Preliminary evaluation of the seismic vulnerability of the Inca's Coricancha temple complex in Cusco

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Abstract

Coricancha probably was the most important Inca temple complex dedicated primarily to Inti, the Sun god. At present, a small part of the Inca stonework is all that remains of the ancient complex. Most of the complex was demolished by Spaniard conquistadors in the 17th century to make way for the construction of Catholic Church of Santo Domingo on this site, using part of the Inca construction as the foundation. This complex is a fine example of how Inca stonework had been incorporated into the structure of a colonial building. Major earthquakes have severely damaged the church, but the Inca stone walls, built out of huge, finely cut tightly-fitting blocks of stone, still stand as a testimony to Inca's architectural skills and sophisticated stone masonry practice.

In this complex, a series of microtremor measurements were carried out to estimate the dynamic characteristics of the structures and the ground. Measurements on buildings include the Inca's masonry walls as well as the tower of the colonial church. Measurements to estimate the ground characteristics were performed in the inner yard and at the outer garden of the complex. In this paper, the results of the measurements and corresponding interpretations are discussed. It was found that the predominant period of vibration of the church tower is comparable to the predominant period of the ground, and therefore, the tower appears to be more vulnerable to earthquake occurrence because of the due to possible resonance phenomenon to be expected.

1 Introduction

Before the arrival of the Spaniard Conquistadors around the year 1535, the Inca culture reached the peak in its development, integrating a vast empire that stretched from the Maule river in Chile to the northern Ecuador, along the western side of the Andes mountain range. This territory, as in present days, had continuously been exposed to natural disasters such as excessive rainfalls, earthquakes, landslides, floods, etc. In spite of such impending disasters, the Incas were able to develop techniques of construction to withstand such natural forces. The awe-inspiring cities and road networks that remain intact to this day serve as witness to their acumen in construction.

The structural system of their construction involves the use of adobe (sun-dried clay bricks), roughly shaped stones laid with mud mortar and finely shaped stones. They also used mud and clay as mortar for surface finishing. Finely shaped stone masonry was used for important building like temples, administrative structures and king's residences. In this type of construction, the adjacent stones are carefully shaped and fit snugly against each other without the use of mortar. The Coricancha temple is the most representative structure of the finest stone masonry of the Incas. At the present, the Inca stonework is incorporated into the structure of a colonial building, giving a hybrid structure for which some evaluation of its seismic vulnerability is done. Basically this evaluation is performed based on the results of micro vibrations measurements that were carried out on structures and ground.

2 Description of the Coricancha temple complex

It is believed that the complex was dedicated to Inti, the sun god, and was formed by a group of constructions located around a central square, as can be observed in Figure 1, which is a view of a scale model. Each building was dedicated to one god respectively. The name of the god corresponding to each temple is indicated in Figure 1. These gods were Inti (sun), Killa (moon), Chasca (stars), Illapa (thunder, rainbow). Also, it is thought that the Incas believed in a creator god, called Wiracocha.

The Coricancha complex was built on a natural hill and between the rivers Shapy-Huatanay and Tullumayo. Its construction was ordered by the Inca Wiracocha around the year 1200 A.D., and later it was embellished or decorated during the reign of the Inca Pachacutec. The architectural distribution of the temples was done inside of a space that was circled by high walls. The shapes of the walls are trapezoidal and have a vertical inclination which is typical of the Inca′s architecture. The stones used in this complex were extracted from the quarries Waqoto and Rumicolca that are located 20 to 30 km away from Cusco city. The stones used by the Incas were plutonic diorite rocks and calcareous rocks. According to the chroniclers the walls of the temples were covered with gold plates and on these plates there were a drawing of the corresponding god.

Figure 1: Scale model of the Coricancha complex

In the 16th century, the Christian Catholic Church was built over the Inca stone structure. For the construction of the church, the Spaniards destroyed some part of the temples that formed the complex and some parts were used as a foundation of the Catholic Church. In this way, the Inca stone structure was incorporated to the colonial construction resulting in a magnificent monument that shows a mixture of Spanish and Inca culture. The Figure 2 shows the plan view of the current building, where the black part represents the remaining Inca's walls and the gray part represents the colonial construction.

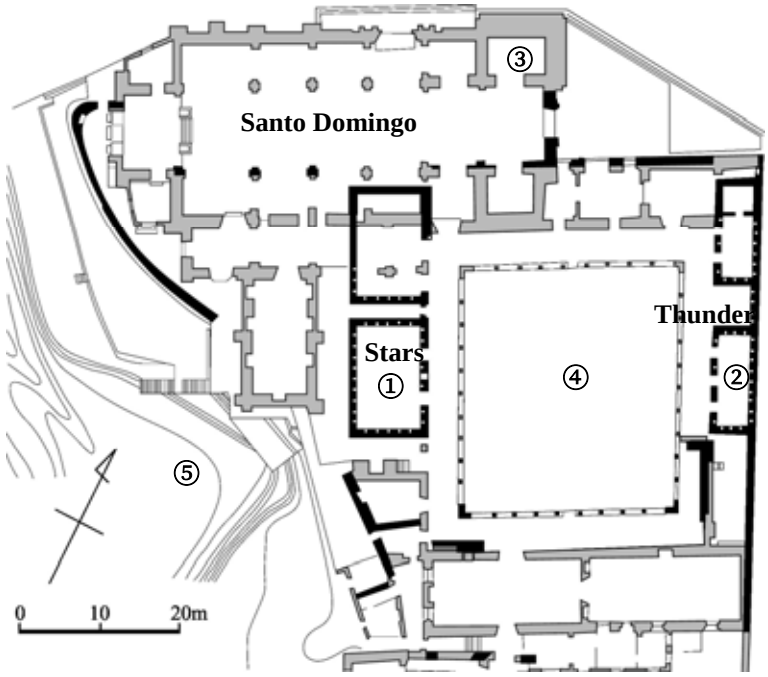

Figure 2: Plan view of the Coricancha complex

3 Microtremor measurements

The stars and the thunder temples, the tower of the colonial church and the inner at outer yards were selected for microtremor measurements. These locations are indicted by encircled numbers in Figure 2. The meaning of the numbering and the purpose of the measurements are described as follows.

① Star Temple (Chasca): Structure Vibration. Measurements of horizontal vibrations in the two principal directions of the building were performed. The sensors were located on the floor level and at walls on all four sides. The sensors at the wall were located on the sill of rectangular offset on the inner wall face closest to center of the wall. The directions were designated NS and EW respectively. However, the actual directions are Northeast-Southwest (regarded as NS) and Northwest-Southeast (regarded as EW). The channels for measurement were denominated ch7, ch8, ch9, ch10 and ch11 as is shown in Figure 3.

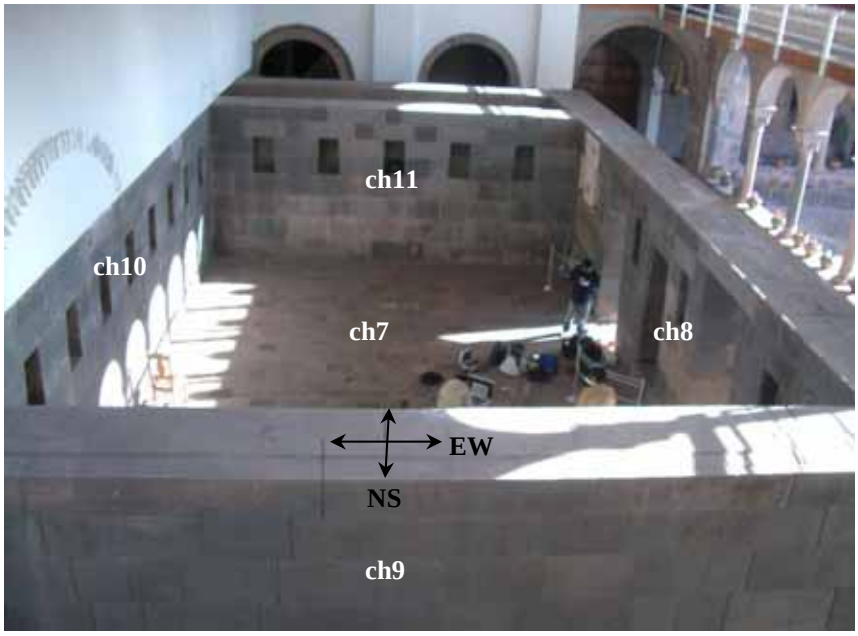

Figure 3: Point of microtremor measurements at temple of stars

② Temple of Thunder (Illapa): Structure Vibration. In a similar manner to the temple of the stars, measurements of horizontal vibrations in the two principal directions of the building were performed. The sensors were located on the floor level and on walls on four sides. The sensors at the wall were located on the sill of rectangular offset on the inner wall face closest to center of the wall. Again, the directions were designated NS and EW, respectively.

③Tower of Santo Domingo Church (Figure 4): Structure Vibration. Three

component of vibration were measured at the top and bottom of the tower. The directions for measurements are indicated in Figure 4.

Figure 4: Tower of the Santo Domingo Church

④ Interior Yard (Ceremonial Fountain): Ground vibration measurement. At this site, array measurements of the vertical components of the ground vibration were carried out. The triangular array configuration of sensors on the yard consisted of approximately 25 meter sides triangles. The array measurement is intended for F-K spectral analysis (F: frequency, K: wave number) to obtain the Rayleigh wave

dispersion curve, from which the shear wave velocity profile of the ground may be estimated by inverse analysis.

⑤ Exterior Garden (Sacred Garden of Sun): Ground vibration measurement. In a similar manner to the interior yard, array measurements of the vertical components of the ground vibration were carried out here. The configuration of sensors again consisted of triangular array with sides of approximately 30 meters. As noted above, array measurement is intended for F-K spectral analysis.

3 Analysis of data

The location of the sensors on the temple of Stars is indicated in Figure 3. Channels 7 to 11 were measured simultaneously during 500 seconds. Then, stable portions of the records were selected to perform the Fourier analysis that permits to estimate the natural period of vibration of the structure. The results of the Fourier analysis are shown in Figure 5. Figures 5(a) and 5(c) show the Fourier spectrum for the EW and NS directions, respectively. The Fourier amplitude spectrum at each measured point of the structure was divided by the one at the ground level, to obtain only the vibration characteristics of the structure. It can be observed from Figure 5(a) and 5(b) that the value of the predominant frequency in the EW direction ranges from 14 to 17 Hz. In case of the NS direction, these values range from 12 to 16 Hz as is shown in Figure 5(c) and 5(d). These differences are due to the presence of a colonial wall on the east wall of the star temple. On the other hand, the length of the wall differs for the EW direction and NS direction, and therefore, each wall vibrates with different frequency. Therefore, the vibration of the structure is intricate and further measurement and analysis is required to establish its seismic behavior. In any case, the predominant frequency is relatively high.

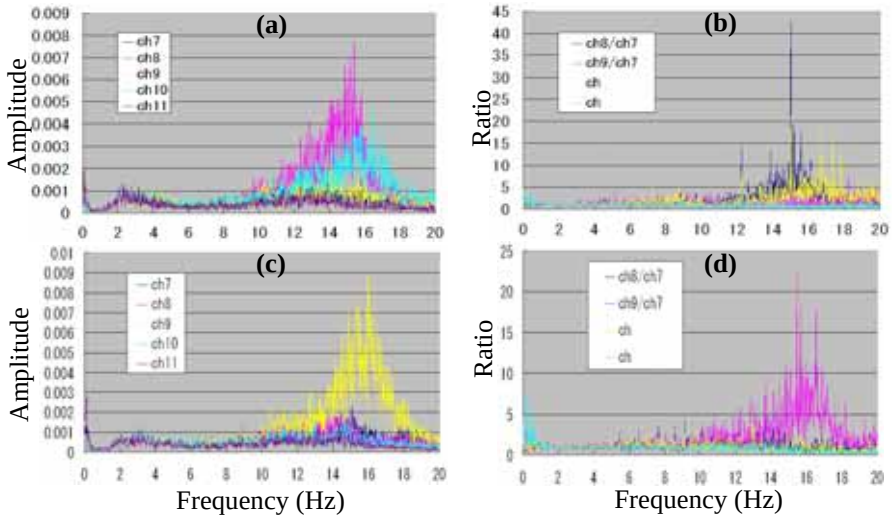

Figure 5: Fourier analysis results for the temple of stars

Figure 6 presents the results of the Fourier analysis for the horizontal vibration of the Colonial tower. These directions NS and EW are indicated in Figure 4. The Fourier amplitude spectrum obtained at the top of the tower was divided by the one obtained at the ground level, to obtain only the vibration characteristics of the structure. It can be observed that the value of the predominant frequency in the EW direction is 2.7 Hz, and in the NS direction is 3.3 Hz.

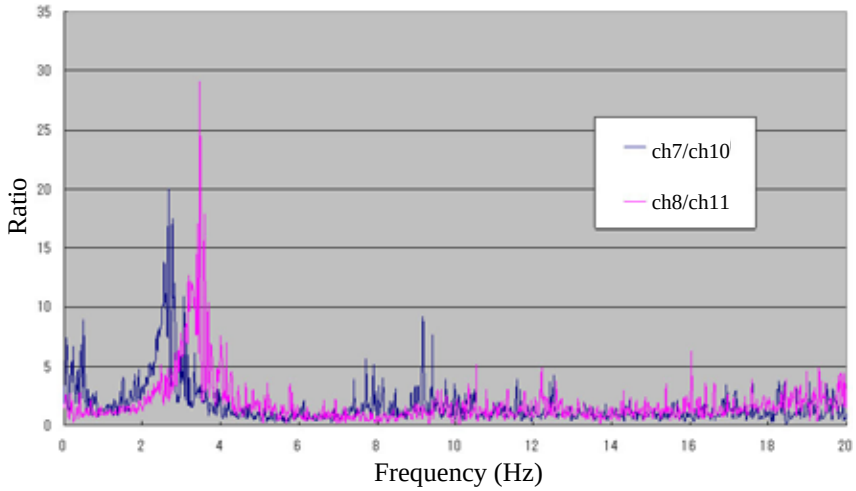

Figure 6: Fourier analysis results for the tower of Santo Domingo Church

Figure 7 presents the dispersion curve obtained from the FK analysis. This result permits to estimate the predominant frequency of the ground as 2.7 Hz. Then, if the result is compared with that obtained for the tower of the Colonial Church, it can be observed that the frequency of the structure and soil are similar, and therefore, the resonance phenomenon is expected to occur. This coincidence of the predominant frequencies could be the explanation of the repeatedly failure of the tower during past earthquakes.

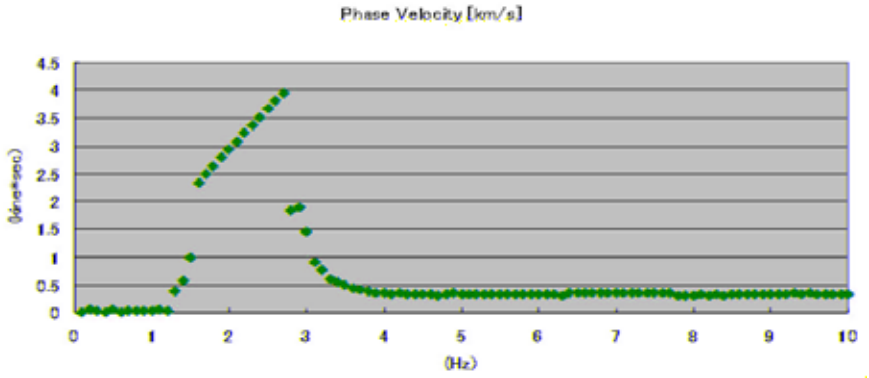

Figure 7: FK analysis result for Coricancha ground site

4 Conclusions

Microtremor measurements performed in representative structures of Coricancha complex have provided the basis for evaluation of the dynamic characteristics of the Inca stone structure and Colonial stone structure.
The measurement at the Inca stone part shows an intricate vibration due to presence of Colonial walls. More detailed measurement and analysis is required to establish the seismic behavior of this stone walls.
It was found that the predominant period of vibration of the church tower is comparable to the predominant period of the ground, and therefore the tower appears to be more vulnerable in case of earthquake occurrence because of the possible resonance phenomenon to be expected.

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