STRUCTURAL CHARACTERISTICS OF A HISTORICAL REINFORCED CONCRETE TEMPLE BUILDING, HIGASHI-HONGANJI HAKODATE BETSUIN

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ABSTRACT

This paper explains the structural characteristics and evaluates the aseismic performance of a reinforced concrete temple in Hakodate, Hokkaido, northern Japan. The Higashi-Honganji Hakodate Betsuin is Japan's oldest example of temple architecture using a reinforced concrete structure. The main hall of the temple was constructed in 1915. Since then, the structure has been repaired several times, including a renovation done in 1988. The temple was designated as one of Japan's Important Cultural Properties in 2007. It is unclear whether the temple has adequate seismic capacity for large future earthquakes. Its structural features need to be understood in order to appropriately evaluate its aseismic performance. We investigated the temple in the following ways to determine its structural characteristics: (1) Structural features and transitions were investigated based on drawings from the time of construction, building materials used in the temple, etc. (2) The structure's vibration characteristics were determined based on micro-tremor measurements carried out on the temple. This analysis showed that the natural frequencies were slightly different in the X and Y directions, and that the amplitude of the oscillation in the X direction at the entrance of the main hall is larger than that of areas deeper in the interior. (3) We conducted earthquake response analysis using a frame model. The frame model response analysis yielded characteristics that agree with the micro-tremor analysis. More detailed investigations using nonlinear behavior analysis will be undertaken in the future.

Keywords: structural characteristics, micro-tremor measurements, response analysis.

1. INTRODUCTION

Higashi-Honganji Hakodate Betsuin, which is in Hakodate, Hokkaido, northern Japan, is the oldest Japanese example of a reinforced concrete (RC) building structure being used in temple architecture. This temple is located within in an area of western Hakodate designated as an Important Preservation District for Groups of Traditional Buildings, and was designated one of Japan's

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Important Cultural Properties in 2007. The architecture must be properly maintained for future preservation. It is unclear whether the temple has adequate seismic capacity for large future earthquakes. We need to understand the temple's structural features to appropriately evaluate its aseismic performance.

To determine the structural characteristics of the temple, we conducted the following investigations: (1) The structural features and transitions within the temple were investigated based on drawings made at the time of construction, the building materials used in the temple, etc. (2) The vibration characteristics of the structure were studied based on micro-tremor measurements carried out on the temple. (3) A frame model earthquake response analysis was conducted.

2. FEATURES OF THE TEMPLE

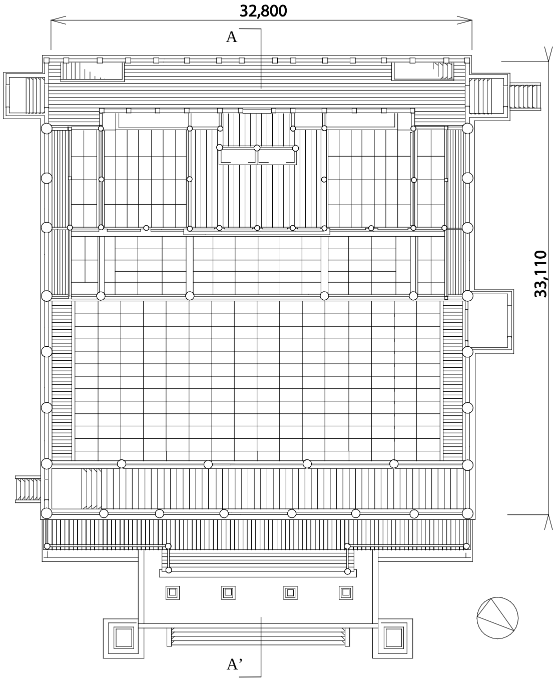
2.1. General Specifications

Table 1 shows the general specifications of the temple. A great fire destroyed the previous temple in 1907. To prevent future burnouts the temple was rebuilt using RC. Figures 1 – 3 show an external view and drawings (Komaki and Watanabe 2006) of the temple. The main structure is RC, except for the roof frame, which is structural steel.

Table 1: General specification of Higashi-Honganji Hakodate Betsuin

Construction year	1915
Designer	Heizaemon Ito (9th generation)
Builder	Yasuzo Kida, Heizaemon Ito (10th generation)
Building Area	1086 m^2
Height	24 m
Renovation year	1988
Designer	Heizaemon Ito (11th generation)

Figure 1: Higashi-Honganji Hakodate Betsuin



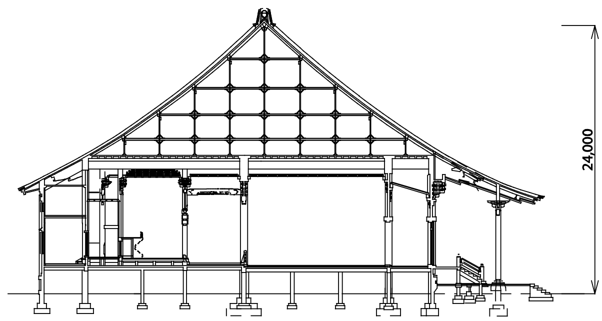


Figure 2: Plan view of the main floor (unit: mm) **Figure 3: Section View (unit: mm)**

2.2. Structural Features

Several features can be identified in drawings from the time of construction. First, the axes of the girders do not match the axes of the columns. A similar technique can be seen in traditional Japanese building methods for wooden houses. Second, the Kahn system was followed in the arrangement of reinforcing bars. This system uses distinctive deformed reinforcing bars as shown in Figure 4. Third, the Floretyle system was used in constructing the floor slabs. This system uses corrugated steel sheets as shown in Figure 5.

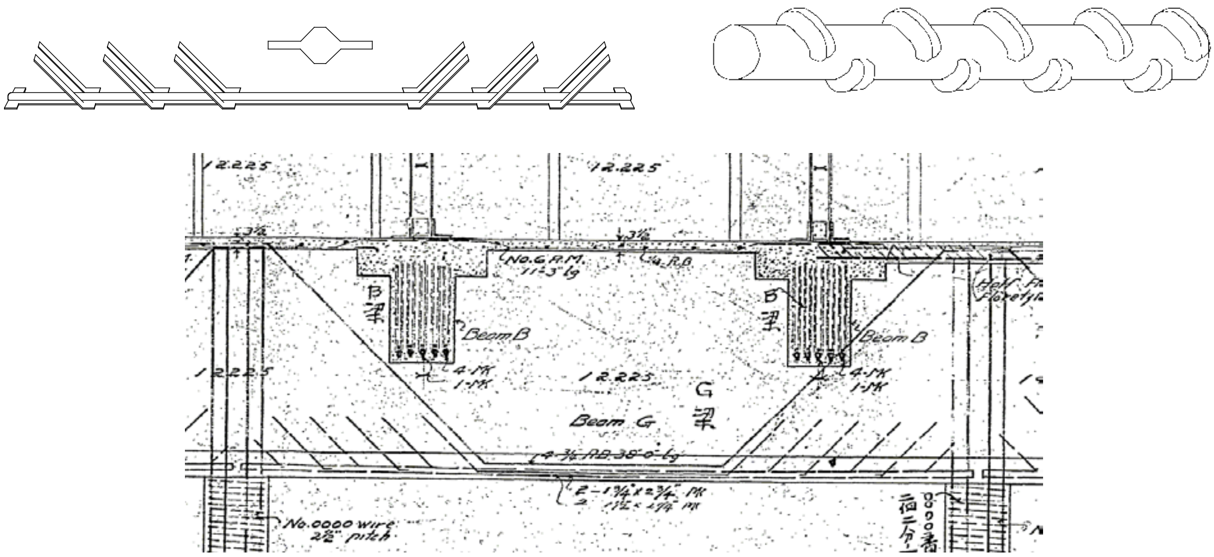


Figure 4: Kahn system

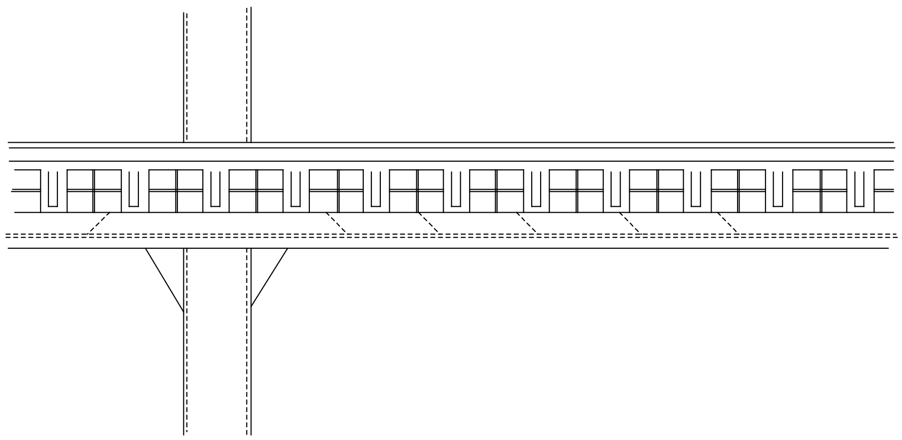


Figure 5: Floretyle system

Investigations of the aging of the temple were conducted from 1975 to 1979 and in 1986. These investigations revealed additional steel reinforced girders installed in the basement floor and separation at the bottom end of the concrete slab that had occurred due to corrosion of the steel bars.

Renovation work was conducted around 1988. Layers of clay on the roof board were removed to diminish the mass of the structure. Walls were added on the basement floor. Columns in the floor have been reinforced using additional concrete castings, and two windows have been filled with concrete to increase the mass of the wall.

3. VIBRATION OBSERVATION

3.1. Vibration Observation Method

A vibration observation of the temple was conducted in 2010. It aimed to investigate the dynamic properties of the temple, such as its natural frequency and the shape of its vibration mode. Eleven velocity sensors were placed on the basement floor, the main floor, the roof floor and outside the temple. Figure 6 shows the sensor configuration. The sampling rate was 500 Hz, and five-minute observations were repeated three times in the X, Y and Z directions.

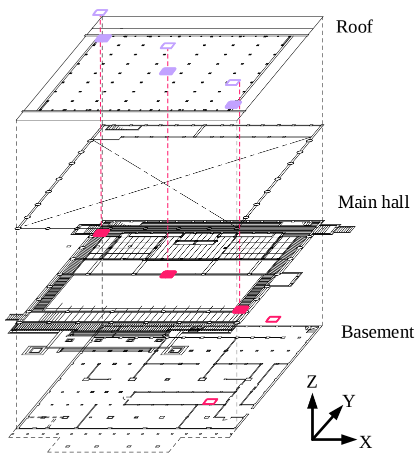


Figure 6: Sensor configuration

3.2. Results

One of the calculated transfer functions is presented in Figure 7. The velocity data obtained from a sensor on the basement floor was used as input. According to the peak frequency and phase transition, the natural frequencies of the temple are 3.5 Hz in the X direction and 3.6 Hz in the Y direction. The observations from sensors in the X direction revealed that the amplitude of the oscillation at the entrance of the main hall is larger than in its inner parts.

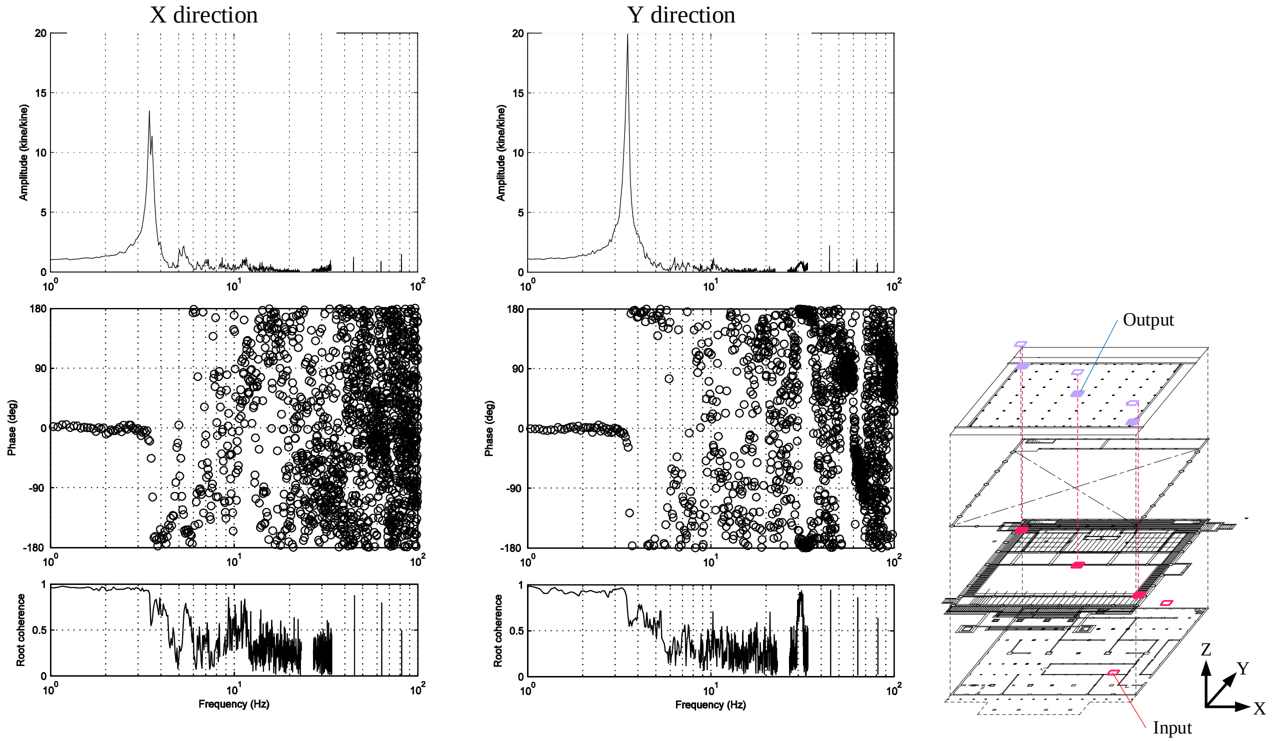


Figure 7: Transfer function (amplitude, phase and root coherence)

4. EARTHQUAKE RESPONSE ANALYSIS

4.1. Numerical Model

The model shown in Figure 8 was created using the SAP2000 Advanced Version 12 software, based on information from the drawings, the results of field surveys and the vibration observation.

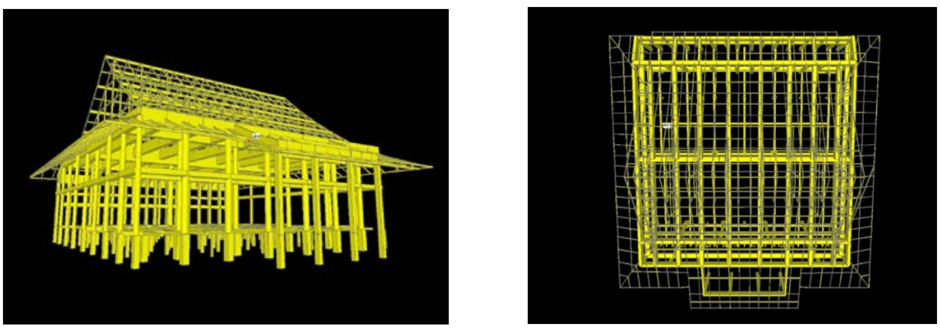


Figure 8: Analytical model of the temple

The analytical model consists of joint objects, frame objects and area objects. Linear material properties and lumped mass system are applied to the model. Considering the age of the temple, we reduced Young's modulus for the concrete in this model.

4.2. Response Analysis result

Figure 9 shows the results obtained from the seismic response analysis in the X direction. The input ground motion is a scenario earthquake at Hakodate (Ishii and Kikuchi 2005). The figure shows the maximum accelerations and displacements of three representative points within each of three levels. The response on the entrance side is larger than that further inside the temple. This tendency seems to be generated by the arrangements of the bearing walls and the columns, and corresponds to the vibration observation results.

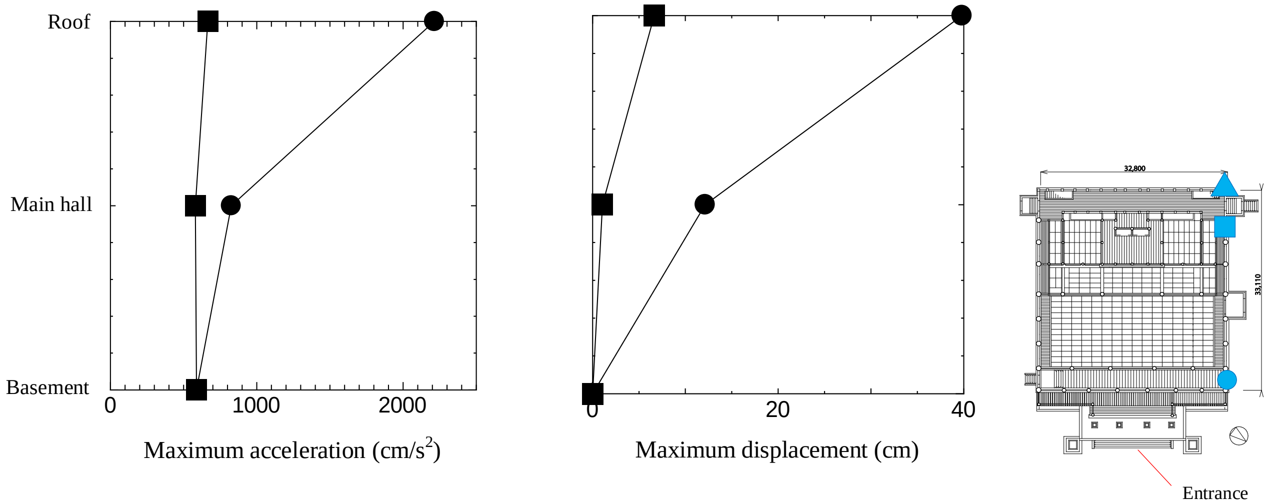


Figure 9: Seismic response analysis results

5. CONCLUSIONS

This study presents the structural characteristics determined for the Higashi-Honganji Hakodate Betsuin and the results of a seismic response analysis conducted on the temple. We investigated drawings of the temple, carried out field surveys, and performed a seismic response analysis to evaluate the temple's dynamic behavior and seismic capacity for large future earthquakes.

Based on the vibration observation, the identified natural frequencies of the temple are 3.5 Hz in the X direction and 3.6 Hz in the Y direction. The amplitude of oscillation in the X direction at the entrance of the main hall is larger than at the inner end. The same characteristics are obtained from the frame model response analysis. More detailed investigations using nonlinear behavior analysis will be undertaken in future work.

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