Outline of Conventional Construction Systems for Pitched Roofs in Eastern Asia

Takashi Ohno*1 and Wang Xihui2

1 Professor, Faculty of Engineering, Tokyo Polytechnic University, Japan
2 Researcher, Tokyo Technology Department, Sekesui House Ltd., Japan

Abstract
Roof construction is one of the most important building construction issues in relation to wind and rain. Government policy dictates that most new buildings have flat roofs, but many conventional existing ones have pitched roofs. These are the subjects of this study. The authors' research focuses on the following four items.

1) Conventional construction systems for pitched roof systems that reflect supply conditions in each area. University and technical college textbooks on building construction and literature on traditional building construction were collected and compiled. The authors also visited construction sites and surveyed students in each area to obtain relevant information.

2) Climate data on wind velocity, especially combined with rainfall, and the probability of simultaneous occurrence.

3) Distribution factors regarding wind pressure on roof surfaces with eaves and rakes that happened during wind.

4) Reinforcing methods considering wind with rain for existing construction systems.

As the first step, this paper outlines pitched roof systems in Eastern Asia.

Keywords: Conventional construction system; pitched roof; Eastern Asia; eaves; rake

1. Introduction
The development of construction systems requires a grasp of legal constraints, weather and other environmental conditions, conditions of use, related policies and cultural aspects, as well as production and construction conditions. Production and construction conditions are composed of various elements, including building materials usable for construction and type of labor. Actual situations are clearly indicated by conventional construction systems.

2. Scope
2.1 Consideration of dwellings as conventional construction systems
As might be expected, construction systems for large buildings expected to have new functions, for example, office buildings and commercial facilities, are almost the same as those used in Japan. These kinds of buildings use global standard construction systems that are almost the same anywhere in the world. Conventional construction systems are suitable for buildings that serve functions that do not change for a certain period of time, and dwellings are typical of such buildings. In many countries, dwellings account for the major part of building construction, and they are likely to reflect the actual situations of conventional construction systems, or production and construction conditions, in each country and area.

2.2 Focus of roof construction system
It is said that wind damage is greater than seismic damage. In the case of earthquakes, some breakage of non-structural members in various parts of a building is acceptable, however, breakage of such members as a result of wind can be critical, because it may lead to complete collapse of the building. Many coastal areas in Eastern Asia are hit by typhoons almost regularly from summer to autumn. (For inland areas, frequent occurrence of tornados has been reported recently with the influence of global warming or unknown causes.) In Eastern Asia, most dwellings generally have masonry walls on all external perimeters, and roofs become the focus of study concerning wind resistance.

Assuming that full collapse-resistant measures are taken for buildings, the major damage by wind is caused by negative pressure and wind updraft.

It is generally assumed that wind damage to
buildings with flat roofs comprising a reinforced concrete slab is rare. However, damage to buildings with pitched roofs has been reported in many countries and areas, and it is a problem that cannot be ignored.

Fig.1 shows some patterns of damage and collapse of buildings due to wind. The target of this research is to develop reinforcing measures to prevent the effects shown in Fig.1.2 (roof parts) and Fig.1.3 (roof structure and roof frame).

3. System of Study

At the beginning of this research, existing pitched roof systems were investigated as follows.

1) Textbooks on building construction of university and technical college were collected and information was compiled to determine common conventional construction systems.

2) Literatures were collected on the pitched roofs of some traditional construction systems on which most such systems are based, as well as various kinds of related materials including production and construction conditions, to complement the above information 1.

3) Construction sites and housing estates were visited to determine which construction systems were actually implemented in each area and to hear opinions from students with knowledge and interest in the building construction of pitched roof systems, to complement the above information 1 as well as 2.

The authors have not yet collected sufficient material and have visited only a few places in the centers of cities for short periods. As a result, this paper describes only part of the actual situation.

4. Results and Discussions

4.1. Roof structure

Fig.2. shows typical roof structures or roof frames that appear in textbooks that were collected. The masonry systems shown in Fig.2.1 are used in many countries and areas other than Japan. The trussed rafter systems shown in Fig.2.3 are peculiar to Singapore and Malaysia with trusses made of wooden boards such as 2×4. A couple roof, as shown in Fig.2.2, and similar systems consist of wooden boards like those used for the wooden trussed rafter system (Fig.2.3), or of round or square timber. The former roof frames are closely spaced as a roofing substrate, like rafters for the trussed rafter system. However, the latter roof frames are more widely spaced, like other roof framing structures.

Fig.2.4 shows a roof truss system that can be engineered with large spans, and is widely used. The
Fig. 3.1 iso. Horizontal Batten on Vertical Batten

Fig. 3.7 iso. Corrugated Sheet as Roof Sheathing

Fig. 3. Layer Construction of Pitched Roof

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post frame systems shown in Fig.2.5 are very common in Japan and are also seen in many other countries and areas.

4.2 Roof layer construction

Fig.3 shows typical layered construction systems from roofing to underlay on roof structures only. Roof frames are widely spaced for types from Fig.3.1 to

Fig.4. Support Type of Eaves

Fig.4.5 dtx. Figure in Vietnamese Textbook
Fig.3.10 with purlins. However, for types shown from Fig.3.11 to Fig.3.15, roof frames are closely spaced, such as trussed rafter systems with wooden boards, couple roofs, and other similar systems. Although the authors think the vertical battens shown in Fig.3.1 (Fig.3.1 iso) are very effective in discharging rainwater, they are rarely seen in Japan, and the type shown in Fig.3.5 is used widely in Eastern Asia including Japan. Types using galvanized metal sheets as roof sheathing, as shown in Fig.3.7 (Fig.3.7 iso) and Fig.3.8, are peculiar to the Philippines and are also seen in Taiwan. Types using thick roofing felts as substitutes for roof sheathing, shown in Fig.3.9 and Fig.3.11, are conventional roof systems in Singapore and Malaysia.

In general, it is expected that systems with more roofing layers can be easily adapted for varied performance. Roofing layers are determined in accordance with the level of precipitation, one of the most important elements in each region, so it is considered that overall roofing construction methods are connected with weather conditions in each region. However, according to the results of the authors' previous investigation, it seems that the distribution of pitched roof construction methods is related to spatial formation (styles) and types of materials, and is not necessarily related to weather conditions. Pitched roof systems made of cast-insitu concrete are excluded from this paper.

4.3 Support system for eaves

As most construction systems with eaves and rakes projecting from the building are cantilevered, they are the weakest points against wind. Fig.4 shows typical support systems at eaves in Eastern Asia. The systems are related to the roof structures or roof frames and layer constructions, and the Common Rafter systems of Fig.4.2 can be seen in many countries and areas including Japan. For systems with roof sheathing shown in Fig.4.3, the eaves are short and the Principal Rafter systems shown in Fig.4.1 allow long eaves.

Fig.4.1 iso is an isometric drawing showing their details. The systems of Fig.4.5 combine various horizontal materials with roof sheathing or common rafter. Every system is expected to be effective in providing structural stability at the eaves. The systems of Fig.4.6 use other special materials for the eaves and it is considered that all of these systems were devised for not only structural reasons but also for their details.

4.4. Support system for rakes

Fig.5. shows typical support systems at rakes in Eastern Asia. The systems are also related to the roof structure or roof frame and layer construction. Other members of Fig.5.2 (Fig.5.2 iso) are used in the case of roof layer construction without purlins, Fig.3.11 or 3.12 and the roof frame type is the Couple roof (Fig.2.2) or Trussed rafter (Fig.2.3).

4.5 Comparison

Table 1. shows structures and framing types of pitched roof identified through textbooks and so on for each country or area in Eastern Asia, Table 2. shows layer construction of roof surface, and Table 3. shows support types for eaves and rakes.

China has a very large land area, and covers most kinds of roof construction systems in Southeast and East Asia. In Malaysia and Singapore, teaching materials of Western countries are used as textbooks and this significantly affects their construction systems. The authors' identifying work covers a limited range through a limited number of documents, students and visited areas. Thus, the results of Table 1., 2. and 3. are not comprehensive and are subject to error. The authors expect various opinions from experts in building construction in each country and area following this contribution to the Journal.

5. Conclusion

Eaves and rakes which project from a building itself are the most important points. However, there are no acknowledged distribution factors of wind pressure on roof surfaces with eaves and rakes and there are no accepted simultaneous probabilities of wind velocity and rainfall. A proposal for standard reinforcing methods for existing conventional construction systems will be decided through a study based on climate data.
Table 1. Frame (Structure) Type of Pitched Roof

|        | M | P | T | R | F | M+P | M+R | M+F | P+R |
|--------|---|---|---|---|---|-----|-----|-----|-----|
| Japan  | o |   | o |   |   |     |     |     |     |
| China  | o | * | o | o | o |     |     |     |     |
| Korea  | o |   | o | o | o |     |     |     |     |
| Taiwan | o |   |   |   |   |     |     |     |     |
| Thailand| o |   | o | o | o |     |     |     |     |
| Vietnam| o |   | o | o | o |     |     |     |     |
| India  | o |   | o | o | o |     |     |     |     |
| Philippine| o |   | o | o | o |     |     |     | o  |
| Malaysia| o | o | o | o | o |     |     |     |     |
| Singapore| o | o | o | o | o |     |     |     |     |
| Indonesia| o | o | o | o | o |     |     |     |     |

O: Textbooks (and so on)  △: Others (visiting and surveying)

Table 2. Layer Construction of Roof Surface

|        | Purlin and Common Rafter | Purlin and Sheathing | Purlin | Surface Structure | Horizontal Batten |
|--------|--------------------------|----------------------|--------|------------------|------------------|
| Japan  | o                        | o                    | o      | o                | o                |
| China  | o                        | o                    | o      | o                | o                |
| Korea  | o                        | o                    | o      | o                | o                |
| Taiwan | o                        | o                    | o      | o                | o                |
| Thailand| o                        | o                    | o      | o                | o                |
| Vietnam| o                        | o                    | o      | o                | o                |
| India  | o                        | o                    | o      | o                | o                |
| Philippine| o                        | o                    | o      | o                | o                |
| Malaysia| o                        | o                    | o      | o                | o                |
| Singapore| o                        | o                    | o      | o                | o                |
| Indonesia| o                        | o                    | o      | o                | o                |
| (Figure)| 1                        | 2                    | 3      | 4                | 5                |

O: Textbooks  *: Traditional?

Table 3. Support Type for Eaves and Rakes

|        | Principle Rafter/ Roof Truss | Common Rafter | Roof Sheathing | Precast Concrete Panel | Combination | Other Member | Parapet/ (Fascia) | Purlin | Other Member | Parapet/ (Verge) |
|--------|-----------------------------|---------------|----------------|------------------------|-------------|--------------|------------------|--------|--------------|------------------|
| Japan  | o                           |   | *             | o                      | o          | o            | o                | o      | o            | o                |
| China  | o                           |   | o             | o                      | o          | o            | o                | o      | o            | o                |
| Korea  | △                           | o             | o              | o                      | o          | o            |      | o    | o            | o                |
| Taiwan | o                           | △             | o              | o                      | o          | o            |      | o    | o            | o                |
| Thailand| o                           | △             | o              | o                      | o          | o            |      | o    | o            | o                |
| Vietnam| o                           | o             | o              | o                      | o          | o            | o                | o      | o            | o                |
| India  | o                           | o             | o              | o                      | o          | o            |      | o    | o            | o                |
| Philippine| o                           | o             | o              | o                      | o          | o            |      | o    | o            | o                |
| Malaysia| o                           | o             | o              | o                      | o          | o            |      | o    | o            | o                |
| Singapore| o                           | o             | o              | o                      | o          | o            |      | o    | o            | o                |
| Indonesia| o                           | o             | o              | o                      | o          | o            |      | o    | o            | o                |
| (Figure)| 1                        | 2            | 3              | 4                      | 5          | 6            | 7,8             | 1      | 2            | 3,4              |

O: Textbooks  △: Others  *: Traditional?
of wind velocity and rainfall, and engineering data of wind force coefficient, as discussed above.

It is effective not only to rigidly connect each member with the roof structure or roof frame through the use of hardware, but also to increase member structural stability in existing construction systems. At the present time, the authors are interested in construction systems using an additional member such as that shown in Fig.4.5 in the textbook from Vietnam.

Fig.4.5 shows the original figure in a textbook from Vietnam.

Acknowledgement

The authors would like to thank Yasuhide Segawa (Archi Shop) for drawing many standardized figures other than Fig.4.5, and would also like to introduce the following students and others who researched teaching materials, collected them, and complemented various information.

China: Li Yuan Qi (Tongji University), Akira Natori (Toyo University)
Korea: Yongsun Kim (Tokyo University), Sungil Hong (Wonkwang University)
Philippine: Ronaldo E.R. Aquino (Vibratemics Inc), Caryn G. Paredes
Thailand: Waricha Wongphyat, Areemit Narongwit
Vietnam: Nguyen Ngoc, Ly The Dan, Thanh Trung Vu
India: K.M. Parammasivam (Anna University), Rajeev Gupta (Indian Institute of Technology)
Indonesia: Pandita (Jl. Tanjung), Yuji Katoh (Sumitomo Corporation)

This paper describes a part of the study that was made under the 21st Century COE program implemented by the Ministry of Education, Culture, Sports, Science and Technology (over a period from fiscal 2003 to 2007).

Notes

1) It is especially difficult to judge whether each foreign construction system is conventional or not.
2) This figure is quoted from pp. 245 of the Vietnamese Textbook in References.

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