Identification of Wood Used for Column Members of Historic Korean Timber Structures

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Abstract

For the maintenance and renovation of historic buildings, it is an essential prerequisite to identify the species of each member of a structure. In historic timber structures, identification of the wood used for structural members is a priority, but very limited data have been collected to date. In this study, columns and other structural members of historic timber structures in Korean cultural heritage buildings were collected to identify their wood species using light microscopy methods.

Among the 999 column members in the wooden heritages investigated, red pine (Pinus densiflora, 55.4%), zelkova (Zelkova serrata, 29.7%), and oriental chestnut oak (Quercus acutissima, 7.7%) were found in 92.8% of the tested column members. Over different eras, the wood species used in historic timber structures changed from hardwood to softwood. Foreign wood species such as western hemlock (Tsuga heterophylla), Douglas-fir (Pseudotsuga menziesii), and pitch pine (Pinus radiata) were observed in a few cases.

Keywords: historic building; light microscopy; red pine; wood identification; zelkova

1. Introduction

The Korean cultural heritages include historic timber structures (post-beam constructions), similar to the Chinese and Japanese wooden heritages. These structures use relatively plentiful wood resources and creative and disciplined wood working technologies in their construction. Horyuji Buddhist temple in Nara, Japan, a UNESCO World Cultural Heritage Site, is an example of timber structures that have been maintained in good condition for 1400 years. Also, there are many valuable wooden heritage buildings and cultural artifacts in Korea such as the Tripitaka Koreana, a UNESCO World Cultural Heritage Site, of wooden printing blocks with over eighty thousand Buddhist scriptures manufactured in the early 13th century. The Geungnakjeon Hall (national treasure 15) of Bongjeongsa temple constructed in 682 is the oldest Buddhist temple in Korea presently. Hwangnyongsa temple had a nine-story (about 80 m high) wooden pagoda built in 645 but it burned down in 1238. Considering these wooden heritages, it can be said that wooden members can have sufficient durability against bio-degradation (aging or weathering), and damage due to natural forces and the atmosphere even over several millennia.

Wooden members, however, are prone to damage by exterior factors, such as nature or human intervention, which threatens the overall structural stability. Generally, it is difficult to identify the wood species of the old members visually because the wood color and texture on the surface are apt to change during indoor or outdoor exposure and by painting for wood protection or artistic effect. To safeguard wooden cultural assets from damage, regular check-ups and repair or maintenance work have been conducted on the structural members. For conservation and preservation purposes, it is essential to collect as much information as possible on these heritage structures and artifacts over time.

For the preservation and maintenance of ancient historic assets, ICOMOS, International Council on Monuments and Sites, established in 1965, charted a principle: the same wood species or equally qualified/graded members should be used for substituting old members without any new constructions and modifications (Doh 2000). In many cases, however, it is uncertain which wood species had been used in the structures at the time of construction. For example, the Tripitaka Koreana (Korean national treasure 32) was said to be made of white birch (Betula sp.), before scientific research (Park and Kang 1996) found that it actually consisted of 8% white birch, 62% sergeant cherry (Prunus sp.), 13% sand pear (Pyrus sp.), and other species.

A few scientific studies on the wood species identification of old wooden materials have been conducted (Park and Kang 1996, KFRI 2005, Kim 1993, Hwang et al. 2008). This study aims to classify the wood species or combination of wood species...
of structural members (columns, beams, etc.) in Korean historic timber structures, as well as to gather information concerning the changes of wood species used in these buildings with a Korean history.

2. Materials and Methods

2.1 Survey Sites and Wood Samples

The number of wood specimens from heritage structures surveyed in this study are shown in Table 1. A total of 999 column members from 13 sites of national treasures, 64 sites of treasures, and 37 other sites were studied. In addition, 510 specimens for other members from 20 sites were also examined. The survey sites were selected based on the possibility of obtaining a suitable size of wood sample for identification purposes. Each member still plays an important role in each structural part such as columns, beams and others. Column members, in particular, provide the most important structural function for not only load resistance but also building appearance. Therefore, column members made up the majority of the samples investigated in this study. Wood samples were collected from decayed or fallen pieces in the field and were processed into a cube shape for microscopic observations. Test specimens for other members were prepared from the substituted members or from the members requested from a restoration company.

Table 1. The Number of Sites and Samples of Surveyed Wooden Heritages

| Category         | Member | Sites | Specimens |
|------------------|--------|-------|-----------|
| National Treasures | Column | 13    | 186       |
| Treasures        | Column | 64    | 519       |
| Other heritages  | Column | 37    | 284       |
| Other members    |        | 20    | 510       |
| Total            |        | 134   | 1499      |

2.2 Test Methods

Wood samples obtained from each site of historic timber structures were processed into small cubes of 2×2×10 mm. For light microscopy, these cubes were softened in 50% alcohol and sliced into cross-section, radial and tangential sections with 20-30μm thickness on a microtome. The sections were then stained in safranine, dehydrated in ethanol, immersed in xylene, then mounted in Canada balsam resin, and prepared into permanent slides called preparat (Eom et al. 2008). The rotten wood samples were frozen before being prepared as temporary slides. Light microscopic observations were conducted on each slide for anatomic characterization and wood identification.

Anatomical identifications for the samples were conducted based on the IAWA list (IAWA Committee 2004) of microscopic features for softwood identification, and several other references (KFR 1966; Park et al. 1987; Lee 1994; Lee 1987; Hong et al. 1987).

3. Results and Discussions

3.1 Wood Species of Column Members

Compared to other members, column members were mainly circular, providing good structural stability and aesthetic appearance. Softwoods such as red pine species provide a refined and simple figure, whereas hardwoods such as zelkova or oak species give a bold and sophisticated feeling.

The total number of wood species identified for column members was 19; where 11 of them were domestic wood species and 8 were foreign. A majority (92.8%) of the column samples were identified as Korean native wood species: 55.4% red pine (Pinus densiflora), 29.7% zelkova (Zelkova serrata), and 7.7% oriental chestnut oak (Quercus acutissima).

Other native wood species were red-leaved hornbeam (Carpinus laxiflora Blume var. laxiflora), chestnut (Castanea crenata), needle fir (Abies holophylla), Sieboldii Chinquapin (Castanopsis sieboldii), common camellia (Camellia japonica), Korean ash (Fraxinus rhynchophylla), Korean aspen (Populus davidiana), and Korean mountain ash (Sorbus aihifolia).

Foreign wood species, whether planted locally or imported, included American sycamore (Platanus occidentalis), Japanese larch (Larix kaempferi), Yezo spruce (Picea jezoensis), Western hemlock (Tsuga heterophylla), apitong (Dipterocarpus grandiflorus), pitch pine (Pinus rigida), radiata pine (Pinus radiata), and Douglas-fir (Pseudotsuga menziesii), and were seen in small amounts in a few sites.

Table 2. shows the percentages of wood species for column members in national treasures and other treasures. The hardwoods such as zelkova and oriental chestnut oak comprised a greater proportion than Korean red pine for national treasures, while the latter is the major component in treasures. Korean red pine is the major component in many types of wooden buildings, and it could be said that it was the preferred wood species of Koreans for wooden buildings. Fig.1. shows the cross-section, radial and tangential sections of Korean red pine, zelkova and oriental chestnut oak through observations by light microscopy.

Six wood species, namely zelkova, Korean red pine, oriental chestnut oak, red-leaved hornbeam, needle fir, and Sieboldii Chinquapin, were used mainly for column members in national treasures. Six other wood species, American sycamore, apitong, Yezo spruce, hemlock, pitch pine, and Japanese larch, seemed to be used in a few cases to substitute for the old members during restoration. Two or more wood species were used as column members for the building of national treasures. In a special case, five wood species including zelkova, Korean red pine, oriental chestnut oak, red-leaved hornbeam, and Sieboldii chinquapin, were used in Guksajeon Hall (national treasure 56) of Songgwangsa Temple, built in 1369. Whereas only a single species of zelkova or oriental chestnut oak
was used for the column members in the Buddhist temples of Muryangsujeon Hall (national treasure 18) of Buseoksa Temple and the Daeungjeon Hall of Sudeoksa Temple (national treasure 49). For treasures, the column members consisted of more various wood species than national treasures, and were identified as zelkova, Korean red pine, oriental chestnut oak, chestnut, needle fir, common camellia, Korean ash, Korean aspen, and Korean mountain ash. Five other wood species, namely Japanese larch, hemlock, pitch pine, radiata pine, and Douglas fir, were seemingly used to substitute the original wood during maintenance and repair works. Column members with Korean red pine alone were used at 27 sites for treasures, including Ojukheon (treasure 165) built early in the Joseon period (1392-1910) as a residence. Only Zelkova was used in Yaksajeon Hall (treasure 146) of Gwallyongsas temple, built in the early Joseon era; oriental chestnut oak was used in Gakhwangjeon Hall (national treasure 67) of Hwaeomsa Temple and Daeungjeon Hall (national treasure 290) of Tongdosa Temple and five wood species (zelkova, Korean red pine, oriental chestnut oak, needle fir, and Korean mountain ash) were used in Bogwangmyeongjeon Hall (treasure 608) of Wibongsa temple. In some special cases, common camellia was used as column members in Daeungjeon Hall (treasure 947) of Mihwangsa temple, and Korean ash and Korean aspen in Daeungjeon Hall (treasure 1243) of Songgwangsa temple in Wanjoo Province.

3.2 Historical Changes of Wood Species

It is possible to predict the type of wood species used in the column members based on the time of construction. Fig.2. shows the change of wood species used for column members over different construction eras. From the 14th to 20th century, the use of Korean red pine had increased from about 40% to 72%, while zelkova had decreased from 55% to 21%.

Column members in a large scale building, such as a royal palace, Buddhist temple, and multi-story pagoda, should be strong enough to support considerable loads; dead load, live load and other loads, which leads to an increase in the size of the members. In addition, column members should be durable because they are apt to be exposed to outdoor environments due to the characteristics of the post-beam structures in Korea.
Considerations of color and texture on the wood surface are taken into account in column members for better aesthetic appearance as well. Only limited wood species could satisfy the above prerequisites with sufficient supply, so zelkova was one of the solutions at that time. Zelkova, the so-called regal tree in Korea, has been used in structures, furniture, and household articles because it has a bold and sophisticated color and texture, and is stiff and hard enough to endure relatively high impact load and drying defects. At the end of the Goryeo era, an ancient Korean state (918-1392), the proportion of zelkova used as column members for highly valued buildings reached 55%, but decreased rapidly to 21% at the end of the Joseon Dynasty. The reduction in the usage of zelkova was compensated for by the increase of Korean red pine.

The application of Korean red pine increased from 40% at the end of Goryeo era to 72% at the end of the Joseon period. It was used for wooden construction such as royal palaces, Buddhist and Confucian temples, and shipbuilding. Throughout the Korean Peninsula, Korean red pine has been the most representative wood species which was available in large quantities and sufficiently large diameter for constructing timber structures. With the decrease of zelkova, which was usually used in temple constructions, a significant proportion of oriental chestnut oak was used as its substitute in column members. Besides being well-known for acorn production, oriental chestnut oak is suitable for shipbuilding, agricultural implements, construction, wine barrels, wagon wheels, charcoal, etc. Its usage rose to 13% in the middle of the Joseon era, but decreased rapidly thereafter.

Fig. 3. shows the distribution of wood species for column members with all building types. The wood species used for column members in national treasures were Korean red pine, zelkova and oriental chestnut oak with the exception of Buddhist temples. Forty-six percent of the column members for treasures in 45 temples were constructed with Korean red pine, 35% with zelkova, and 7% with oriental chestnut oak. For structural column members in treasures, residential buildings, pavilions, arbors, and government offices, 86% of the members were built with Korean red pine and 7% with zelkova, with a small portion of Korean ash. As shown in the right of Fig. 3., the proportion of main wood species used in all historic buildings were 23.8% zelkova, 41.3% Korean red pine, 13.4% oriental chestnut oak and 21.5% other species, 8.7% domestic wood species and 12.8% foreign species.

In general, hardwoods were used in arbors, pavilions, shrines, and Confucian temples, but not in residential buildings. Excluding an old residence with chestnut species in Bosung province, the constitution of wood species was the same as mentioned above in other timber heritages (important folklore materials and city/province designated heritages). Overall, softwood was thought to be preferred in residential buildings because of its odor and lower noise emission caused by indoor drying.

3.3 Wood Species of Other Members

A total of 510 specimens for other members were gathered from 20 sites for wood identification. Generally, if the building is not undergoing renovation or disassembly, collection of wood specimens from the structural members is firmly restricted (almost prohibited) because these members of historic buildings still play their structural roles and need to be preserved. Most of the samples examined (excluding columns), were softwood, about 90% (459 samples) of Korean red pine, and minor portions of pitch pine, needle fir, and ginkgo. Hardwoods such as red-leaved hornbeam, oriental chestnut oak, and zelkova were used for other structural members as well.

From the results of this study, it can be seen that the wood species used in historic timber structures varies with cultural and natural conditions, as well as the situation of the specified wood resources at that time. Irrespective of wood species (softwood and hardwood), currently plentiful wood species can be used as structural members or as substitutes for old structural members. However, the durability grade or strength level of wood species should be taken into consideration following the principle of ICOMOS.

Regarding the choice of wood species to be used in wooden heritage buildings and other artifacts in Korea, while the principles of ICOMOS and cultural and natural conditions are considered, Korean red pine and zelkova are the best wood species as are Japanese cedar (Cryptomeria japonica) and Japanese cypress (Chamaecyparis obtusa) in Japan (Jeon 1995).

4. Conclusion

Identification of wood species by using light microscopy was conducted on the structural members of historic timber structures in Korea: 114 sites in total including 13 national treasures, 64 treasures, and 37 other sites. The 999 column members in wooden heritages were found to be constructed from 19 different wood species: 11 domestic wood species such as Korean red pine (55.4%), zelkova (29.7%), and oriental cedar (25.8%).
chestnut oak (7.7%) constituted 92.8% of these column members, and 8 foreign wood species that seemed to have been used to substitute old members during restoration or maintenance.

For other structural members, 510 samples from 20 sites were collected for wood identification. Most samples investigated were softwood, where 90% (459 samples) of them were Korean red pine with small proportions of pitch pine, needle fir, and ginkgo.

Based on the results, it is concluded that the choice of wood species for cultural constructions in Korea was affected by both cultural and natural conditions, where the availability of wood resources was the main factor of consideration, taking into account the simplicity of maintenance and renovation. Regardless of softwood or hardwood, currently many wood species can be used as structural members or as substitutes for old members. However, it is important to consider the durability and strength of these wood species in terms of preservation and maintenance as structural wood members. The results of this study could serve as a good reference in choosing the right wood species for future construction and building renovation, as well as restoration of the existing structural members.

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