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VIBRATION PROPERTIES OF TRADITIONAL MASONRY WALLS OF CORTES CHURCH

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The Santo Niño Church in Bohol Island was partially damaged in the Bohol Earthquake in October 2013. In this study, we investigated the structural property of the Santo Niño Church to understand the vibration characteristics of Philippine masonry constructions by checking the main damage and conducting measurement surveys and microtremor measurement on the structure and ground. The major findings of this study can be summarized as follows: (a) Collapsed walls, peeling wall stone, corner deformation, and collapsed ceiling were the main damages that were observed. The collapsed wall was measured, and the make-up and material thickness of the wall was verified. (b) By performing microtremor measurements on the walls, the vibration property of the church, such as the natural frequency and vibration mode of the longest wall A was clarified. The 1st natural frequency of the longest wall A is the lowest.

Keywords: The 2013 Bohol Earthquake, Masonry structure, Microtremor measurement, Natural frequency, H/V spectra.

1 INTRODUCTION

The Earthquake that hit Bohol Island, Philippines in October 2013, killed 222 people; more than 3 million people all over Philippines suffered its effects (Ministry 2016). According to a previous disaster investigation, 23 churches in Bohol Island with masonry structures were completely or partially damaged (Japan 2014) owing to their poor seismic performance.

The walls of a traditional masonry church in Bohol is constructed using the fixed rammed-earth method; mud which containing stones, shells, gravel, and lime paste is piled up into layer form and is tamped dawn (Hanazato 2000, Rammed 2016).

These churches are used as places of assembly; thus, they need to have sufficient seismic performance to minimize damages caused by an earthquake. However, these churches were constructed without considering. Moreover, some structures were damaged by the earthquake, while some structures were not.

In this study, we clarify the vibration characteristics of Philippine masonry constructions by conducting a measurement survey and microtremor measurements on the structure and ground. The Santo Niño Church in Bohol Island was selected as the target structure; the official name of the church is St. Niño Parish Church in Cortes.

2 DAMAGE OF SANTO NIÑO CHURCH

The Santo Niño church was constructed on a hill by Augustinians Recollect in 1880 (Japan 2014). Its location is shown in Figure 1. The outside appearance of the church before earthquake and its drawing are shown in Figure 2. Photographs showing the main damages suffered by the church are shown in Figure 3.

2.1 Santo Niño Church

The church has a cruciform plan and an octagonal bell-tower. The construction of the bell-tower was finished in the 20th century. The roof frame consists of a wooden structure. The wooden floor is arranged only on the east side, and the other area consists of a large space with a high ceiling.

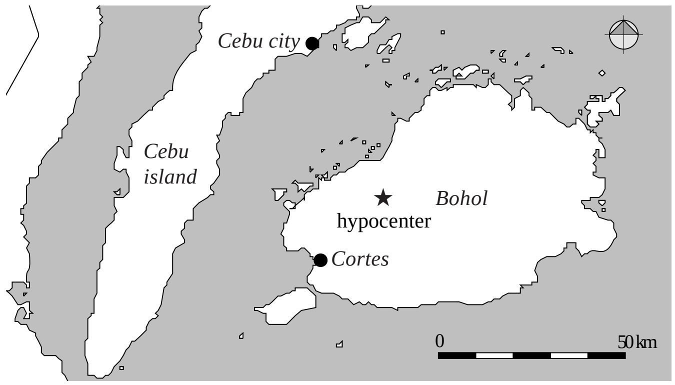
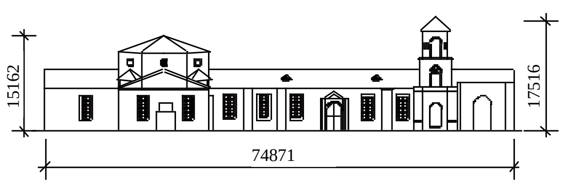
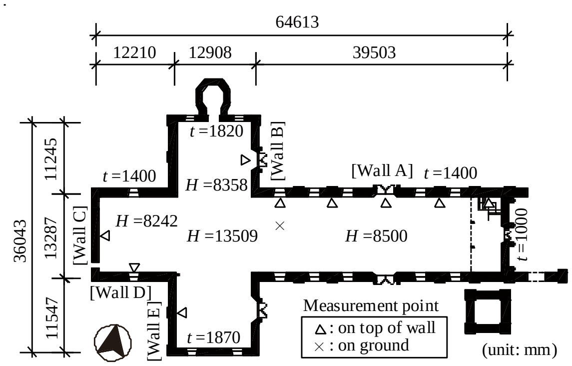


Figure 1. Location of Santo Niño Church in Cortes.

(a) Southeastern part of church before Bohol earthquake



(b) Southern elevation



(c) Plan and measurement point

Figure 2. Drawing of Santo Niño Church in Cortes and microtremor measurement points.

2.2 Main Damage

Collapsed walls, peeling wall stone, corner deformation, and collapsed ceiling were the main damages observed. The points of main damage are illustrated by dashes line and arrow head in Figure 3 (a). Then, (b) to (f) say the photographing point of Figure 3 (b) to (f).

The eastern wall of the second floor collapsed, as shown in Figure 3 (b); significant damage was observed around the opening and top of the southern gable wall, as shown in Figure 3 (c) and (d). The northern gable wall collapsed completely, as shown in Figure 3 (e). The shear deformation of the eastern wall of the ground floor is shown in Figure 3 (f). Such types of damage were observed throughout the church.

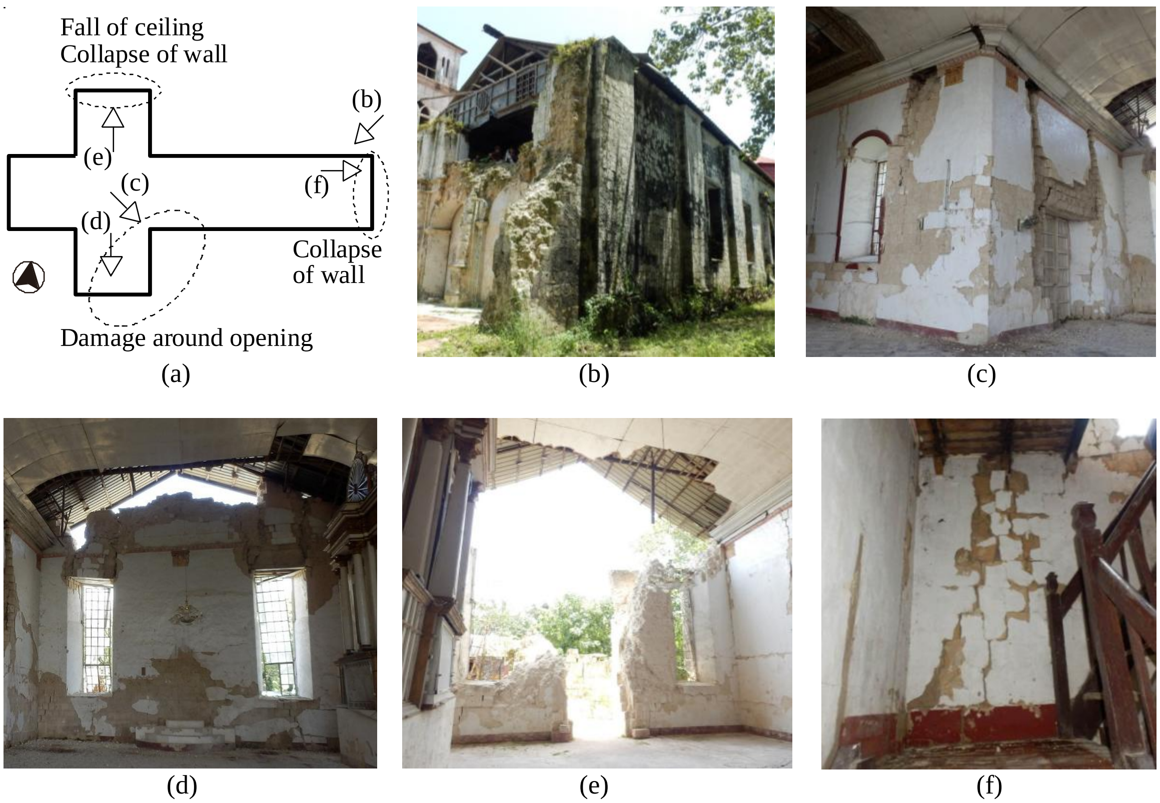


Figure 3. Damage due to Bohol earthquake; photographed on August 1, 2014.

3 STRUCTURAL INVESTIGATION

The structural investigation was conducted in September 19, 2015.

3.1 Masonry Wall

As the entire northern wall collapsed, the make-up and material thickness of the wall could be verified, as shown in Figure 4. Coral stones are arranged on both surfaces of the thick wall; the radius and thickness of each stone was approximately 300 mm and 150 mm, respectively. The space between the coral stones is filled up with mud mortar, which had a thickness of approximately 1000 mm.

We measured the dimensions of the church, and the length, thickness, and height of each wall, as shown in Figure 2 (c) and Table 1. Then, estimated values of the nearest wall, as shown in '( )', were used as thickness value for walls whose thickness could not be measured.

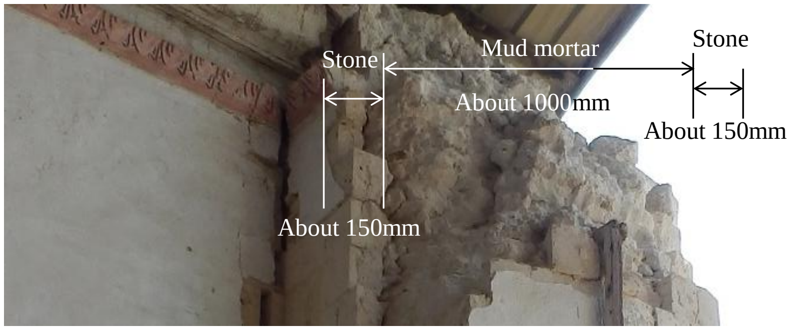


Figure 4. Construction of wall.

Table 1. Size and natural frequency of wall.

Wall	Wall size [mm]			1st natural frequency [Hz]	
	Length	Height	Thickness	Out-of-plane	In-plane
A	39,503		1,400	3.3	12.6
B	11,245		(1,820)	4.6	12.1
C	13,287	7,300	(1,400)	4.5	12.6
D	12,210		(1,400)	5.3	11.9
E	11,547		1,870	5.2	12.1

3.2 H/V Spectra on Ground

We conducted microtremor measurements of the ground to clarify surface conditions. The measurement was performed on the free ground at x point, as shown in Figure 2 (c). The frequency of the ground ranged between 7–9 Hz, as shown in Figure 5.

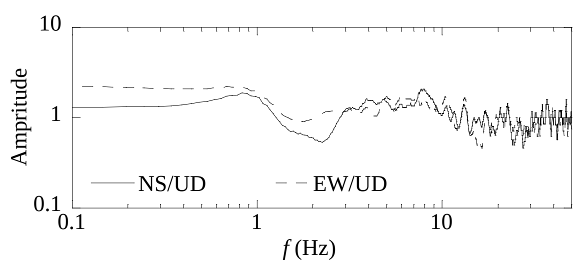


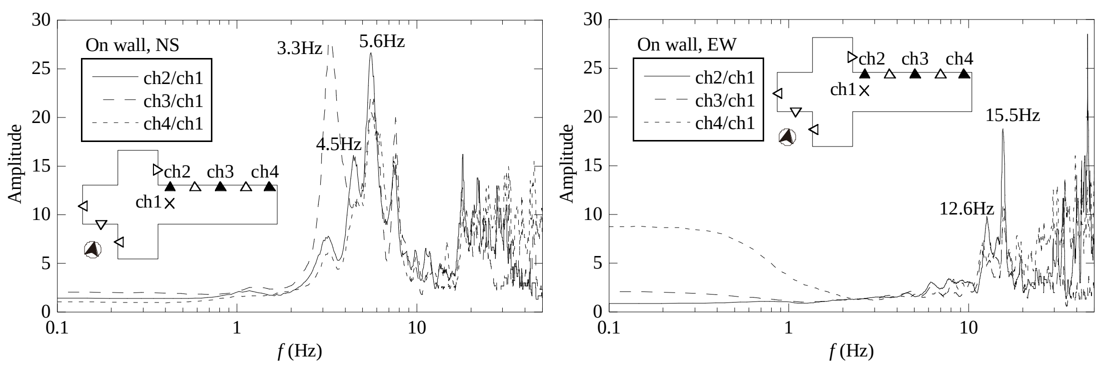
Figure 5. H/V spectrum on the ground point.

3.3 Natural Frequency and Vibration Mode of Masonry Wall

We conducted microtremor measurements on the walls to clarify the vibration property of the church. The measurement was performed at several points on the top of walls, A–E, as shown in Figure 6. In Figure 2 (c), the measurement points are marked by triangles. The simultaneous measurement was conducted at multiple points by installing one velocity sensor on the ground and some sensors on the wall. Five sensors were installed at wall A to understand the vibration mode. Then, the Fourier spectral ratio is defined as the Fourier spectra on the wall divided by on the ground.

Fourier spectral ratios in the out-of-plane and in-plane directions, obtained using the three sensors installed in wall A, are illustrated in Figure 7. The peaks are clear in both directions; the 1st, 2nd, and 3rd natural frequencies in the out-of-plane direction are 3.3 Hz, 4.5 Hz, and 5.6 Hz, respectively. In addition, the 1st and 2nd natural frequencies in the in-plane direction are 12.6 Hz and 15.5 Hz, respectively. The 1st natural frequencies of walls A to E in both the directions are indicated in Table 1.

Figure 6. Measurement point.



(a) For walls in the NS direction (b) For walls in the EW direction

Figure 7. Fourier spectral ratio.

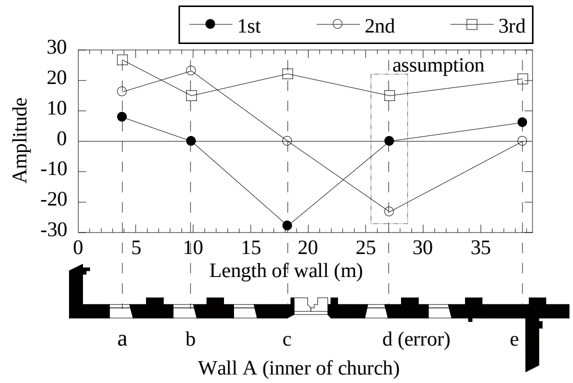


Figure 8. Vibration mode of Wall A.

The vibration mode of wall A is shown in Figure 8. The five sensors are named a to e, and the 1st to 3rd modes are illustrated. As measurement could not be performed using sensor d, the value of sensor b is used, based on a past study (Takiyama 2012).

4 CONCLUSIONS

In this study, we clarify the vibration characteristics of Philippine masonry constructions by conducting a measurement survey and microtremor measurements on the structure and ground. The Santo Niño Church in Bohol Island was used as the target structure, which was partially damaged by The October 2013 Earthquake. The major findings of this study can be summarized as follows:

(a) Collapsed walls, peeling wall stone, corner deformation, and collapsed ceiling were the main damages observed. The collapsed wall was measured, and the make-up and material thickness of the wall was verified.

(b) By conducting microtremor measurements on the walls, the vibration property of the church, such as the natural frequency and vibration mode of the longest wall A, was clarified. The 1st natural frequency of the longest wall A was the lowest.

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References

Hanazato, T., Monitoring to the Paoay Church, the Philippines, ICOMOS, 2000.

Japan Consortium for International Cooperation in Cultural Heritage, *Survey Report on the Protection of Cultural Heritage in Republic of the Philippines*, Japan, 2014.

Ministry of Land, Infrastructure, National Spatial Planning and Regional Policy Bureau, An Overview of Spatial Policy in Asian and European Countries. Retrieved from http://www.mlit.go.jp/kokudokeikaku/international/spw/general/philippines/ on June 1, 2016. (in Japanese)

Rammed earth construction. Retrieved from http://www.rammedearthconstructions.com.au/ on June 1, 2016.

Takiyama, N., Toshiyuki, T., and Hayashi, Y., Evaluation of out-of-plane vibration characteristics for unreinforcement walls of historic masonry constructions, *Journal of structural and constuction engineering*, Architectural Institute of Japan, 77(673): 475-482., 2012. (in Japanese).