XXI ICTAM, 15-21 August 2004, Warsaw, Poland

VIBRATION CHARACTERISTICS OF THE MAIN TOWER, THE BAYON TEMPLE

Yoshikazu Sugiura[*], Yuki Fukumoto[*], Toshiro Maeda[*]
[*]*Department of Architecture, Waseda University, 3-4-1 Ookubo, Shinjyuku- ku, Tokyo, JAPAN*

Summary In order to capture the structural characteristics of the Main tower, we conducted micro-tremor measurement at the Bayon temple. Soil-coupled vibration natural frequencies of the structure are evaluated by power spectrum density of micro-tremor at the top of the structure and damping ratios are deduced by the random decrement method. Base-fixed natural frequencies of the structure are deduced from the transfer function of the top to the base.

INTRODUCTION

The Bayon temple is one of the main historical monuments in Angkor remains. The masonry temple was built in late 12th century to early 13th century. Since collapse and degradation are advancing, it is anxious for the elucidation of collapse mechanism for the purpose of preservation and restoration. With biased settlement of earth structure and intrusion of plants, there have been pointed out a possibility that micro-tremor excited by strong wind may cause some effects upon the collapse, especially in the rainy season, where strong wind of 20-40 m/s was actually observed. The structures will be analyzed by FEM or DEM to demonstrate the effects of micro-tremor on collapse of the Bayon temple. We measured micro-tremor and studied vibration characteristics of the Bayon temple to provide the reference to this future work. Soil-coupled natural frequencies of the structure are evaluated by power spectrum density of micro-tremor at the top of the structure and damping ratios are deduced by the random decrement method. The base fixed natural frequencies of the structure are deduced from the transfer function of the top to the base.

EXPERIMENTS OF MAIN TOWER AT BAYON TEMPLE

Specification of the main tower

The structure of the main tower consists of a central tower and surrounding eight sub towers as shown in Fig.1.The structure is dry-masonry and made with sandstone. The height of the central tower is 42.2m from the ground level. The main tower stands upon the upper terrace at GL+10m and the diameter of the tower at the bottom is about 25meters.

Seismographs and their arrangements

The portable seismographs GPL-6A3P made by Akashi, which consist of three-component-accelerometer and data logger are used for micro-tremor measurements. Acceleration is acquired from the differentiated over-damped pendulum motion with frequency range of 0.1Hz to 100Hz and sensitivity of 1mV/gal. Sensor outputs are low-pass filterd at 10Hz or 30Hz and amplified by 1000times, then discretised by 20 bit AD converter with 100Hz sampling.

These seismographs were arranged to capture representative motion of top of the central tower and sub towers, the gallery and the bottom of the structure as shown in Fig.1.

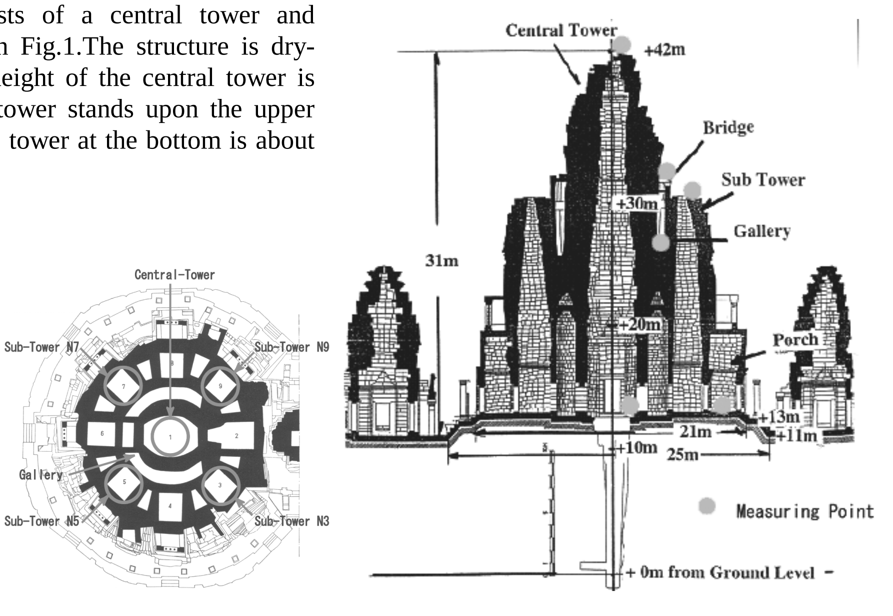

Fig.1 Plan and Section of the Main Tower of the Bayon temple

VIBRATION CHARACTERISTICS OF THE MAIN TOWER

Soil coupled characteristics

Power spectrum densities for horizontal NS, EW motion and vertical motion at the top of the central tower are shown in Fig.2. Soil-coupled 1st predominant frequencies are 2.8 Hz for horizontal motion and 5.9 Hz for vertical motion. Damping ratio of soil-coupled system is evaluated for horizontal motion by the random decrement method (logarithmic damping factor evaluated by superposition of five thousand 5 sec. waves band passed from 2Hz to 4Hz) as shown in Fig.3. The damping ratios are 2.1% for NS and 2.3% for EW horizontal motion. The same procedure is applied to the surrounding sub towers, except that normal and tangential horizontal components to the central tower are used, since principal analysis reveals predominant horizontal motion are in those directions as shown in Fig.5. The soil-coupled 1st predominant frequencies in tangential direction are higher than in normal direction and they are between 7Hz and 10Hz as shown in Table.1. Damping ratios are estimated between 1.1% and 3.4%.

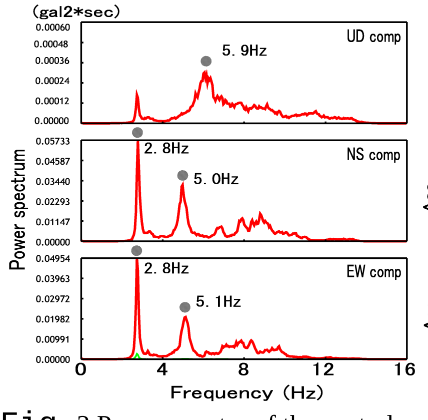

Fig.2 Power spectra of the central tower

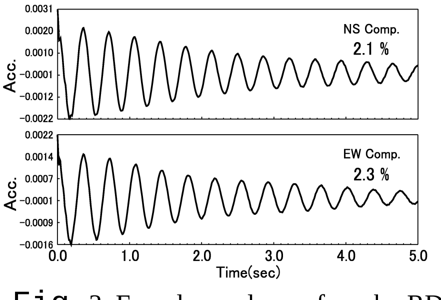

Fig.3 Free damped waveform by RD method for the central tower

Table 1. 1st Predominant frequencies and damping ratios of Sub-Towers

Tower	normal	tangential
N3	9.0Hz 3.4%	9.7Hz 3.1%
N7	6.8Hz 1.1%	7.8Hz 1.3%
N9	6.8Hz 3.1%	7.9Hz 2.1%

Base fixed characteristics

Transfer functions of horizontal motion at the top to the bottom are computed by H_v evaluation shown in equation (1a), where G_{AA}'s are auto or cross power spectrum densities, G_{AB}'s are cross power spectrum densities, and H_v is obtained for the smallest eigenvalue of ε.

$$\begin{bmatrix} G_{AA} & G_{AB} \\ G_{BA} & G_{BB} \end{bmatrix} \begin{Bmatrix} -H_V \\ 1 \end{Bmatrix} = \varepsilon \begin{Bmatrix} -H_V \\ 1 \end{Bmatrix} \qquad (1a)$$

The natural frequencies of the central tower are evaluated 3.0 Hz and 3.1 Hz in NS and EW directions, respectively as shown in Fig 4.

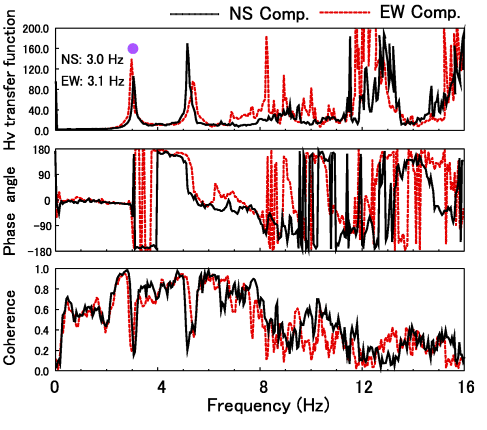

Fig.4 Transfer functions of horizontal motion

Principal axis of the Vibration

Principal vibration axes of the central tower and sub-towers are computed by principal components analysis on each 1sec data of 1800sec data. Most frequently observed principal axes are shown in Fig.5. It is noted that the principal axis of the central tower is similar to the direction of inclination and those of sub-towers are in normal and tangential to the central tower.

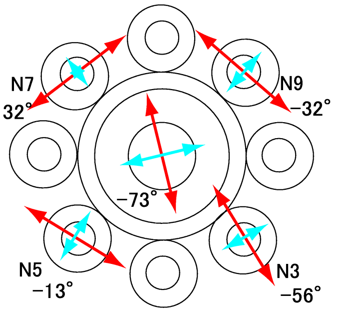

Fig.5 Principal axis of the Vibration of the central tower and sub-towers

CONCLUSIONS

We conducted micro-tremors measurement at the Bayon temple to show that soil-coupled 1st predominant frequency for horizontal motion of the central tower is 2.8 Hz and the damping ratios is about 2%; Base fixed natural frequency for horizontal motion is about 3Hz.The soil-coupled frequency is much higher than that of general building structures of similar height, e.g. 1Hz. In the future analysis for micro-tremor induced deterioration, additional stiffness provided by thick walls and surrounding sub towers must be included along with detailed material properties.

ACKNOWLEDGMENT

This research is a part of the investigation for Bayon temple preservation master plan creation by JSA (Japanese Government Team for Safeguarding Angkor). We appreciate their kindness and hospitality during this experiment.