ABSTRACT: This paper reports on the progress of our research project on the seismic performance of unique boat house using oblique nuki. In Part I, 14 existing boat houses are investigated to understand structural characteristics such as construction method or material, and vibration characteristics. Furthermore, the details of wooden frame construction using the oblique nuki form of joints are also investigated.

KEYWORDS: Traditional wooden structure, Boat house, Oblique nuki

1 INTRODUCTION

Many earthquakes have occurred in Japan. The 1995 Hyogoken-Nanbu Earthquake (M7.3) damaged many structures, and 90 percent of over 5 thousand people suffered because of collapsed wooden houses [1, 2]. On the other hand, there were traditional wooden structures that did not collapse even after experiencing many earthquake disasters.

The Ine district at Tango Peninsula in northern Kyoto, which was registered as IPDGHB (Important Preservation District for Groups of Historic Buildings) in 2005, is a fishing village [3, 4] and contains many traditional residential houses and boat houses. The 1927 Kita-Tango Earthquake (M7.3) occurred at the foot of Tango Peninsula [5]. More than 5 thousand houses collapsed and there were nearly 3 thousand victims because of the shallow hypocenter. The intensity of 6 on the Japanese seven-stage seismic scale was recorded near Ine; nevertheless, any documents recording damage to any boat houses were unable to find. Hence, it is very important to understand the structural characteristics of boat house construction and their seismic resistance, behavior, and mechanical characteristics.

Therefore, the purpose of this project is to understand the seismic performance of boat house construction in Ine and to clarify the effectiveness of the traditional construction method.

In Part I, a field survey of boat houses is carried out in Ine to understand their structural characteristics and maintenance methods.

In Part II, cyclic loading test of typical frames is conducted to identify the seismic characteristics. The experimental results are simulated using a simple model, and the existing boat house performances are estimated based on the investigation in Part I.

2 LOCATION CONDITION

2.1 INVESTIGATION DISTRICT

Ine was registered IPDGHB as a fishing village in 2005,
and is a seaside village located on Tango Peninsula. A shallow road runs along the coast. Many household have a residential house built on the mountain side of the road and a boat house built on the seaward side of the road, as shown in Fig. 1. The residential house and boat house [6] are built in a line, and building pitch is small. There are about 230 boat houses in this district. Figure 2 shows boat houses photographed from the sea.

Figure 1: Townscape in Ine

Figure 2: Appearance of boat houses from sea

2.2 OUTLINE OF INVESTIGATION

Boat houses were investigated in Ine from October 22 to 25, 2010. 14 boat houses were targeted:

a) Exhaustive survey: The state of boat houses were investigated throughout the district: recording construction method, use, exterior details, etc.

b) Drawing plans: Floor and sectional plans were drawn to clarify the structural constituents, joint details, house weight, etc.

c) Interviews: Inhabitants was asked for house information and maintenance methods. Carpenters were interviewed about the construction methods and materials.

d) Deterioration check: Termite damage, moisture contents of columns, and any inclination of the houses were confirmed.

e) Microtremor measurement: Microtremor measurements were conducted of each boat house and the ground.

2.3 EARTHQUAKE LISK

The hazard curve of Ine is shown in Fig. 3 with other districts (Kiragawa, Yuasa, Kyoto, and Miyama) [7-9] which have many traditional wooden houses in Japan. The earthquake risk of Ine is lower than these other districts.

Figure 3: Hazard curve

2.4 SURFACE GROUND CONDITION

Microtremor measurements of the ground were conducted to clarify the surface ground condition. The measurement was done at several points on the seaward and mountain sides of the road. Figure 4 shows a topographical map with the measurement points A, B, and the resultant H/V spectra.

At point A, on the mountain side, the natural frequency is 4.2 Hz, NS direction; and 3.0 Hz, EW direction. On the seaward side; 2.2 Hz, NS direction; and 3.5 Hz, EW direction. At point B, on the mountain side, the natural frequency is 3.0 Hz, NS direction; 3.7 Hz, EW direction, but the peaks are not clear. On the other hand, at one of seaward side, the natural frequency is 3.8 Hz, NS

Figure 4: Topographical map and result of microtremor measurement of ground
direction; 2.9 Hz, EW direction. The same measurement was performed at 10 further points. Some of these had soft ground and hence a low natural frequency on the seaward side, but at the other points, there was no difference in natural frequency for both sides. Through the whole of the district, the ground is relatively solid and hence amplification is small.

### 3 Exhaustive Survey

An exhaustive survey was conducted to understand the state of the district’s boat houses. The survey was done in 5 regions within the Ine district, as shown in Fig. 4: Hide, Takanashi, Kameyama, Nibi, and Tateishi. All boat houses are investigated: (a) The material of outer walls and the direction of wooden siding as exterior, (b) Classification of roof style, (c) Classification of the surface condition of the 1st and 2nd floors of each boat house.

![Figure 5: Classification of material of outer wall](image)

![Figure 6: Classification of siding direction](image)

The material of outer wall was classified as shown in Fig. 5. Most boat houses have wooden wall sidings in all regions.

Direction of siding is classified as shown in Fig. 6, for those boat houses which have wooden outer walls. In about 80% of them, the siding is fitted vertical.

The roof type of boat houses was classified as shown in Fig. 7. Most boat houses have Kiritsuma style - Tumairi roof. Kiritsuma style is gable roof, Tumairi has the main entrance on the gable side, and Hirairi has the main entrance on the orthogonal gable side.

Six relation types were decided upon between sea water and the 1st floor of boat houses, as shown in Fig. 8. The facade on the sea front are focused on, and investigated how large the opening is and whether the surface soaks in the sea or not. The classification results for 1st floor condition of boat houses are shown in Fig. 9.

![Figure 7: Classification of roof style](image)

![Figure 8: Relationship between sea water and 1st floor](image)

![Figure 9: Classification of 1st floor condition](image)

The boat house was intended originally for mooring, so the 1st floor needs to slope down to seaward and soak in the sea, and the opening needs to be wide enough to anchor the boat. Boat houses of type a, b, and c of Fig. 8 satisfied the requirements and comprises 68.42% of the boat houses. In the past, type a was mainly used. However, some boat
houses were renovated as parking garages and shore protection works, and so the 1st floor no longer soaks in the sea.

Three types of 2nd floor of boat houses were decided upon, as shown in Fig. 10, where we investigated whether the 2nd floor of a boat house has openings and/or a veranda. The classification results of 2nd floor condition of boat houses are shown in Fig. 11.

Type A is the most. In many boat houses, 2nd floor have opening, using as living space.

![Figure 10: Types of 2nd floor](image)

**Figure 10: Types of 2nd floor**

**Figure 11: Classification of 2nd floor condition**

### 4.1 Interviews for Inhabitants

The inhabitants of 12 houses were asked for information about the houses and maintenance methods. Note that KF house has been empty and KA1 and KA2 houses had the same ownership.

The houses ages are shown in Table 1. 4 of the 11 houses with age data have been built for over 100 years.

Many households have a carpenter caring for their house, whom they also depend on for extension and construction. Extension and construction had been done on all households we interviewed. There were no households that had done or plan to conduct seismic reinforcement, because they have no descendant, and it was thought that building and ground condition in the region is better than elsewhere.

Many survey subjects listed the 2004 typhoon and the 1927 Kita-Tango Earthquake as disasters which had occurred at Ine in the past. But experiences about the Kita-Tango Earthquake were tradition from ancestor. In relation to typhoons, however, many countermeasures are needed: close the frontage of the seaward side, take the burden to the upper story because seawater penetrated deep into the boat houses.

The ground of seaward side has subsided. For some houses the ground has subsided ~15 cm more than it was 60 years ago. Therefore shore protection works are conducted by state, prefecture, or individuals, such as cementing, paving with stone, etc.

In past years, people who were not fisherman also had boats, and boats were used as a means of transportation. However, in recent years, cars are increasingly used. Because of this, many householders cut the road side of their boat house and extended the road toward the sea.

<table>
<thead>
<tr>
<th>House</th>
<th>Region</th>
<th>Age of house</th>
<th>Stories</th>
<th>Number of column [1F]</th>
<th>Height of story (m) [1F]</th>
<th>Floor space [1F] (m²)</th>
<th>N/A (l/m³)</th>
<th>Natural frequency (Hz)</th>
<th>Ridge Dir.</th>
<th>Span Dir.</th>
</tr>
</thead>
<tbody>
<tr>
<td>KM Kameyama</td>
<td>142</td>
<td>2</td>
<td>31</td>
<td>2280 2790</td>
<td>76.6</td>
<td>0.405</td>
<td>2.9</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>YK Kameyama</td>
<td>57</td>
<td>2</td>
<td>49</td>
<td>2660 2400</td>
<td>106.0</td>
<td>0.462</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KH Hide</td>
<td>26</td>
<td>2</td>
<td>2280 1740</td>
<td>62.3</td>
<td>0.417</td>
<td>3.8</td>
<td>3.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NY Takanashi</td>
<td>100</td>
<td>2</td>
<td>32</td>
<td>2520 1520</td>
<td>77.7</td>
<td>0.412</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WN Nibi</td>
<td>35</td>
<td>2</td>
<td>28</td>
<td>2980 2480</td>
<td>76.6</td>
<td>0.366</td>
<td>4.7</td>
<td>3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OS Nibi</td>
<td>29</td>
<td>2</td>
<td>1910 2020</td>
<td>79.8</td>
<td>0.363</td>
<td>3.7</td>
<td>3.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JW Tateishi</td>
<td>80</td>
<td>2</td>
<td>33</td>
<td>2200 2100</td>
<td>71.9</td>
<td>0.459</td>
<td>2.8</td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KA1 Tateishi</td>
<td>40</td>
<td>2</td>
<td>12</td>
<td>1850 3140</td>
<td>43.6</td>
<td>0.275</td>
<td>4.9</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KA2 Tateishi</td>
<td>40</td>
<td>2</td>
<td>30</td>
<td>2470 2270</td>
<td>49.6</td>
<td>0.605</td>
<td>3.5</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SJ Takanashi</td>
<td>147</td>
<td>2</td>
<td>36</td>
<td>2700 1820</td>
<td>85.8</td>
<td>0.420</td>
<td>5.0</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH Hide</td>
<td>79</td>
<td>2</td>
<td>25</td>
<td>2430 2620</td>
<td>63.9</td>
<td>0.391</td>
<td>3.6</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OY Hide</td>
<td>28</td>
<td>2</td>
<td>2120 2490</td>
<td>49.1</td>
<td>0.570</td>
<td>5.4</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KT Tateishi</td>
<td>59</td>
<td>2</td>
<td>31</td>
<td>3180 2220</td>
<td>38.9</td>
<td>0.797</td>
<td>4.5</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KF Takanashi</td>
<td>1</td>
<td>20</td>
<td>2550</td>
<td>-</td>
<td>42.2</td>
<td>0.474</td>
<td>7.0</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Unknown, ** KF house is the oldest boat house in Ine district, built in the Edo period.
converting the boat house to a storage room or garage.

4.2 GENERAL VIEW

The conventional use of boat houses is as moorings. They sit low, as shown in Fig. 2. As an example, the appearance of the SJ boat house from the sea is shown in Fig. 12. Most boat houses that were surveyed were two-storied. The number of columns per unit area is 0.46 m⁻².

Figure 12: Appearance of boat house (SJ house)

The cross section along the ridge of KT boat house is shown in Fig. 13(a), and the span cross section is shown in Fig. 13(b). Columns are set on the base. The bases are in the ridge direction, as shown in Fig. 14. There are the penetrating tie beams as crosspieces in the ridge direction. The penetrating tie beam is called nuki. In the span direction, the boat houses have frame with unique joints called oblique nuki, shown in Fig. 13(c). This joint with oblique nuki is the special characteristic of boat houses in Ine district.

Figure 14: Base in span direction (SJ house)

4.3 INTERVIEWS FOR CARPENTERS

In past years, castanopsis timber could be gathered on the hill behind the residential houses. Castanopsis resists salt well. So the material for columns and foundations has been usually castanopsis, and for the beams has been pine. However, more recently, cypress and cedar have been used for columns and foundations.

To avoid roofs overlapping each other, and to assure large boat space below, the columns and walls incline slightly inward. In the ridge direction, nuki was put through columns and wedges were driven in. In the span direction, oblique nukis were put through columns and beams. Oblique nukis are ~30-mm thick and ~150-mm wide. Many oblique nukis were placed at an angle <45°. The oblique nuki is designed such that the upper width is larger, and it is driven from above the beam. When an earthquake occurs, and joint becomes loose, it is assumed that they re-jam naturally gradually by gravity. The outer casing was fitted horizontal in the old way, but recently the incidence of vertical fitting is increasing. In case of horizontal fitting, it is difficult to drain rainwater and leads to increased rot.

In past years, the boat house roof was thatched, and there were many fires. The carpenters inherited construction methods and sizes from their masters. However, recently the number of carpenters has decreased, and young carpenters tend to all work the same way.

4.4 FRAME WITH OBLIQUE NUKI

Oblique nukis are arranged in the span direction, as shown
in Fig. 15(a). An oblique nuki put through a column and beam is shown in Fig. 15(b). Details of the joint with oblique nukis are shown in Table 2 and Fig. 15(c). In Table 2 the WN house is excluded because it does not have an oblique nuki.

![Introspective picture (SJ house)](image1)
![Oblique nuki](image2)
![Details of oblique nuki](image3)

**Figure 15: Frame with oblique nuki**

![Damage by death watch beetles](image4)

**Figure 16: Damage by death watch beetles**

![Deterioration of column base](image5)

**Figure 17: Deterioration of column base**

**Table 2: Measurements specification of joint with oblique nuki and column inclination**

<table>
<thead>
<tr>
<th>House</th>
<th>Diameter of column (mm)</th>
<th>Section of beam</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>nuki Thickness (mm)</th>
<th>nuki Width (mm)</th>
<th>nuki Deg (deg.)</th>
<th>Cotter (num., size)</th>
<th>Column inclination (rad)</th>
<th>Ridge Dir.</th>
<th>Span Dir.</th>
</tr>
</thead>
<tbody>
<tr>
<td>KM</td>
<td>200</td>
<td>380x380</td>
<td>522</td>
<td>165</td>
<td>335</td>
<td>210</td>
<td>408</td>
<td>38</td>
<td>130</td>
<td>123</td>
<td>38</td>
<td>2-30x 30</td>
<td>2/1000</td>
<td>2/1000</td>
</tr>
<tr>
<td>YK</td>
<td>210</td>
<td>310x230</td>
<td>545</td>
<td>160</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>33</td>
<td>148</td>
<td>33</td>
<td>1-20x 20</td>
<td>7/1000</td>
<td>5/1000</td>
<td></td>
</tr>
<tr>
<td>NY</td>
<td>155</td>
<td>300x300</td>
<td>536</td>
<td>155</td>
<td>320</td>
<td>230</td>
<td>430</td>
<td>35</td>
<td>130</td>
<td>128</td>
<td>34</td>
<td>None</td>
<td>15/1000</td>
<td>1/1000</td>
</tr>
<tr>
<td>OS</td>
<td>130</td>
<td>250x250</td>
<td>200</td>
<td>-</td>
<td>-</td>
<td>270</td>
<td>485</td>
<td>34</td>
<td>135</td>
<td>130</td>
<td>37</td>
<td>None</td>
<td>1/1000</td>
<td>7/1000</td>
</tr>
<tr>
<td>IW</td>
<td>175</td>
<td>330x255</td>
<td>608</td>
<td>205</td>
<td>440</td>
<td>220</td>
<td>420</td>
<td>35</td>
<td>135</td>
<td>125</td>
<td>43</td>
<td>2-unknown</td>
<td>9/1000</td>
<td>-2/1000</td>
</tr>
<tr>
<td>KA1</td>
<td>150</td>
<td>250</td>
<td>-</td>
<td>135</td>
<td>-</td>
<td>230</td>
<td>-</td>
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<td>118</td>
<td>30</td>
<td>unknown</td>
<td>5/1000</td>
<td>0/1000</td>
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<tr>
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<td>140</td>
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<td>200</td>
<td>399</td>
<td>236</td>
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<td>143</td>
<td>40</td>
<td>-</td>
<td>1/1000</td>
<td>1/1000</td>
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<tr>
<td>SJ</td>
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<td>210</td>
<td>510</td>
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<td>154</td>
<td>39</td>
<td>-</td>
<td>3/1000</td>
<td>7/1000</td>
</tr>
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<td>-</td>
<td>-</td>
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<td>500</td>
<td>40</td>
<td>160</td>
<td>152</td>
<td>31</td>
<td>2-30x 20</td>
<td>2/1000</td>
<td>0/1000</td>
</tr>
<tr>
<td>KT</td>
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<td>-</td>
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<td>128</td>
<td>41</td>
<td>None</td>
<td>0/1000</td>
<td>5/1000</td>
</tr>
<tr>
<td>KF</td>
<td>180</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>35</td>
<td>150</td>
<td>145</td>
<td>45</td>
<td>None</td>
<td>76/1000</td>
<td>100/1000</td>
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</tr>
<tr>
<td>Ave.</td>
<td>165</td>
<td>306x263</td>
<td>34</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>36</td>
<td>2-unknown</td>
<td>9/1000</td>
<td>10/1000</td>
</tr>
</tbody>
</table>

* Width of oblique nuki is measured on 3 parts. The values from the left are part on directly under beam, the center and inside surface of column.
The tenon of the beam sticks into the gain of the column and some cotters are driven in. An oblique nuki sticks into both gains of the beam and column.

The diameter of columns vary widely, with the maximum being 210 mm at the KH house and the minimum being 130 mm at the OS house. There are also a variety of types of beams, such as rectangular timber or logs. The diameter of beam sections is large, ~300 mm.

The value of $a-e$ in Table 2 corresponds to Fig. 15(c). The thickness of oblique nuki is 34 mm on average. The width of oblique nuki is not even. The top is wider than the bottoms. The construction angles of oblique nuki are all different; however, the angle, $\theta$, defined by column, beam, and oblique nuki (see Fig. 15(c)) is $36^\circ$ on average. This is confirmed from interviews with the carpenters.

4.5 DETERIORATION CHECK

It was found by visual inspection that some parts get out of position at some joints because of dry shrinkage. The bottoms of some nuki are off the lateral surface of the column.

The incline of columns were measured, and it was found the maximum deformation angle was 0.076 rad inside the boat house in span direction, and 0.1 rad seaward in ridge direction, on average.

Moisture contents of the columns of boat houses were 41.8% on the seaward side, and 18.7% on the mountain side on average. Moreover, it is possible that columns on the seaward side soak in the sea at high tide, so moisture contents of column bases are higher than the tops. Moisture contents were 24.3% at the top of column, 29.9% in the middle, and 39.7% at the column base, on average.

Termite damage was not found in any boat house. But marks from death watch beetles were found, as shown in Fig. 16, and some deterioration of column bases were found, as shown in Fig. 17.

4.6 VIBRATION CHARACTERISTICS

Microtremor measurements of existing boat houses were conducted. Several over damping accelerometers which can measure 1 vertical and 2 horizontal components were used. Simultaneous measurement was conducted for 10 minutes.

The result of microtremor measurement of KT house is shown in Fig. 18. Measurement points are indicated in Fig. 13 (c). Accelerometer 1 was set up on the ground, whereas accelerometers 3–5 were set up on the beams. The 1st natural frequency in the ridge direction is 4.5 Hz, significantly higher than the 2.4 Hz of the span direction.

The results of all boat houses are indicated in Table 1. Distribution of 1st natural frequency of all boat houses is shown in Fig. 19. Natural frequency is 2–4 Hz in the span direction and 2–7 Hz in the ridge direction. The 1st natural frequency in the ridge direction tends to be higher than in the span direction.

![Figure 18: Fourier spectral ratio (KT house)](image)

![Figure 19: Distribution of natural frequency](image)

5 CONCLUSIONS

This paper reported on the progress of our research project on the seismic performance of unique boat houses using oblique nuki.

In this paper, 14 boat houses of Ine district were surveyed.
Our findings can be summarized as:

a) Most boat houses have wooden walls. In ~80% of the boat houses with wooden outer walls, siding is fitted vertically. Most boat houses have gable-styled roofs, with the main entrance on the gable side.

b) Oblique nuki are arranged in the span direction.

c) An oblique nuki sticks into both gains of the beam and column. The width of oblique nuki is not even, the tops are larger than the bottoms. Many oblique nuki are placed at <45°.

d) The columns incline slightly. Maximum deformation angle is 0.076 rad inside the boat house in the span direction and 0.1 rad seaward in the ridge direction, on average. The moisture contents of the columns are 42% on the seaward side, and 19% on the mountain side, on average. Columns on seaward soak in the sea at high tide; therefore, the moisture contents of the column bases are higher than those of the column tops.

e) The 1st natural frequency of the ridge direction of the boat houses is higher than the span direction.

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REFERENCES