Dynamic characteristics of traditional adobe-quincha buildings in Peru

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SUMMARY:
The adobe-quincha system is a traditional construction technology that was used widely in Peru during the colonial period and at the beginning of the republican era. At present this constructions are located in the old part of the main cities of Peru like Lima, Arequipa, and Trujillo. These cities are trying to preserve these old constructions since they form part of their historical centres. This system was used to construct mainly particular residences and sometimes palaces, and consist of a first floor made of adobe or sun-dried bricks and upper floors made of quincha. The quincha is formed by wooden frames or panels which support a mesh of cane to receive a finishing plaster of mud and gypsum. Apparently, from experiences of past earthquakes that strike Peruvian cities, a second floor or upper floors made of light material provided better seismic behaviour. However since the basic material is earth (earthen constructions) is obvious that appropriate maintenance and conservation task are necessary. Therefore, in this research, a preliminary evaluation of structural condition of these kinds of buildings is performed. As example, a building that was used as hotel is presented, where ambient vibration measurements were performed to estimate its period of vibration. The building presents some partial collapse of interior walls and serious deterioration of the quincha walls. Although light weight of the upper stories could signify a better seismic behaviour, deterioration and lack of repair and maintenance make critical the vulnerability of these buildings.

Keywords: Earthen constructions, Ambient vibration measurements, Seismic vulnerability

1. INTRODUCTION

Old parts of the cities that were founded during the colonial era in Peru have historical constructions that in some cases have been declared as architectural heritage. In the case of Lima city, the capital of Peru, the central part of the city (historic center) contents many historical buildings and architectural environments, and for that reason this portion of the city has been declared as Cultural World Heritage. The city of Lima, the capital of Peru, was founded by Spanish conquistador Francisco Pizarro on January 18, 1535 and given the name City of the Kings. Lima played a leading role in the history of the New World from 1542, when Carlos V establish 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 in the time of 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. In other cities of Peru like Trujillo and Arequipa it can also been observed that the central part of the city has many historical monuments. Since their foundation these cities have suffered the action of many earthquakes that have severely affected historical buildings and reconstruction works have been done keeping the originality of the buildings. However due to the age of buildings studies for retrofitting or strengthening are necessary.

In this study attention is focused on one type of traditional construction called adobe-quincha. A difference than churches and palaces this type of construction was widely used to construct residences or houses. At present this old big houses in some cases had been converted into slum dwellings. These buildings consist of a first floor made of adobe or sun-dried bricks and upper floors made of wooden frame or panels which support a mesh of cane to receive a finishing plaster of mud and gypsum. This system of wooden frame with cane and plaster is called as quincha. In this paper a preliminary study of the dynamic characteristics of these traditional buildings is presented. Apparently, from experiences of past earthquakes that strike the coast of Peru, a second floor or upper floors made of light material provided better seismic behavior. However since the basic material is earth (earthen constructions) is obvious that appropriate maintenance and conservation tasks are necessary. Therefore, in this research, a preliminary evaluation of structural condition of these kinds of buildings is presented. As example a building that correspond to an old hotel is presented where ambient vibration measurements were performed to estimate the period of vibration. The building presents some partial collapse of interior walls and serious deterioration of the quincha walls. Although light weight of the upper stories could signify a better seismic behavior, deterioration and lack of repair and maintenance make critical the vulnerability of these buildings.

At present the adobe-quincha system is investigated in Peru as an alternative for low cost housing in towns and rural areas. In those zones buildings are mostly adobe masonry structures and due to the increasing need of housing in populated areas and the low cost of construction, two story adobe dwellings are often built in cities and small towns in the interior regions where adobe is sometimes the only material available. However, two story adobe masonry structures have shown poor behavior during earthquakes, due, mainly, to the large weight of the walls. One alternative, to these two-story adobe buildings is to employ a lightweight second story. However the main problem became the connection and continuity between the first story made of adobe and the second story made of a lightweight material.

2. THE ADOBE QUINCHA SYSTEM

Figure 1 shows a typical adobe-quincha construction and some details of the upper floors made of wooden frame and mud plaster (quincha). In these old constructions, the adobe walls of the first floor have a thickness that varies from 60 cm. to 100 cm. The height of the first floor reaches sometimes 5 m. or more. The thickness of the upper floors ranges from 20 cm to 50 cm. In general the wooden frames were constructed in-situ and the connection between elements presents different patterns like insertions of beam ends into the columns, nailed joints, joints fixed with ties made of animal fur or leather, etc. The mesh of cane is made of very thin canes called “carrizo”, and “caña brava”. These canes are fixed to the wooden structure by means of cords or ropes made also of vegetal material. To fix the quincha system to the adobe walls the bottom part of the wooden frame is constraint by means of heavy materials like adobe itself or clay bricks as can be observed in right part of Figure 1.

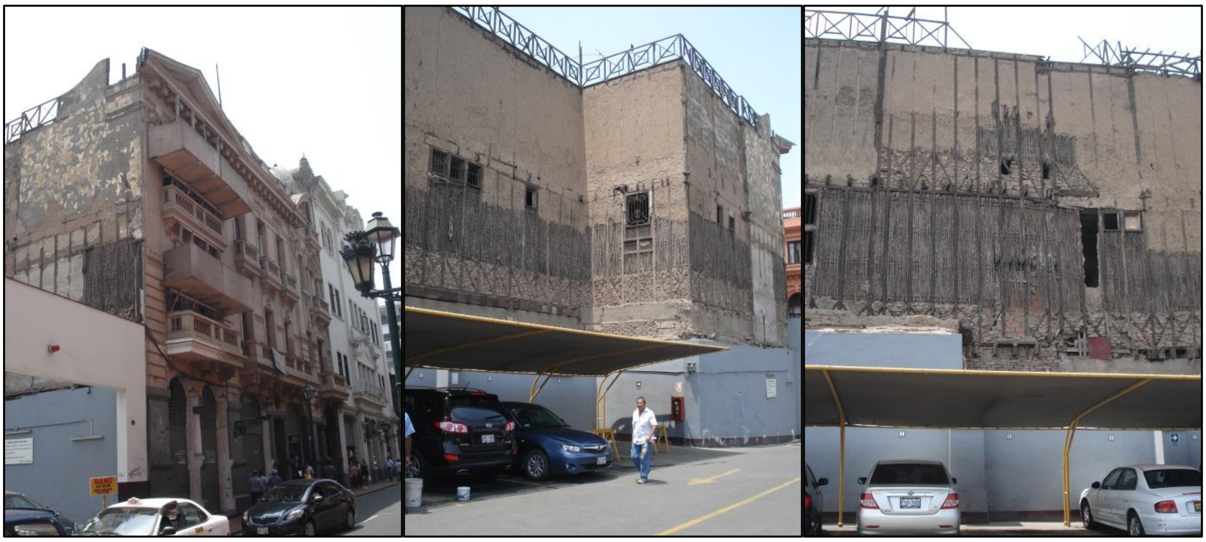

Figure 1. Typical adobe-quincha construction

In some cases the adobe-quincha buildings presents good appearance. For example in Figure 2 it can be appreciated the façade of a building located in the historical center of Lima where the color of the walls are changed or re-painted almost every year. However the structural condition of the interior walls is critical as can be observed in the bottom part of the same figure. This deterioration of the structure is due mainly to the aged of the building and due to the action of the humidity that affect the earthen constructions. The humidity also affects the wood frame and the cane mesh of the quincha since they are organic materials.

Figure 2. Typical adobe-quincha construction and structural condition details

To explain the dynamic characteristics of the adobe quincha system the model employed by Miranda et al. (2000) is used. This model is shown in Figure 3. In this case the system is a kind of prefabricated quincha panels that consists, basically of wood panels with a kind of bamboo mesh and a plaster made of mud and gypsum. The construction of this full-scale model has permitted to solve some constructive problems in relation to the inter-story floor and the connection between the adobe walls and the quincha panels of the second floor. As it is observed, the first floor is made of adobe masonry and the second floor consists of wood panels with finishing plaster of mud and gypsum. The thickness of the walls of the first floor is 40 cm, while the second floor walls are of 10 cm of thickness. In order to connect appropriately the first floor and the second floor, eucalyptus rods of 7.5 cm of diameter were fixed in the foundation to act as columns. These rod columns are embedded in the adobe wall and are located at the corners and distributed along the wall with 1.2 m of spacing. To permit the inclusion of the rod columns in the walls, the adobe masonry units have an especial shape as is shown in Figure 4. The adobe masonry units have a modular dimension of 40×40 cm and 10 cm of height with semicircular incisions of 10 cm of diameter in two opposite sides. Also there are adobe units which are half units to permit the appropriate fabric of the masonry. The incisions of the adobe masonry units permit to form the cylindrical space to allocate the eucalyptus rod columns.

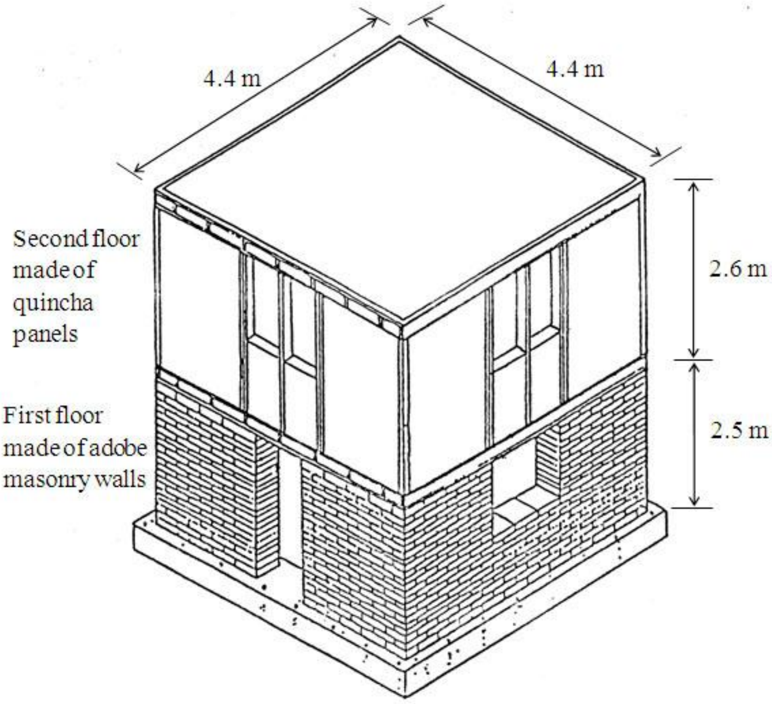

Figure 3. Prototype of the adobe-quincha system

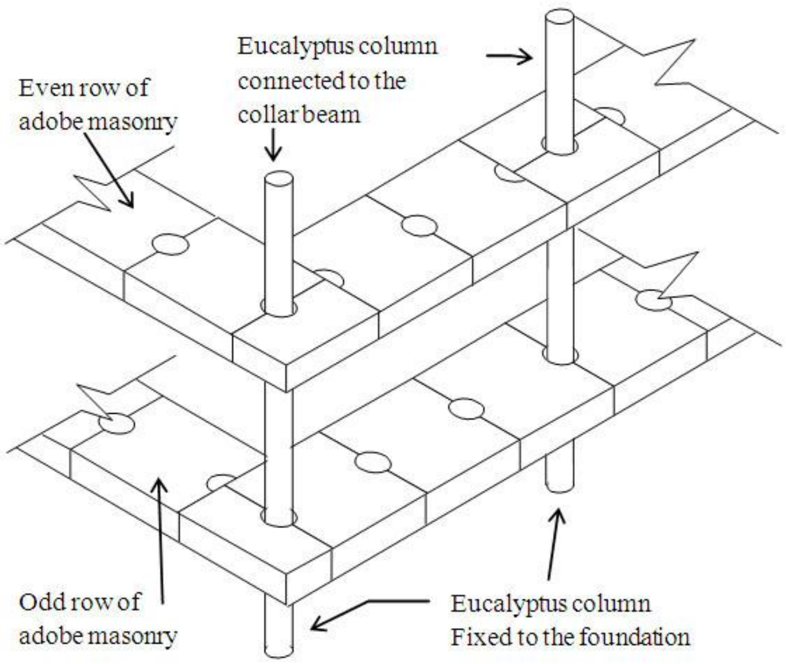

Figure 4. Detail of the adobe masonry and eucalyptus columns

These rod columns permit to fix the collar beam in the upper perimeter of the adobe walls. In this way the adobe masonry wall is confined and the collar beam on the top of the masonry wall permit an efficient connection with the quincha panels as is shown in Figure 5. These rods also contribute to take the tension stress produced by the lateral load during earthquakes. The inter-story floor is supported by the floor beams, which rest on the collar beam, transmitting the load to the walls of the first floor. Also these beams receive the load transmitted by the quincha panels. The quincha panels are fixed to the inter-story floor beams with nailed connections.

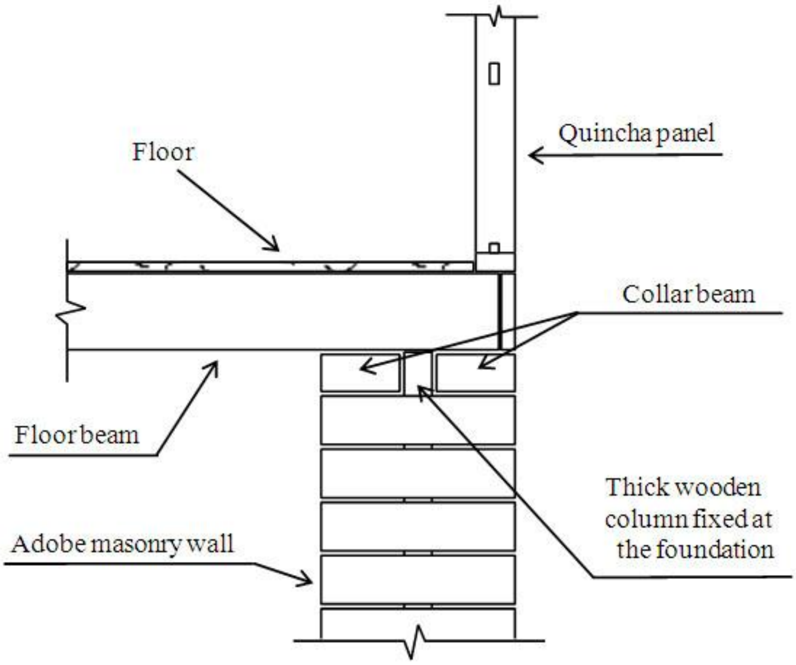

Figure 5. Detail of the adobe masonry and eucalyptus columns

3. VIBRATION CHARACTERISTICS

3.1 Pseudo dynamic test

A series of pseudo-dynamic tests were performed on prototype described in the previous section to verify the dynamic behavior of this system. The pseudo-dynamic test method uses on-line computers to monitor and control a test specimen closely resemble those that would occur if the test specimen were tested dynamically. Pseudo-dynamic tests combine analytical and experimental techniques. Experimental measurements are made of the restoring forces during the test. These measured forces are used by the computer, together with a set of mathematical equations which, ideally, describe the dynamic responses of the structure, to determine changes in the structural displacements that should be imposed on the specimen as a consequence of the given ground acceleration. The structural restoring forces are experimentally measured rather that computed from a mathematical model, and physical force actuators are used to cause the displacements of the test specimen to equal the computed structural displacements.

Two degree of freedom systems with lumped masses at floor level were adopted to model the specimens. The degrees of freedom were associated to the horizontal displacements at the center of each floor since perfect symmetry was assumed.
In order to obtain initial flexibility matrices of the specimens, a load was applied at one of the floor level while the other floor level was free. The fundamental period computed from these preliminary tests was 0.12 s.

Viscous damping was considered in the form of a matrix proportional to initial stiffness, with 2% of critical damping for the first mode and remained unchanged during the test.

The specimen was tested with a ground acceleration corresponding to the N08E component of the Lima earthquake of October 10, 1966, (IGP66-NE). A portion from 18.25 to 22.25 seconds, which contains the peak acceleration of 293.6 Gal, was selected for this test program. The record was scaled to have maximum ground acceleration of 100, 200, 400 and 600 Gal. The specimen was tested with these earthquake motions. The average duration of each test was 6 hours.

Time history responses for story displacements were obtained for the test sequence. Figure 6 shows the time history responses for displacements of the first and second floor when specimens were tested with the ground acceleration scaled to 400 Gal. Solid line plots the displacement of the first floor while dashed line plots the top displacement of the second floor.

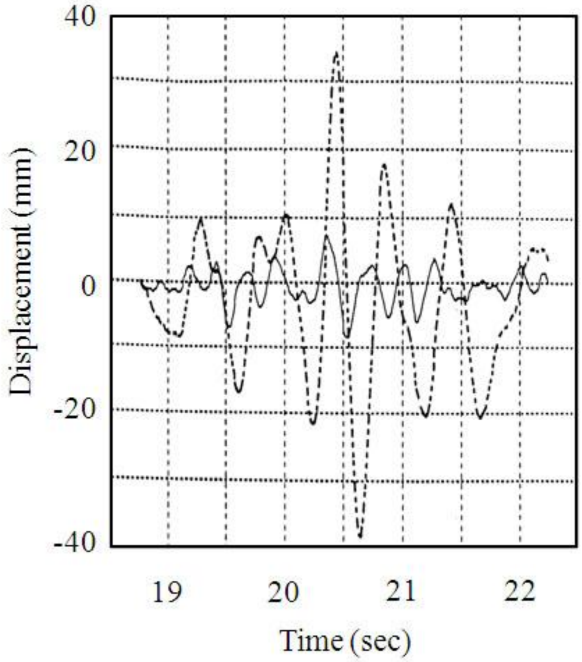

Figure 6. Time history displacement response (IGP-66, 400 Gal)

Figure 7 shows the load-displacement curves obtained for the input motion scaled to 400 Gal. It can be observed that the shape of the hysteretic loop shows large energy dissipation. These pattern were observed in all test performed with 100 Gal, 200 Gal, 400 Gal and 600 Gal respectively.
The failure of the specimen was by shear in the walls of the first floor. The adobe-quincha model resisted the 400 Gal earthquake and even the 600 Gal earthquake. However, very large displacement was observed in the second floor with considerable loss of stiffness. This excessive displacement produced during large earthquakes requires additional research to control and keep the lateral displacement of the second floor below a reasonable value.

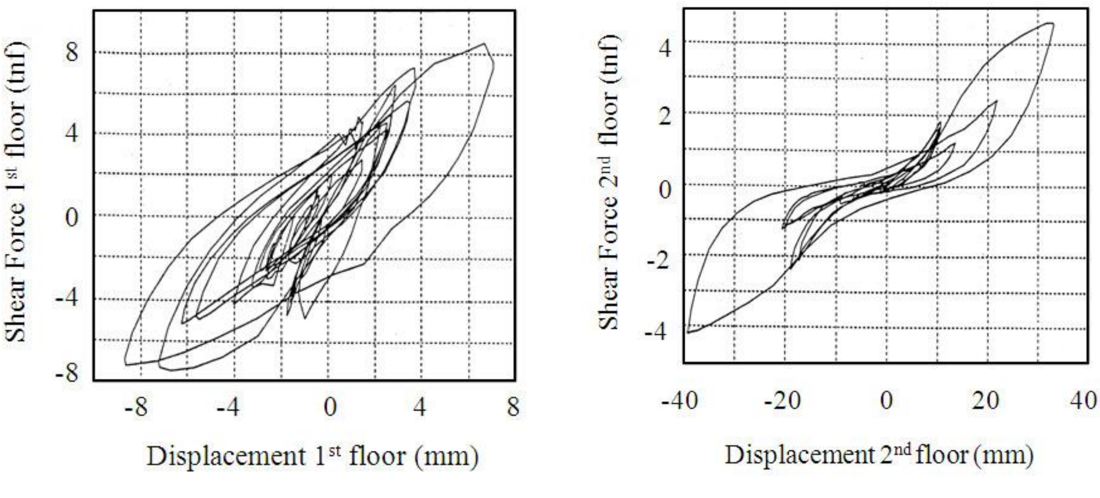

Figure 7. Load-displacement curves (IGP-66, 400 Gal)

The maximum values of shear forces and shear stress that were observed during the tests are presented in Table 1. It can be observed that even for 600 gal earthquake the maximum shear stress in the walls of the first floor was 0.3 kg/cm^2 that is slightly larger than the allowable design shear stress specified in the current Peruvian code on adobe constructions.

Table 1. Maximum shear forces and shear stress

Input Motion	Shear force (tonf)	Shear stress (kg/cm^2)
IGP-66-100 gal	6.13	0.21
IGP-66-200 gal	7.42	0.26
IGP-66-400 gal	8.47	0.29
IGP-66-600 gal	8.75	0.30

Maximum relative displacements that were observed in each run are presented in Table 2. It can been observed that the adobe-quincha model is very flexible, specially the second floor reaching a displacement of 50.56 mm when the model was subjected to the input motion of 600 Gal. of maximum acceleration. This displacement represents a drift angle of 1/50 approximately, which could be excessive for this type of constructions, although the specimen has not collapsed.

These results have permitted to analyze the general behavior of the typical traditional constructions of two-story in Peru, and show that the appropriate use of a lightweight material in the upper story could be an appropriate solution to get a better behavior of these buildings during earthquakes. However the excessive relative displacement of the upper floors could be a problem during earthquake occurrence.

Table 2. Maximum displacements observed during tests

Input Motion	1st floor (mm)	2nd floor (mm)
IGP-66-100 gal	2.32	9.40
IGP-66-200 gal	3.68	20.12
IGP-66-400 gal	8.70	39.17
IGP-66-600 gal	12.54	50.56

3.2 Ambient vibration measurements

As example a building that correspond to an old hotel is presented where ambient vibration measurements were performed to estimate its period of vibration. This building was described previously (See Figure 2). Walls of the upper stories (second and third floors) are made of quincha and the first story is made of adobe walls. The building presents some partial collapse of interior walls and serious deterioration of the quincha walls. Figure 8 shows the setup of measurement equipment.

Figure 8. Ambient vibration measurements on adobe-quincha building at historic centre of Lima

Results of ambient vibration show a predominant frequency of the order of 3.3 Hz. Figure 9 shows the 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 that is perpendicular to the façade the predominant frequency is 3.21 Hz. These frequencies represent reasonable values for a building of 12 m of height however more detailed measurement are necessary to detect the local vibration of portions of the building that could indicate the condition of deterioration.

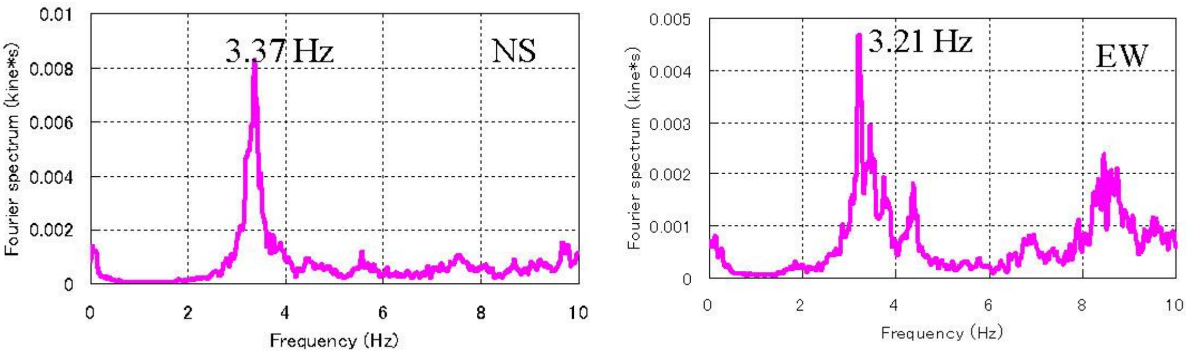

Figure 9. Predominant frequency of selected historical building of centre of Lima

4. CONCLUSIONS

Vibration characteristics of heritage architecture made of traditional adobe-quincha system that is located in Lima city were discussed. Since the heritage architecture is exposed to the action of earthquakes, the understanding of the dynamic properties of these constructions is very important as a first step for future recommendations in relation to conservation, repair and maintenance works. The adobe-quincha heritage architecture is mostly in a state of disrepair and therefore the seismic risk and other kind of risks are particularly acute.

The mixed adobe-quincha system could represents a suitable alternative for two-story traditional constructions in Peru since the lightweight second floor reduces the base shear force during earthquake motions having a better seismic behavior than heavy two-story adobe buildings. However the large displacement that can occur at the upper floor needs more research to be controlled appropriately.

Ambient vibration measurements at typical adobe-quincha construction have permitted to determine the predominant period of vibration of this building which falls in a reasonable value considering the building height. This value could be used to construct and calibrate analytical models for future analysis on seismic behavior of this kind of buildings.

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