that even when wooden materials are used in walls, provided the ceiling finishing is made non-combustible, burning during the initial stages of a fire is controlled to some extent. We were able to gain valuable insight in terms of evaluating the fire safety of spaces that use wooden materials for interior finishing.

Photo 6: Fire test using classroom-sized compartment

We have also conducted other fire experiments designed to ascertain the time taken to reach flashover and the risks of a fire spreading to upper floors due to flames emerging from below when creating classroom-sized compartment and finishing interiors with wood or other materials (**Photo 6**).

If we are able to properly evaluate the fire safety of wooden interior finish spaces by pursuing further research in the future, we expect the scope within which wooden materials can safely be used will widen.

This report was compiled by Hagiwara Ichiro (director), Kagiya Koji and Suzuki Junichi (chief research engineers) at the Department of Fire Engineering, Building Research Institute.