Regional Structural Investigation on the Preservation Districts of Yuasa and Ine in Japan

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Abstract
The preservation district of groups of traditional buildings is an important category of cultural properties in Japan. Japan has entered an earthquake active period. However, conventional culturally and socially oriented site investigation methods hardly satisfy the requirements of risk management of district preservation. In this study, the authors introduce an investigation method from the structural and security perspectives. They explain the study procedure, methods and results. Results of the investigation of two coastal districts, namely, Ine and Yuasa, are comparatively studied, and regional disparities are highlighted. The study concludes that district vulnerability and house structural performance should be considered as important indices when making decisions regarding district preservation.

Keywords: preservation districts; seismic risks; traditional wooden buildings; regional structural investigation; structural properties

1. Introduction
Districts of groups of traditional buildings exist extensively in Japan. These buildings exhibit various regional characteristics that highlight Japanese traditional wisdom and construction skills. The historical value of traditional districts is widely recognised. Hence, the category designated as important preservation districts of groups of traditional buildings (IPDGHB) was introduced via an amendment to the Law for Protection of Cultural Properties of Japan in 1975. IPDGHB are classified based on either one of the following criteria: a) groups of traditional buildings that display excellent general design, b) groups of traditional buildings and land distribution that thoroughly preserve the old state of affairs and c) groups of traditional buildings and their surrounding environment that demonstrate remarkable regional characteristics1. To date, the number of designated districts has increased to 1062.

Though the social-cultural value of traditional districts has been intensively investigated and manifested through conventional district investigations, such pursuit in traditional districts in terms of the physical–environmental dimension remains insufficient3. Earthquake records indicate that Japan has entered an earthquake active period. The damage statistics of Japan suggest that most fatalities are attributed to the structural failure of old wooden buildings. Thus, studying the seismic performance of buildings as well as the intention of conducting a seismic retrofit for the houses are important.

2. Investigation Methods
Individually evaluating the structural performance of traditional buildings is difficult because of the large number of buildings and the increasing number of designated preservation districts. Traditional buildings reflect the social, technical and environmental context of the corresponding district and share the same regional characteristics. The authors propose an onsite survey method for traditional districts that considers both the structural properties of wooden houses and the social context4.

To manage a large number of buildings, a regional structural investigation on traditional districts is divided into two parts, namely, overall district investigation and detailed house investigation. Overall district investigation is conducted to capture the status of an entire district, whereas detailed house investigation is performed on individual buildings to further explore the structural properties, performance and status of the inhabitants. Table 1. shows the items used in the investigation5.

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2.1 Overall District Investigation

(1) Regional structural characteristics
Overall investigation on regional structural characteristics is performed on all houses in the investigated district for structure types, usage and surroundings. These attributes are readily observed and measured from the exterior of a house. Certain items, such as types of structure, types of buildings, position of ventilation and distance between buildings, are inspected (Table 2).

(2) Questionnaire survey
The questionnaire survey aims to clarify the regional structural characteristics, way of life, maintenance situation, construction methods, house style and scale, housing maintenance status and disaster prevention difficulties.

(3) Ambient vibration measurement
Ambient vibration measurement is conducted to obtain the natural frequency (f) of the ground of the entire district. To estimate the seismic performance of the ground, the geographical condition of the ground is also considered.

The authors used a seismometer (GPL-6A3P, Mitsutoyo Corporation) to conduct ambient vibration measurement. Each accelerometer has three channels, i.e. one in the vertical direction and two in the horizontal direction. These channels work simultaneously. All the accelerometers are synchronised using Global Positioning System signals. The sampling frequency is 100 Hz. Each time series datum is divided into segments with duration times of 40.96 s. To minimise errors of noise, the ensemble mean is calculated and then fast Fourier transform (FFT) is applied to the ensemble mean. For each measurement, the authors use the peak frequency of the dominant period of the H/V spectrum of the microtremor records as the predominant frequency of the ground. The authors then apply FFT on the records and obtain the Fourier spectral ratio by dividing the amplitudes of the NS and EW directions by the UD direction.

(4) Interview with carpenters
The carpenters are introduced by the municipality for the interviews. The interviews focus on the material of columns and beams, typical construction methods and techniques, joints of columns and beams, maintenance of houses and disaster preparedness.

2.2 Detailed House Investigation
Detailed investigation is conducted on individual houses to obtain structural details, performance and information of owners.

(1) Interview with inhabitants
The interview with inhabitants focuses on the following aspects: house history and maintenance, disaster experience, inhabitant awareness and changes.
in neighbourhood. House owners are engaged in conversation whilst measurements and inspections are being conducted in the house (Fig.1.).

(2) Ambient vibration measurement of houses
To identify the vibration characteristics of the houses, ambient vibration measurements are performed on selected houses (Fig.2.). The authors use the same device applied in the ambient vibration measurement of the ground. More than two accelerometers are set on the second floor of each house to identify torsional mode, whilst one accelerometer is set on the soil surface9.

![Fig.1. Interview with Residents](image1)  ![Fig.2. Ambient Vibration Measurement of the Houses](image2)

(3) Deterioration inspection
Deterioration frequently compromises the capability of a wooden structure. The deterioration of a wooden structure can result from physical (overloading and ground motion) and biological (fungus and termite attack) processes8. Fungi begin to feed on wood after prolonged exposure of wooden structures to moisture. Fungi are most active when the moisture content of the wood is between 30% and 60%9. Deterioration inspection involves the measurement of inclination, Young's modulus (Fig.3.(a)) and moisture content of columns (Fig.3.(b)). The process also includes checking the locations and numbers of ventilation units, under-floor space, decay and termite damage and house repair work.

(4) Investigation on structural properties
The materials and dimensions of structural components are important parameters when estimating the structural performance of a house. The yield base shear coefficient \( C_y \) is used to evaluate the seismic capacity of a wooden house as a whole from the ridge and span directions10. The yield base shear coefficient \( C_y \) can be calculated from the horizontal restoring force of the first floor at 1/30 rad of deformation angle \( Q_y \) divided by the total weight of the house, which includes fixed and live loads11. This information can be simply calculated from the first floor plan of the house11. In the investigation on structural properties, the structure of a house is recorded via photographs, cartographic sketches and architectural drawings. In addition, typical structural details and joints are measured and studied.

3. Investigated Districts
3.1 History
Since the late 9th century, Ine has prospered as a haven and trading post because of the establishment of Manorialism and the coastal trade with China. This area enjoys an extensive forest cover and rich aquatic resources; hence, halieutics has developed well in Ine. The period between the late 19th century and the middle of the 20th century was the heyday of fishery in Ine, and the majority of the boat houses seen today were built during that period. In 2005, Ine was designated as an IPDGHB and a fishery town12.

Since the Heian Period, Yuasa had flourished as a pilgrimage site on the Kumano Road. Simultaneously, as a transport hub for both sea and land, the town promoted the prosperity of fisheries and trading. During the Kamakura Period, the miso manufacturing technology was obtained from China and soy sauce was accidentally produced. Since then, the place has been known as the birthplace of Japanese soy sauce. In 2006, Yuasa was designated as an IPDGHB and classified as a brewing town as characterised by the aforementioned period of history13.

3.2 Architectural Features and Townscape
Fig.4. shows the location of the two districts. The preservation area (320.1 ha, east–west: 2650 m, south–north: 1700 m) in Ine extends along the Wakasa Bay from east to west. Two typical traditional wooden buildings are mainly associated with fishery in Ine. One of these buildings is the main house along the mountain side, whereas the other is the boat house (Funaya) along the sea side. Both houses are constructed with a gabled roof (Kirizumazukuri). The entrances to the main houses are constructed parallel to the roof ridges (Hirairi), whereas the entrances to the boat houses (Tsumairi) are along the gabled sides and openings that face the sea for mooring (Fig.5.).

The preservation area (6.3 ha, east–west: 400 m, south–north: 280 m) in Yuasa is the site where the brewing industry flourished at the end of the 16th century. At present, the traditional streets, lanes and town houses associated with the brewing industry feature storage houses with gabled roofs (Kirizumazukuri) covered with alternating flat and rounded tiles (Hongawara-buki) and lime-plastered walls with decorative lattice (Mushiko window). These attributes highlight the local characteristics of this district (Fig.6.)14.
3.3 Industries and Population

A general consensus exists that demographic and economic statuses significantly influence regional social vulnerability to environmental hazards. Fig. 7 shows the proportion of the working population from the different industries in Ine and Yuasa as reported by a national census (1980–2005). The primary industries are agriculture, forestry, mining and fishery. The secondary industries include manufacturing and construction. The tertiary industries involve transportation, information and communication, electricity and gas and water supply. In Ine, the employed population is decreasing, and the ratio of employment in secondary industries has drastically declined. By contrast, the proportion in tertiary industries is constantly increasing. The amount of fishery production and the number of employees involved in fishery have been considerably reduced. The percentage of the population employed in primary and secondary industries has decreased, and an increasing number of people are becoming engaged in tertiary industries. Orange and fish account for the main production of Yuasa; however, both the number of employed people and the amount of production have currently declined.

The depopulation trend is more evident in both Yuasa and Ine than in Kyoto (Fig. 8.). The situation is particularly serious in Ine, and the population is half that of 2005 within a period of 30 years. The aging population problem is also more severe in Ine than in Yuasa. The aging population (over 65 years old) will gradually increase to half of the total population in Ine in 2030 (Fig. 9.).

3.4 Hazards

Fig. 10 illustrates the hazard curve of three important preservation areas (relationship between the maximum velocity of the engineering base and the probability of exceedance in 30 years), which indicates that risk increases as the probability of exceeding the maximum velocity rises (National Research Institute for Earth Science and Disaster Prevention). As indicated in the figure, Yuasa is facing a considerably higher seismic risk than Kyoto and Ine. Seismic damage in Yuasa may be derived from both epicentral and subduction earthquakes along the Nankai Trough. In subduction earthquakes, considerable damage associated with ground motion and tsunami will occur. Although a coastal district, Ine possesses a lower risk of tsunami occurrence than Yuasa because of Aoshima, which functions as a natural breakwater that reduces large waves approaching the district.
Moreover, Yuasa is easily affected by typhoons, which originate from Kyushu and pass through Japan. These typhoons frequently bring heavy rains and floods. Houses in Ine, which spread across a narrow space along the bay and are close to the mountains, may be damaged by landslides.

4. Results of Investigation

A regional structural investigation on traditional wooden buildings was conducted in Ine in October 2010; 12 main houses (1 one-story and 11 two-story buildings) and 14 boat houses were investigated in detail. A similar investigation was conducted in Yuasa in October 2011; 10 buildings (8 two-story and 2 one-story buildings) are investigated in detail.

4.1 Site Condition

Both Ine and Yuasa are very close to the sea; however, these towns confront different types of disaster risk. The probability of seismic activity is relatively lower in Ine, and the ground condition is significantly better. However, the buildings face landslide threat from nearby hills.

The traditional district in Ine is located on a narrow site between Ine Bay and steep mountains that consist of volcanic rocks. Consequently, the soil deposit in the district consists of shallow marine or nonmarine sediments. The H/V spectrum amplitude, particularly site amplification at over 2 Hz varies by site because of the sedimentary layers.

The traditional district in Yuasa is located on a bar, and no significant difference in ground conditions is observed in the district. For example, H/V spectra in the district display clear peaks. The natural frequency is approximately 2–4 Hz, which is close to the value of the natural frequency of the houses. Thus, the amplitude of vibration amplifies during an earthquake because of ground softness. During the 1854 Nankai earthquake, tsunami affected half of the designated district. The imminent Nankai earthquake is expected to be stronger than the previous one. Thus, the entire designated district is at risk of being inundated by tsunami.

4.2 Structural Characteristics

(1) Material

In Ine, the columns and foundations of boat houses (Funaya) are made from *Castanopsis*, whereas the beams are constructed from Japanese pine. *Castanopsis* is stronger when wet, and thus, is suitable for use on boat houses. However, the newly constructed boat houses are made of cypress, and Japanese pine is substituted for Oregon pine for both main and boat houses. Cedar and cypress are used as columns of the main houses. Zelkova is occasionally used for the mainstay of the main building.

In Yuasa, the material of most centre columns is hemlock, whereas other centre columns are built from cypress because of the rising price of hemlock in recent years. Hemlock was previously obtained from the surrounding area but is currently unavailable. The beams are frequently made from pine in the past but are presently built from cedar. Compared with the traditional mud walls, which were typically produced about 6 months after mud is mixed with straw, the current mud walls are weaker in water. Few people have mastered this construction technique in Yuasa, and only one shop builds mud walls. The use of mud walls has declined amongst new construction projects, and the material of old mud walls is occasionally reused.

(2) Space and frame

The form of houses in Ine is called the Tango type, which is widespread in the northwest of the Tango area (currently northern Kyoto Prefecture). The typical Tango-type house is a set of rooms under a gabled roof with entrances parallel to the ridges of the roof (Kirizuma Hirairi) and an earth floor (Doma) next to a spacious living room (Daidokoro) and parallel to two bedrooms in a row (Fig.13.(a)). In Yuasa, an earth-floored passage (Tooriniwa) is located along a row of rooms in the majority of the houses, and room arrangement is based on the pattern of two rows of two rooms (Fig.13.(b)).

In both Ine and Yuasa, many houses have more walls on the second floor than in the living room of the first floor to extend space. Continuous columns rarely exist. In general, columns are divided by beams or other horizontal structures. Thus, horizontal resistance is too weak in this typical structure. Large hanging walls and void spaces are found in both districts. Large hanging walls are distributed around the living room (Daidokoro) as a square in Ine and around the earth-floored passage (Tooriniwa) as a cross in Yuasa. This arrangement may be ascribed to the void space above the kitchen, and the lack of a floor on the second floor...
of the void space. In this case, the horizontal force cannot be transferred. The columns connected to the hanging walls are also easily damaged. Therefore, the horizontal force problem for the typical structure of numerous hanging walls must be addressed to prevent the columns from cracking. Although the local construction method is part of district preservation, carpenters and designers must be fully aware of the weakness of the conventional construction methods and must apply improvements to upgrade the structural performance of traditional buildings.

(2) Vibration characteristics

Fig.15. shows the spectral ratio of the natural frequencies of a KM house in Ine and a TC house in Yuasa to demonstrate the measurements. The locations of the accelerometers are indicated in Fig.13., i.e. KM house (first floor: {1} and second floor: {2}, {3}) and TC house (first floor: {1} and second floor: {2}, {3}, {4}, {5}), and torsional vibration may occur during earthquakes.

Fig.16. shows the natural frequency of the main houses in Ine and Yuasa by ridge direction (f_R) and span direction (f_S). The natural frequency is higher for the span direction of Hirairi houses in Ine, except for the Tsumairi house. In addition, the natural frequency of the span direction is lower than that of the ridge direction. The natural frequency of the houses in Yuasa is close to that of the ground; therefore, the vibration will be amplified during an earthquake. The natural frequency is higher for the span direction than for the ridge direction in both districts.

4.3 Maintenance Status

(1) Moisture content of columns

Fig.17. indicates the average moisture content of columns in the main houses and boat houses in Ine, as well as under the floor and first floor of the houses in Yuasa. The moisture contents of the columns under
the floor in Yuasa and the first floor of the boat houses in Ine are extremely high at approximately 30%. Increasing the number of ventilation units is strongly recommended for these houses. In general, moisture content is higher on the seaside portion than on other parts of a boat house.

Fig.17. Average Moisture Contents of Houses in Ine and Yuasa

(2) Maintenance activity and preparedness
Half of the investigated houses in Ine are approximately 100 years old. All the houses have been renovated via roof material replacement and pipe maintenance in kitchens and toilets. Reconstruction is frequently initiated around events, such as weddings, or moving out of a family member. For maintenance, ventilation changes in the bathroom and weeding is frequently conducted, but no effort is exerted on mitigating termite damage and decay. In addition, few houses have undergone seismic retrofit but owners do not consider repeating the activity in the future. The owners also believe that their offspring may not reside in their houses in the future, which support the perceived lack of need for further maintenance.

In Yuasa, several beams of the houses that extend outward from the roofs and bring rainwater into rooms easily damage structures and cause the roof and walls to decay. Nearly all of the houses have been damaged by termites, and some countermeasures have already been implemented. Moreover, pillars and horizontal structures are rotten, and new pillars are added without removing the original structure because of economic consideration. The limited budget and aging problems render the inhabitants increasingly hesitant to conduct seismic retrofitting for their houses. When typhoons or earthquakes occur, carpenters frequently inquire about the houses that they originally worked on. Typically, the actual condition is found to be considerably worse than expected once construction workers begin retrofitting.

4.4 Structural Properties
Given the results of an investigation on structural properties, several indices that determine the structural performance of houses are calculated and compared between districts. These parameters include the first floor area \((A_f)\), weight and height of houses, number of columns on the first floor, dimension of columns and yield base coefficient \((C_y)\) for the ridge direction and span direction of the houses (Fig.18.). Only the data for the two-story buildings are presented in Fig.18. Moreover, the authors are unable to estimate the weight of the two buildings in Ine. Therefore, the data related to weight are not plotted for the two buildings in Ine in Figs.18. (a), 18.(c) and 18.(e). \(C_y\) (yield base shear coefficient) is used to evaluate the seismic capacity of a wooden house as a whole based on the ridge and span directions. The yield base shear coefficient \((C_y)\) can be calculated from the maximum horizontal restoring force of the first floor \((Q_y)\) divided by the total weight of the house, which includes fixed and live loads. The dimensions of a column are typically 120 mm × 120 mm in Yuasa and 135 mm × 135 mm in Ine. Although seismic hazard is not severe in Ine, many houses exhibit a yield base coefficient of less than 0.2. A comparison between the two districts shows no significant difference in \(W/A_f\) and \(H\), and the ratio of \(D_{y1}\) to \(W/N_{c1}\) is larger in Yuasa than in Ine. \(C_y\) is relatively larger in the span direction than in the ridge direction in both districts, and the houses in Ine are relatively weaker than those in Yuasa.

5. Conclusion
The method of structural investigation on IPDGHB is introduced in this study as a supplementary approach that can be combined with conventional district investigation methods to establish an integrated evaluation system of traditional districts that consider both values and risks.

Two coastal preservation districts, namely, Ine and Yuasa, are investigated and compared. Regional structural characteristics and district vulnerability differ amongst regions and should be considered as important indices for decision making in district preservation. Both Ine and Yuasa are confronting issues, such as traffic inconvenience, depopulation, aging population and the recession of primary and secondary industries, which increase risks in district preservation. Moreover, the problems are more severe in Ine. However, seismic risk is higher in Yuasa, but preparedness is insufficient. The natural frequencies between the ground and the buildings are closer in Yuasa than in Ine. Thus, vibration amplitude will amplify during an earthquake because of ground softness.

After comparing the structural characteristics of the traditional buildings in the two districts, the authors find no significant difference in \(W/A_f\) and \(H\). Nevertheless, several differences are noted as follows.
(1) Although the seismic hazard is not severe in Ine, many houses are too weak, with a yield base coefficient of less than 0.2.

(2) The moisture contents of under-floor columns in Yuasa and the first floor of boat houses in Ine are extremely high. Hence, the risk of deterioration is also high.

(3) The large hanging walls and void spaces, which are found in both districts, may cause buildings to collapse during strong ground motions. The columns under large hanging walls are easily damaged, and the horizontal force cannot be transferred to the neighbouring plane frames of
the structures through void space. Therefore, the dimensions of columns and the distribution of hanging walls are significant factors during the seismic performance assessment of buildings. The following differences are observed. Column dimensions are typically 120 mm × 120 mm in Yuasa and 135 mm × 135 mm in Ine, and large hanging walls and void spaces exist around the living room (Daidokoro) as a square in Ine but are distributed around the earth-floored passage (Tooriniwa) as a cross in Yuasa.

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