Paper:

Diagnosis for Seismic Vulnerability Evaluation of Historical Buildings in Lima, Peru

Carlos Cuadra[*], **Taiki Saito**[**], **and Carlos Zavala**[***]

[*]Faculty of Systems Science and Technology, Akita Prefectural University
Tsuchiya, Honjo Campus, Yurihonjo, Akita 015-0055, Japan
E-mail: carlos@akita-pu.ac.jp
[**]Department of Architecture and Civil Engineering, Toyohashi University of Technology
1-1 Hibarigaoka, Tempaku-cho, Toyohashi 441-8580, Japan
[***]Faculty of Civil Engineering, National University of Engineering
Av. Tupac Amaru s/n, Puerta 7, CISMID, Rimac, Lima, Peru

[Received October 31, 2012; accepted January 8, 2013]

The city of Lima, the capital of Peru, was founded on January 18, 1535, and played a leading role in the history of the Americas from 1542, when king Carlos V established the vice royalty of Peru, until the middle of the 18th century. In 1988, UNESCO declared the historic center of Lima a World Heritage Site for its originality and high concentration of historic monuments constructed at the time of the Spanish presence and at the beginning of the Republican era. The architecture of buildings corresponds in general to typical Hispano-American baroque of the 17th and 18th centuries. Since its founding, the city has suffered many earthquakes that have severely and adversely affected historic buildings. Reconstruction work has been done keeping the originality of buildings. This study starts first with a general diagnosis of problems concerning the city and its buildings. A survey for preliminary evaluation of the structural condition of buildings is then planned. This evaluation of the seismic vulnerability of historic buildings at the historic center of Lima represents the basic study that is necessary to initiate detailed investigation for the preservation and conservation of these historic buildings. The study intends to establish a general guideline for vulnerability evaluation of historic buildings that could be applied to the evaluation of other historic cities of Peru.

Keywords: Lima city, architectural heritage, seismic vulnerability, ambient vibration

1. Introduction

Conservation of historic buildings is an important task that implies, as a first step, the evaluation of their vulnerability. Evaluation of the vulnerability of a single building could mean the estimation of mechanical characteristics by means of detailed structural analysis or in-situ measurements. When this evaluation must be performed for a group of buildings, however, simplified evaluation is required to establish general characteristics and hence to grasp the vulnerability of target buildings.

In this study, the historic center of Lima, the capital city of Peru, is selected as the target for performing a preliminary diagnosis that will serve as the basis for evaluating the vulnerability of historic buildings located at this site. Lima city was founded on January 18, 1535, by Spaniard conquistador Francisco Pizarro and played a leading role in the history of the New World from 1542, when king Carlos V of Spain establish the vice royalty of Peru, until the middle of the 18th century, just before the start of independence movements.

The historic center of Lima was declared a World Heritage Site in 1988 for its originality and high concentration of historic monuments constructed at the time of the Spanish presence and at the beginning of the republican era. The architecture of the buildings corresponds in general to typical Hispano-American baroque of the 17th and 18th centuries.

The coast of Peru, which includes the area where Lima city is located, is part of a zone with a high seismic hazard level due to the tectonic activity of the Nazca and the South American plates. The city has suffered the effects of many earthquakes that have severely damaged historic buildings. Reconstruction work has been done keeping the originality of buildings.

In the present research, a general diagnosis of problems concerning the city and to the buildings is done first. A survey for preliminary evaluation of structural conditions of buildings is then planned to be undertaken. In this step, a simple methodology for estimating earthquake resistance or vulnerability of buildings is proposed.

Evaluation of the seismic vulnerability of historic buildings at historic center of Lima represents a basic study that is necessary to initiate detailed investigation for the preservation and conservation of these historic buildings. A method is proposed based on simple indexes to establish the potential vulnerability of buildings. Detailed observation and in-situ estimation of the dynamic characteristics of critical buildings is then proposed by using ambient vibration measurements. Measurements results will permit us to verify the analytical models for detailed

Fig. 1. Map of Lima city.

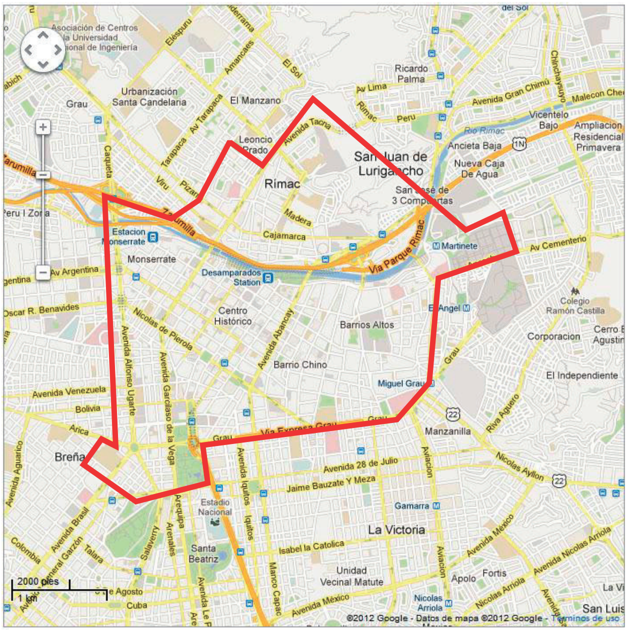

Fig. 2. Lima World Heritage Site (Google map).

structural analysis to establish the vulnerability of specific target buildings.

The study will also serve to establish a general guideline for vulnerability evaluation of historic buildings that could be applied to the evaluation of other historic cities in Peru.

2. Historic Center of Lima

Lima city is located in the western part of Peru near the Pacific Ocean. In **Fig. 1**, a map of metropolitan Lima city (Google map), the location of the historic center of Lima is indicated by a circle.

In **Fig. 2**, a close-up of Lima Center is shown where the zone that was declared a World Cultural Heritage is delimitated by an irregular polygon.

Lima city has a population density of 2,715 per square kilometer (2010). The area of the historical center represents 5% of the total area of the city. Its population density, however, is 14,225 per square kilometer; an indicator of a high population density that leads to the formation of slum areas at the city center.

The weather in Lima is mild, with annual average temperatures between 18°C and 22°C. In general there is no heavy rain. The winter, however, is characterized by high humidity, with an annual average of 80%.

At the time of the founding of Lima by the Spaniards conquistadores, the site was occupied by a local government called Curacazgo and the governor, who was the local representative of the Inca emperor, was called Curaca. Only temples called Huacas and administrative constructions existed at that time, and they were replaced by Spanish-style constructions. The city was organized in a shape of a chessboard following the original Inca distribution of streets. This portion can be appreciated in the central part of **Fig. 2**, where straight streets and square blocks can be observed. Sometimes this portion of the city alone is called the historic center. The area declared by UNESCO to be a World Heritage Site is larger, as was indicated previously.

At the end of the 15th century, many neighborhoods appeared mainly located around new churches that were constructed by Catholic religious groups. At the beginning of the 16th century, public works like parks and bridges over the Rimac river were constructed. In the first third of this 16th century, Lima had 25 urban blocks and the population was around 14,000.

The Viceroyalty of Peru reached its peak of development by the middle of the 17th century. Its political and economic stability is shown in the magnificence architecture of the time called Lima Baroque. At that time the population of Lima was 25,000, consisting of Spanish, Creoles, Natives and Slaves.

In 1684, a great wall was constructed to enclose the city that more or less corresponds to the borders of the World heritage zone indicated in **Fig. 2**. This wall had a height of 3 to 5 meters and was of 5 meters thick. This wall was demolished in 1870 to construct wide avenues for the modern city.

Lima city has suffered the effects of many earthquakes. One of them occurred in 1687 and the city was rapidly reconstructed under the influence of the baroque style that had great influence on architectural development in the next two centuries. A big earthquake that destroyed Lima and its port of Callao occurred in 1746. Callao port was also affected by a tsunami originating in the earthquake. This earthquake marks the decline in the Lima Baroque style that had been supported mainly by religious organizations. Instead of religious activities, great activity started in the social, academic and cultural fields. The city was then reconstructed under the influence of the Rococo style for new urban buildings. In 1791, the population of Lima reached 52,627.

The expansion of the city stopped from the end of the 18th century until 1821, when Peru gained its independence from Spain. Since the city was limited by a wall, the development of the city was slow until 1870 when the great wall was demolished to create new avenues and to permit the expansion of the city. In these years at the beginning of the republican era, new construction was influenced by New European Baroque. From 1920 to 1940, the architecture of the city was greatly influenced by English urban style based on the concept of the "Garden City." In 1906, the population of Lima was 140,000.

With the expansion of Lima, the decay of the historical center also started, since rich and middle class persons moved to the new urban areas. The historical center became the place of residence for the poor, who subdivided the buildings and converted them slams. Some buildings, however, were converted or adapted to serve as commercial shopping centers and educational institutions. In the worst, case these old buildings were demolished to construct apartment and office buildings, thereby distorting traditional urban space. By 1940, the population of Lima was approximately 400,000. A rapid increase in the population and expansion of the city started in 1940. The historical center of Lima was abandoned by its owners and traditional inhabitants and was saturated by new migrants from rural areas of Peru.

At present, Lima city occupies an area of three valleys. The original valley was corresponded to the Rimac river. By then, however, occupied area reached the valleys of the Chillon river to the north and the Lurin river to the south. In general, the place is a desert area with beaches, some hills and soft slopes near the ocean with increasing slopes to the east of the city that correspond to the beginning of the Andes mountains.

3. Lima Historical Center Buildings

An understanding of the characteristics of existing buildings is important to the assessment of their structural safety. Lacks in detailed knowledge will signify to assume uncertainties that will affect the modeling of the structures. In the case of the evaluation of the vulnerability of an area of the city, characteristics of buildings located at this site must be analyzed, and this task in crucial in the case of historic construction.

At historic center of Lima, historic buildings can be divided according to their use. In this case, important buildings include churches in 50 places considered religious monuments. Then there are buildings that were used as residences, institutions like banks, commercial shops, hotels, and finally some palaces or administrative offices like city hall and the presidential palace.

Buildings can also be divided, however, according to the material of construction, where modern buildings are mainly made of reinforced concrete or confined masonry, while old buildings use traditional construction materials. These traditional materials are unreinforced masonry, adobe (sun-dried bricks) and quincha (earthen construction with a wooden frame). **Fig. 3** shows the city hall of Lima, which is a reinforced concrete building combined with confined masonry.

Fig. 3. Lima city hall.

Fig. 4. San Francisco church.

Figure 4 shows a view of the San Francisco church (unconfined masonry and adobe) and **Fig. 5** shows a typical quincha construction.

4. Plan for Vulnerability Evaluation of Historic Monuments of Lima

The former National Institute of Culture of Peru (Ministry from 2010) has elaborated a catalogue of historic monuments in at center of Lima. Based on this list, it is necessary to

(a) perform a detailed survey to obtain general characteristics of the monuments,

(b) define the survey form for this kind of structure and

(c) define a computer platform for storing and analyzing obtained data.

Fig. 5. Typical quincha construction.

Table 1. List of religious buildings at Lima's historical center.

ID	Name	ID	Name
1	El Milagro Chapel	27	San Francisco Church
2	Santa Rosa Monastery	28	Santa Clara Church
3	T. Francisco Monastery	29	Concepcionistas Church
4	3 St. Francisco Monastery	30	Santa Ana Church
5	San Pedro Monastery	31	La Trinidad Church
6	Cathedral and El Sagrario	32	Las Nazarenas Church
7	Mercedarias Monastery	33	Las Trinitarias Church
8	San Agustin Monastery	34	Sra. El Prado Church
9	Veracruz Church	35	Santa Catalina Church
10	Santo Cristo Church	36	Santa Rosa Church
11	San Carlos Church	37	Sra. Del Carmen Church
12	Jesus Maria Church	38	Recoleta Church
13	La Merced Monastery	39	Concepcion Monastery
14	La Soledad Church	40	Bishop Palace
15	Cocharcas Church	41	Santa Rosa Sanctuary
16	Concepcion Church	42	Santo Domingo Monastery
17	Monserrate Church	43	Sra. de la Cabeza Church
18	San Agustin Church	44	Paulo Nuevo Church
19	San Marcelo Church	45	San Lazaro Church
20	San Pedro Church	46	Santa Liberta Church
21	San Pedro Nolasco Church	47	Del Rosario Church
22	San Sebastian Church	48	Sra. Copacabana Church
23	Santiago Church	49	Del Parocinio Church
24	Santo Domingo Church	50	Los Descalzos Church
25	Corazon de Jesus Church	51	San Francisco de Paula
26	La Buena Muerte Church		Monastery

Since there are many types of monuments, it would be adequate to choose some specific types of buildings to initiate vulnerability evaluation. In this case, churches are proposed as target construction because they present a critical or weak part which is the bell tower. In the case of earthquakes, these towers failed dramatically as was observed in previous earthquakes. In the present research, the study of churches is therefore proposed as the target objective. **Table 1** shows the places at Lima's historical center that are religious constructions like churches, convents, and cathedrals.

The classification of the vulnerability of historic monuments provides the opportunity to identify critical buildings where more detailed measurements can be performed as priority. In this case, for selected buildings, ambient vibration measurements are proposed to estimate the dynamic characteristics of buildings. From these measurements, it is possible to establish indexes for seismic vulnerability of historic buildings.

This process of investigation could be used to elaborate guidelines for the evaluation of vulnerability or earthquake resistant characteristics of historic buildings in Peru. The developed methodology could then be applied to evaluating historic building located in other cities of Peru like Arequipa, Trujillo, and Cusco.

5. Simplified Methods for Evaluation of Seismic Vulnerability

The method presented by Lourenço and Roque [4] is proposed to be adopted. This methodology consists of calculating simple indexes for establishing the potential vulnerability of buildings. The method was originally proposed for the evaluation of churches in Europe (Portugal), and must be adapted for a zone of higher seismicity like Peru. The method and its applicability are discussed briefly in the following paragraphs.

As is describe by Lourenço et al. [4], the analysis of historic masonry constructions is a complex task, mainly because

(a) geometry data is missing;

(b) information about the inner core of structural elements is missing;

(c) characterization of mechanical properties of materials used is difficult;

(d) large variability exists among mechanical properties due to workmanship and the use of natural materials;

(e) significant changes in the core and constitution of structural elements are associated with long construction periods;

(f) the construction sequence is unknown;

(g) existing damage to structures is unknown;

(h) regulations and codes are non-applicable.

Moreover, behavior of the connections among masonry elements – walls, arches and vaults – and masonry elements and timber elements is usually unknown.

All of these factors indicate that quantitative results of structural analysis must be looked at with care, in the case of vertical loading and, even more carefully, in the case of seismic action. More complex and accurate methods therefore do not necessarily correspond to more reliable and better analysis.

The usage of simplified methods of analysis usually requires that the structure be regular and symmetric, that the floors act as rigid diaphragms and that the dominant collapse mode is in-plane shear failure of walls.

In general, these last two conditions are not verified in ancient masonry structures, meaning that simplified methods should not be understood as quantitative safety assessments but merely as simple indicators of the possible seismic performance of a building. Here, the following simplified methods of analysis and corresponding indexes are considered:

- Index 1: In-plan area ratio;
- Index 2: Area to weight ratio;
- Index 3: Base shear ratio.

These methods can be considered as an operator that manipulates the geometric values of structural walls and produces a numerical index. Because methods measure different quantities, their application to a large sample of buildings contributes to further understanding of their application. As stated above, a more rigorous assessment of the actual safety conditions of a building is necessary to have quantitative values and to define remedial measures, if necessary.

5.1. In-Plan Area Ratio

The simplest index for assessing the safety of ancient construction is the ratio between the area of the earthquake-resistant walls in each main direction (transversal x and longitudinal y, with respect to the church nave) and total in-plan area of buildings. According to Eurocode 8 [8], walls should only be considered earthquake-resistant if thickness is larger than 0.35 m and the ratio between wall height and thickness is smaller than nine. This first index is given by the following equation:

$$\gamma_{1,i} = \frac{A_{wi}}{S} \quad \dots\dots\dots\dots\dots\dots \quad (1)$$

where A_{wi} is the in-plan area of earthquake-resistant walls in direction i and S is the total in plan area of the building.

Non-dimensional index $\gamma_{1,i}$ is the simplest one, being associated with base shear strength. Special attention is required when using this index because it ignores the slenderness ratio of walls and the mass of the construction. Eurocode 8 recommends values up to 5-6% for regular structures with rigid floor diaphragms.

In the case of the Peru, adobe buildings (sun-dry brick masonry) and confined masonry constructions have similar characteristics to historic masonry buildings described previously. In the Peruvian Adobe Code, a minimum area ratio of around 7% is specified for shear walls. For confined masonry, the minimum area of shear-resistant walls is specified as 4%. Then, as is recommended by Eurocode 8, in cases of high seismicity, a minimum value of 10% is to be recommended for historic masonry buildings. For simplicity's sake, high-seismicity cases are assumed to be those where design ground acceleration for rock-like soils is larger than 0.2 g.

5.2. Area to Weight Ratio

The area to weight ratio is an index that provides the ratio between the in-plan area of earthquake-resistant walls in each main direction (again, transversal x and longitudinal y) and the total weight of construction. This index is given by the following equation:

$$y_{2,i} = \frac{A_{wi}}{G} \quad \dots\dots\dots\dots\dots \quad (2)$$

where A_{wi} is in-plan area of earthquake-resistant walls in direction i and G is quasi-permanent vertical action.

This index is associated with the horizontal cross-section of the building, per unit of weight, therefore the height – i.e. the mass – of the building is taken into account. A major disadvantage of this is, however, that the index is not non-dimensional. This means that it must be analyzed for fixed units. In cases of high seismicity, a minimum value of 1.2 m^2/MN is recommended for historic masonry buildings.

5.3. Base Shear Ratio

The base shear ratio provides a safety value with respect to shear safety of construction. Total base shear for seismic loading ($V_{Sd,base} = F_E$) is estimated from analysis with horizontal static loading equivalent to seismic action ($F_E = \beta \times G$), where β is an equivalent seismic static coefficient related to design ground acceleration. The shear strength of the structure ($V_{Rd,base} = F_{Rd}$) is estimated from the contribution of all earthquake-resistant walls $F_{Rd,i} = \Sigma A_{wi} \times f_{vk}$, where, according to Eurocode 6, $f_{vk} = f_{vk0} + 0.4\sigma_d$. Here, f_{vk0} is cohesion, which is assumed equal to a low value or zero in the absence of more information, σ_d is the design value of normal stress and 0.4 represents the tangent of constant friction angle φ, equal to 22°. This new index γ_3 is given by the following equation:

$$\gamma_{3,i} = \frac{F_{Rd,i}}{F_E} \quad \dots\dots\dots\dots\dots \quad (3)$$

If zero cohesion is assumed, ($f_{vk0} = 0$), $\gamma_{3,i}$ is independent of building height and is given by the following equation:

$$\gamma_{3,i} = \frac{V_{Rd,i}}{V_{Sd}} = \frac{A_{wi} \tan\varphi}{A_w \beta} \quad \dots\dots\dots\dots \quad (4)$$

For non-zero cohesion, however, which is most relevant for low-height buildings, $\gamma_{3,i}$ is expressed as follows:

$$\gamma_{3,i} = \frac{V_{Rd,i}}{V_{Sd}} = \frac{A_{wi}\left[\tan\varphi + f_{vk0}/(\gamma \times h)\right]}{A_w \beta} \quad \dots \quad (5)$$

where A_{wi} is the in-plan area of earthquake-resistant walls in direction i, A_w is the total in plan area of earthquake-resistant walls, h is the (average) height of the building, γ is volumetric masonry weight, φ is the friction angle of masonry walls and β is an equivalent static seismic coefficient. Here, it is assumed that normal stress in walls is due to their self-weight alone, i.e., $\sigma_d = \gamma \times h$, which is on the safe side and is a very reasonable approximation for historic masonry buildings that are usually made of very thick walls.

Moreover, assuming a tangent of the friction angle of 0.4, a value of the cohesion f_{vk0} of 0.1 N/mm^2, and volumetric weight γ equal to 20 kN/m^3 (2×10^{-5} N/mm^3), the modified value of $\tan\varphi$ in Eq. (5) gives the following relationship:

$$\tan\varphi + f_{vk0}/(\gamma \times h) = 0.4 + 0.1/(2 \times 10^{-5} \times h) \quad (6)$$

This means that the contribution of cohesion is very large – for a height h equal to 5.0 m, Eq. (6) equals 1.4, for 10.0 m, 0.9, and for 20.0 m, 0.65. Eq. (5) must be used rather carefully because gives high values of the index and therefore it is better to use more conservative values given by Eq. (4).

This non-dimensional index considers the seismicity of the zone, taken into account in β. Building safety with an increasing ratio (earthquake resistant walls/weight), i.e., larger relation (A_{wi}/A_w) and lower height. For this type of building and action, a minimum value of $\gamma_{3,i}$ equal to 1 is acceptable.

Using these simplified indexes, a priority list of target buildings is elaborated to proceed with the next step which consists of the detailed measurement of dynamic characteristics by using ambient vibration measurement. Finally, for some critical buildings, detailed structural analysis and posterior repair and reinforcement plans could be proposed.

6. Ambient Vibration Measurement

Using the simplified indexes described previously, a priority list of target building is made to proceed with the next step, which consists of the detailed measurement of dynamic characteristics by using ambient vibration measurement.

After estimation of the dynamic properties of buildings by means of ambient vibration measurement, detailed structural analysis for critical buildings is proposed in order to analyze vulnerability and to establish plans for repair, restoration and reinforcement.

Ambient vibration measurement is a reliable method for estimating the dynamic characteristics of buildings and, in the case of historic buildings, is used to estimate the vibration characteristics of some portions of structures that are susceptible to collapse. This applicability was demonstrated in reference [9], where ambient vibration of the Santo Domingo church (see **Fig. 6**) located in Cusco city, Peru, was performed.

Here, ambient vibration of ground was also performed and, as is indicated in **Fig. 7**, vibration characteristics of the church tower are similar of those of ground and therefore great amplification of the tower response is expected to occur in the case of an earthquake. This fact could explain failures of towers during past earthquakes.

A building that was an old hotel in Lima city is presented as an example in which ambient vibration measurements were performed to estimate its period of vibration. This building is shown in **Fig. 8**. Walls of the upper stories (second and third floors) are made of quincha and first story walls are made of adobe. The building presents some partial collapse of interior walls and serious deterioration of quincha walls due to ageing and humidity.

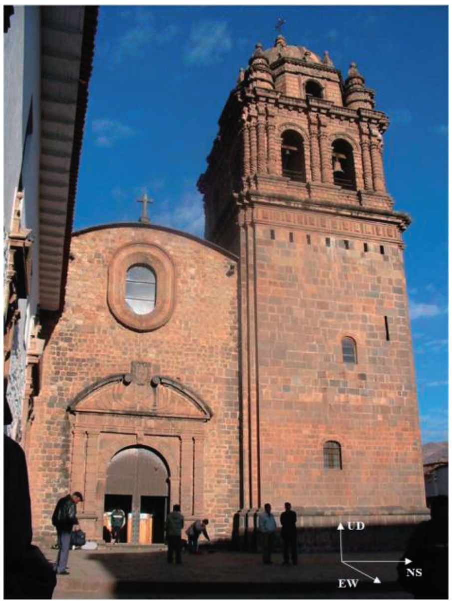

Fig. 6. Santo Domingo church, Cusco, Peru.

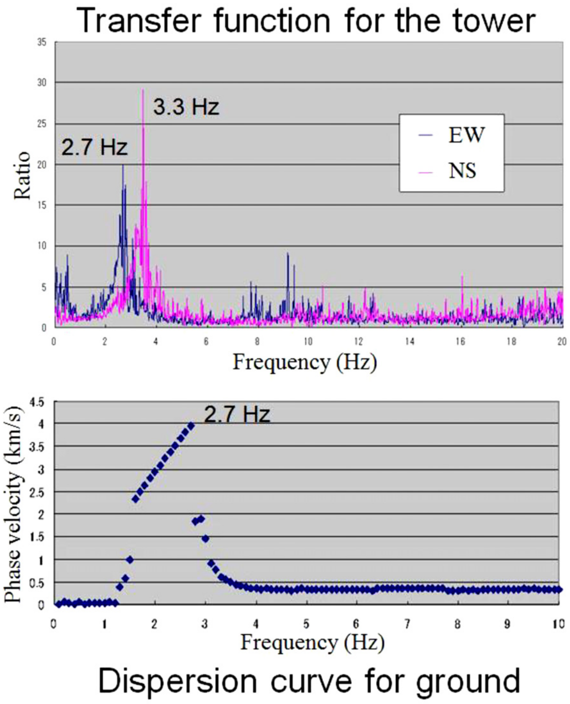

Fig. 7. Ambien vibration results for Santo Domingo church tower and ground.

Figure 9 shows the setup of ambient vibration sensors. These micro velocity sensors were located on the third floor and at the corners of the building.

Results of ambient vibration show a predominant frequency on the order of 3.3 Hz. **Fig. 10** shows predominant frequencies for NS and EW directions respectively. The NS direction was taken as the direction parallel to the façade and the predominant frequency is 3.37 Hz. In the EW direction, which is perpendicular to the façade, the predominant frequency is 3.21 Hz. These frequencies represent reasonable values for a building 12 m in height.

Fig. 8. Typical quincha construction for measurements.

Fig. 9. Microtremor measurement of adobe-quincha building.

More detailed measurement is necessary, however, to detect the local vibration of portions of the building that could indicate conditions of deterioration.

7. Conclusions

This report has presented a brief description of the general characteristics and condition of historic constructions located at historic center of Lima. A list of monuments includes 50 religious monuments like churches and convents which have some critical conditions for structural safety. In the case of earthquakes, church towers failed dramatically as was observed in previous earthquakes. It is therefore proposed as a first step to concentrate efforts to evaluate the vulnerability of this kind of building.

For selected target buildings, it has been proposed to make a rapid survey to establish a priority list for starting detailed evaluation, starting from the most vulnerable buildings. The classification of vulnerability of historic monuments provides the opportunity to focus more detailed measurement on the most critical buildings. In this case, for selected buildings, ambient vibration measurements have been proposed to estimate dynamic characteristics of buildings or structural portions of constructions. From these measurements, it is possible to establish indexes of the seismic vulnerability for historic buildings.

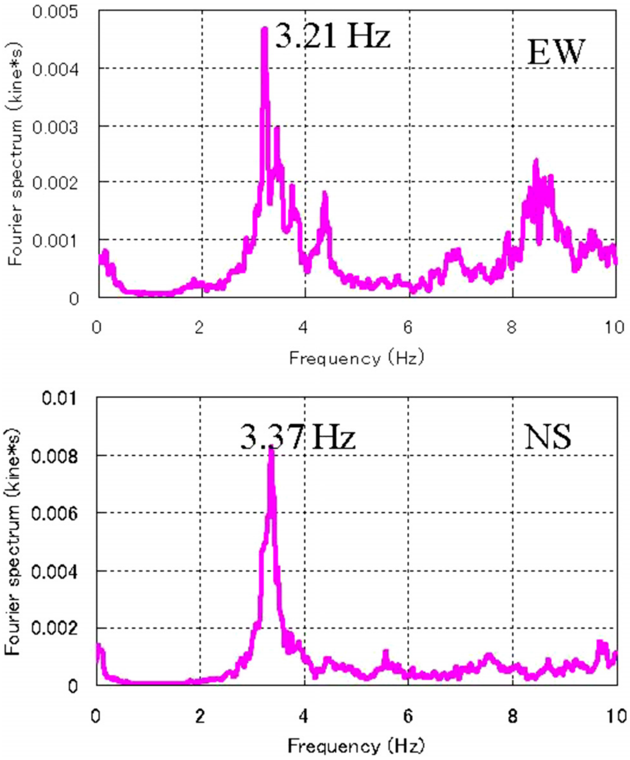

Fig. 10. Predominant frequency of selected historical building.

From the list of most vulnerable monuments, critical buildings could be selected for more detailed analysis. In this case, analytical models using the finite element method or some similar method should be prepared. Ambient vibration measurement results could be used to calibrate the reliability of modeling.

This process of investigation could be used to elaborate guidelines for the evaluation of vulnerability or earthquake-resistant characteristics of historic buildings in Peru. The developed methodology could then be applied to evaluating historic buildings located in other cities of Peru like Arequipa, Trujillo, and Cusco.

Acknowledgements

The authors acknowledge the support of JST/JICA, SATREPS in research for Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru, under which this survey was conducted.

References:

[1] L. Cardenas and C. Zavala, “Estudio de Vulnerabilidad Estructural del Hotel Comercio” (Study on Structural Vulnerability of Hotel Comercio), CISMID-UNI Report, 2008 (in Spanish).

[2] C. H. Cuadra, T. Saito, C. A. Zavala, and M. A. Diaz, “The challenges of protect historical adobe constructions in Peru,” 14th European Conference in Earthquake Engineering, Ohrid, Macedonia, CD ROM, Paper No.392, 2010.

[3] C. Cuadra, M. B. Karkee, J. Ogawa, and J. Rojas, “An evaluation of earthquake risk to Inca’s historical constructions,” Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver,

B.C., Canada, CD-ROM, Paper No.150, August 1-6, 2004.

[4] P. B. Lourenço, and J. A. Roque, "Simplified indexes for the seismic vulnerability of ancient masonry buildings," Construction and Building Materials, pp. 200-208, 2006.

[5] O. Miranda, J. Gallardo, C. Cuadra, and J. Ogawa, "Reduction of seismic damage in Peruvian traditional constructions," 2nd International Conference on Computer Simulation in Risk Analysis and Hazard Mitigation, Risk Analysis II, Bologna, Italy, pp. 389-396, Oct. 2000.

[6] J. Ogawa, C. Cuadra, M. B. Karkee, and J. Rojas, "A study on seismic vulnerability of Inca's constructions," Proceedings of the 4th International Conference on Computer Simulation in Risk Analysis and Hazard Mitigation, Risk Analysis IV, Rhodes, Greece, pp. 3-12, 2004.

[7] S. R. Shrestha, M. B. Karkee, C. H. Cuadra, J. C. Tokeshi, and S. N. Miller, "Preliminary study for evaluation of earthquake risk to the historical structures in Kathmandu valley (Nepal)," Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, CD-ROM, Paper No.172, August 1-6, 2004.

[8] CEN, "Eurocode 8: Design of structures for earthquake resistance," prEN 1998-1, Brussels : CEN, 2003.

[9] C. H. Cuadra, "Seismic Vulnerability of Santo Domingo Church, Cusco, Peru," Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal, Paper No.1012, September 24-28, 2012.

[10] C. H. Cuadra, T. Saito, and C. Zavala, "Dynamic characteristics of traditional adobe-quincha buildings in Peru," Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal, Paper No.2653, September 24-28, 2012.

Name:
Carlos H. Cuadra

Affiliation:
Associate Professor, Faculty of System Science and Technology, Akita Prefectural University

Address:
Tsuchiya, Honjo Campus, Akita 015-0055, Japan

Brief Career:
1984 National University of Ancash, Peru
1989 National University of Engineering, Lima, Peru
1999 Akita Prefectural University

Selected Publications:
- "Earthquake risk to Inca's historical constructions in Machupicchu," Advances in Engineering Software, Computational Modelling of Historical Constructions, ELSEVIER, Vol.39, pp. 336-345, 2008.

Academic Societies & Scientific Organizations:
- Member of the Scientific Advisory Committee of STREMAH, WIT, UK
- Member of the Scientific Advisory Committee of ERES (Earthquake Resistant Engineering Structures), WIT, UK

Name:
Taiki Saito

Affiliation:
Professor, Toyohashi University of Technology

Address:
1-1 Hibarigaoka, Tempaku-cho, Toyohashi 441-8580, Japan

Brief Career:
1990-1996 Research Associate, Tohoku University
1996-2000 Senior Research Engineer, Building Research Institute
2000-2012 Chief Research Engineer, Building Research Institute
2013- Professor, Toyohashi University of Technology

Selected Publications:
- T. Saito, T. Takahashi, R. Hasegawa, K. Morita, T. Azuhata, and K. Noguchi, "Shaking Table Test on Indoor Seismic Safety of High-rise Buildings (Part 2. Movement of Furniture under Long Period Earthquake Ground Motion," Proceedings of 14th World Conference of Earthquake Engineering, S10-014, 2008.10.

Academic Societies & Scientific Organizations:
- Architectural Institute of Japan (AIJ)
- Japan Association for Earthquake Engineering (JAEE)

Name:
Carlos Zavala

Affiliation:
Researcher, Laboratory of Structures, CISMID
Professor, Faculty of Civil Engineering, National University of Engineering

Address:
Los Ishipingos (Ex-Abetos) 245 Dpt. 202 Urb. El Remanso La Molina,
Lima 12, Lima, Peru

Brief Career:
1984 Undergraduate Course, Faculty of Civil Engineering, National University of Engineering (UNI), Lima, Peru
1989 Master Course, Graduate School Faculty of Civil Engineering, National University of Engineering (UNI), Lima, Peru
1995 Ph.D., Graduate School of Architecture, University of Tokyo, Japan
2001 Professor, Faculty of Civil Engineering, National University of Engineering, Lima, Peru
2007-2012 Director of Japan Peru Center of Earthquake Engineering Research & Disaster Mitigation CISMID

Selected Publications:
- C. Zavala, K. Ohi, and K. Takanashi, "A general Scheme for Substructuring On-line Hybrid Test on Planar Moment Frames (The Neural Network Model)," Proceedings of 4th Pacific Steel Structures Conference, Pergamom Press, October 1995.
- C. Zavala, "Improvement on low cost housing through non-conventional construction systems," Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand, February 2000.
- C. Zavala, C. Honma, P. Gibu et. al, "Full Scale On Line Test On Two Story Masonry Building Using Handmade Bricks," Proceedings of the 13th World Conference on Earthquake Engineering (WCEE), Vancouver, Canada, August 2004.
- C. Zavala, Z. Aguilar, and M. Estrada, "Evaluation of SRSND Simulator against Fragility Curves for Pisco Quake," Proceedings of the 8th International Conference on Urban Earthquake Engineering Tokyo Institute of Technology, Tokyo, Japan, 2011.

Academic Societies & Scientific Organizations:
- Peru Engineering Association (CIP)