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Mejoramiento estructural de la vivienda tradicional de adobe de Chiapa de Corzo, Chiapas

Structural improvement of the traditional housing of adobe from Chiapa de Corzo, Chiapas

Melhoria estrutural da tradicional casa de adobe em Chiapa de Corzo, Chiapas

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Resumen

En México existe una larga tradición constructiva precolombina y colonial, y en el caso del estado de Chiapas, la ciudad de Chiapa de Corzo, fundada durante el preclásico (2000 a. C.), destaca por su importante arquitectura colonial y tipología de viviendas tradicionales, consideradas patrimonio histórico y cultural de México y del mundo; sin embargo, debido a que Chiapas se localiza en una región de alta sismicidad, la riqueza cultural edificada de la ciudad es vulnerable. Por tal motivo, en este artículo se presentan los resultados obtenidos en trabajos de investigación desarrollados para reducir la vulnerabilidad sísmica en dos viviendas tradicionales de adobe. Para esto, se realizó el reforzamiento de muros a base de aplanados de mortero combinados con malla electrosoldada con el propósito de conservar el patrimonio construido y, lo más importante, ofrecer mayor seguridad a las familias que habitan las viviendas, especialmente las de bajos ingresos. Las mediciones realizadas *in situ* con acelerómetros, en condiciones previas y posteriores al refuerzo en una de las viviendas, muestran una disminución en el valor máximo del periodo fundamental de vibración, lo que indica que se incrementó su capacidad sismorresistente; también, con el método de elementos finitos se elaboró un modelo analítico tridimensional representativo para examinar el comportamiento de la vivienda ante los efectos de cargas sísmicas. Los resultados corroboran similitud con los análisis de campo e indican que los valores de los periodos de vibración se redujeron 13 %; además, el estudio muestra que los desplazamientos laterales disminuyeron cerca de 45 %.

Palabras clave: adobe, capacidad sismorresistente, patrimonio edificado, vivienda tradicional, vulnerabilidad.

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Abstract

In Mexico there is a long tradition of constructive pre-Columbian and colonial, and in the case of the State of Chiapas, the city of Chiapa de Corzo, founded during the pre-classic period (2000 b.c.), noted for its important colonial architecture and type of housing traditional considered historical and cultural heritage of Mexico and of the world; However, due to the fact that Chiapas is located in a region of high seismic activity, the built cultural wealth of the city is vulnerable. This article presents the results obtained in research carried out, looking for solutions to reduce the seismic vulnerability in two traditional houses of adobe, with the reinforcement of walls flattened of mortar-based combined with mesh welded, with the purpose of conserving built heritage, and most importantly, offer greater security to families living in dwellings, especially those of low income. Measurements made on-site with accelerometers, able to pre-and reinforcement in one of the houses, show the maximum value of the fundamental period of vibration reduction; Therefore, increased its earthquake-resistant capacity; also, with the finite element method, a representative three-dimensional analytical model, was developed to analyze the behavior of the housing against the effects of seismic loads. The results corroborate similarity with field tests and indicate that periods of vibration values dropped 13%; In addition, the study shows that lateral movements decrease around 45%.

Keywords: adobe, earthquake-resistant capacity, built heritage, traditional dwelling, vulnerability.

Resumo

Há uma longa tradição de construção pré-colombiana e colonial no México, e no caso do estado de Chiapas, a cidade de Chiapa de Corzo, fundada durante o pré-clássico (2000 aC.), Conhecida por sua arquitetura colonial e importante tipo de casas tradicionais , considerado patrimônio histórico e cultural do México e do mundo; no entanto, porque Chiapas está localizada em uma região de alta sismicidade, a riqueza cultural construída da cidade é vulnerável. Portanto, neste artigo os resultados do trabalho de pesquisa desenvolvido para reduzir a vulnerabilidade sísmica em duas casas tradicionais de adobe são apresentados. Para isso, o reforço das paredes com base achatada argamassa combinado com telas soldadas, a fim de preservar o património construído e, o mais importante foi realizada, proporcionando maior segurança para as famílias que vivem nas casas, especialmente aqueles com baixos rendimentos. O medições in situ com acelerómetros, no pré e pós-reforço das condições de alojamento, mostram uma diminuição do valor máximo do período fundamental de vibração, indicando que a sua capacidade sísmica aumentada; Além disso, com o método de elementos finitos de um modelo de análise tridimensional representativo foi desenvolvido para analisar o comportamento da caixa para os efeitos das cargas sísmicas. Os resultados corroboram a similaridade com as análises de campo e indicam que os valores dos períodos de vibração foram reduzidos em 13%; Além disso, o estudo mostra que os deslocamentos laterais diminuíram em cerca de 45%.

Palavras-chave: adobe, capacidade sísmica, patrimônio edificado, moradia tradicional, vulnerabilidade.

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Introduction

The buildings of the pre-Columbian period and the colonial period that remain today in the city of Chiapa de Corzo (state of Chiapas, Mexico) are a tangible sample of the historical past of important cultures that have developed in this place. In the year 2000, the National Institute of Anthropology and History cataloged the cultural wealth of a significant number of its buildings and officially declared them historical monuments; likewise, the historic center of the city was territorially delimited (Official Gazette [DO], 2000). This declaration included traditional dwellings, built predominantly in the ancestral style, that is, with stone foundations laid with lime-sand stucco, adobe walls made with earth and straw, covered with lime-sand plasters or plated with annealed bricks, and roofs built with wooden structure that support the roofs of mud tiles (Moya, 1988).

Likewise, and in the Inventory of Properties of the Minor Architecture in Chiapa de Corzo of 1991, there are records of adobe dwellings conceived as built heritage, which show the city with harmonious urban-architectural characteristics and with 67% of traditional dwellings; However, in 2001 it was recognized that only 27% of the houses existed, and it was determined that the main cause of the loss was due to telluric phenomena, such as the earthquake that occurred in October 1975 that caused damage and collapses in a large number of homes. estate. At that time, some houses had to be demolished and others rebuilt, without taking into account the formal characteristics or the original materials with which they were built (Ocampo, 2003).

Recently, the earthquake of September 7, 2017, which occurred on the coast of the state of Chiapas, of magnitude 8.2 on the Richter scale, caused severe damage in some old buildings of Chiapa de Corzo, classified as patrimonial; among them, the church of El Calvario (built in the seventeenth century) and the church of Santo Domingo (built in the sixteenth century). These temples registered landslides in the roofs, as well as cracks and damages in the walls, the domes and in the bell towers; likewise, damages were reported in traditional dwellings with adobe walls, which due to the characteristics of their materials and the limited structural confinement, were not exempt from damage and in some cases had partial and total collapses. In this sense, the geographic location of the city of Chiapa de Corzo in a region of high probability of seismic occurrence, recognized by the phenomenon of subduction of the Cocos tectonic plate under that of North America (National Center for Disaster Protection [Cenapred] , 2006, Federal Electricity Commission [CFE], 2008), which throughout history has generated earthquakes of considerable magnitude, warns that the built cultural wealth of the city, as a whole, is vulnerable to damage (Figure 1).

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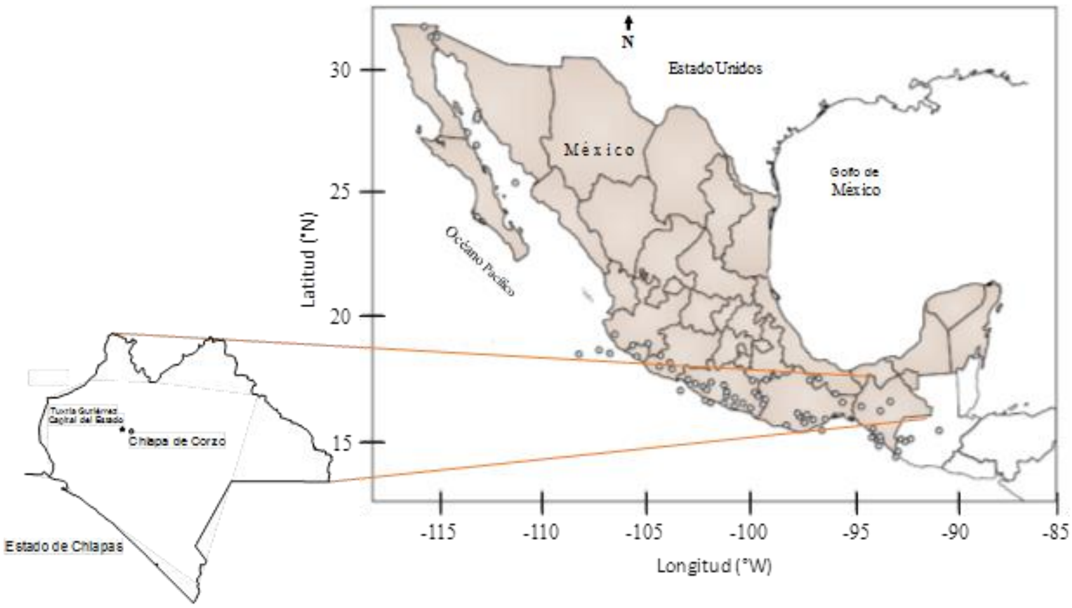
Figura 1. Sismos con magnitud superior a 7 en la escala de Richter ocurridos en el siglo XX en México



Fuente: Cenapred (2006)

Another cause of the disappearance of traditional housing is the abandonment in which they are, exposed to the action of rain and wind. This problem increases gradually due not only to the economic impossibility of the inhabitants to conserve them, but also to the indecision of the authorities, which have not created programs or maintenance actions (figure 2). Therefore, the most recent figures show the decline of traditional dwellings and the unceasing advance of the architectural transformation of the city (Ocampo, Escamirosa y Salgado, 2005).

Figura 2. Vivienda tradicional con muros de adobe en Chiapa de Corzo, Chiapas

Fuente: Fotografía de Carlos Del Carpio

As seen in figure 2, the adobe of the walls of traditional dwellings is made up of prismatic pieces formed in wooden molds and dried only in the sun, which makes them vulnerable to seismic action. Even so, this material has been used historically in homes that have passed from generation to generation without any type of professional supervision (Flores, Pacheco and Reyes, 2001).

However, in order to find solutions that allow structural rehabilitation, the conservation of housing heritage and the safety of the inhabitants of these dwellings, in 2014 a research project called Structural Reinforcement Proposal for the consolidation of the traditional housing of the historic center of Chiapa de Corzo, Chiapas, which has been developed by the Urban Development Academic Body of the Autonomous University of Chiapas (CADU-UNACH), and funded by the Ministry of Public Education (SEP) through the Teacher Improvement Program (Promep)) (Escamirosa, Ocampo, Villers, Zebadúa and Mérida, 2015).

This project has given the work team the opportunity to build a proposal for the reinforcement of adobe walls that considered the typological characteristics of the dwelling, the uses and customs of the inhabitants and the conservation as much as possible of the original materials, among other aspects. , to analyze the behavior of traditional housing in the face of possible seismic effects of a certain magnitude, where researchers from the Academic Body Natural Hazards and Geotechnology of the Autonomous University of Guerrero have also participated. (CARNG-UAGRO).

The team of researchers made the first interventions to structurally reinforce two adobe dwellings inhabited by low-income families. The rehabilitated houses were presented to the National Institute of Anthropology and History and to the municipal government of Chiapa de Corzo as an appropriate alternative to contribute to the preservation of the built heritage of the city, since it increases the levels of safety against earthquakes and, consequently, It offers security, confidence and tranquility to its inhabitants (Escamirosa, Ocampo and Arroyo, 2014).

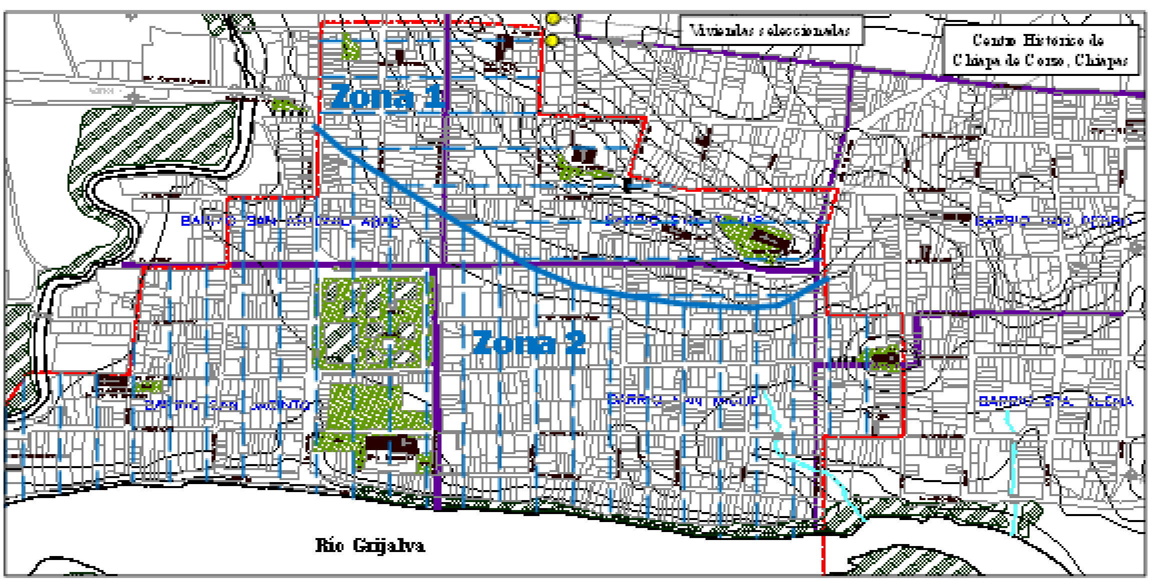
In this described context, the objective of this research was to evaluate the seismic capacity of adobe houses that were reinforced structurally through reinforced concrete membranes with wire mesh and fixed on both sides of the adobe walls. To measure this capacity, measurements were made in situ with accelerographs, in pre and post-reinforcement conditions, in one of the dwellings. The results obtained show the decrease of the maximum value of the fundamental period of vibration, so it can be affirmed that the seismic capacity of the walls has increased. Likewise, with the finite element method, a representative three-dimensional analytical model was developed to analyze housing behavior in the face of possible seismic scenarios. The study was based on field measurements and analysis of Fourier spectra in each record, which allowed to obtain the spectral ratio with the technique of Nakamura (1989) and determine the fundamental periods of vibration of the houses.

Background of the investigation. Seismic zoning of Chiapa de Corzo, Chiapas

In 2003, a team of specialists from educational and research institutions from Guerrero, Oaxaca and Chiapas was organized to identify the most vulnerable areas in the face of seismic action and to create proposals for seismic zoning and site spectra in three historic centers in southeastern Mexico: Taxco de Alarcón (Guerrero), Oaxaca de Juárez (Oaxaca) and Chiapa de Corzo (Chiapas) (Salgado, Escamirosa and Calvo, 2005).

The seismic zoning of each historical center was made according to the fundamental periods of vibration of the soil type, established based on measurements made in situ with accelerograph. In the study, environmental vibration analyzes were made and the available information was considered, such as the morphology, soil science, geology and hydrology of each city; In addition, measurements were taken in several adobe houses in each city. The processing of the records obtained to estimate the dynamic characteristics of the soil was carried out by means of spectral quotients with the Nakamura technique. (1989) (Salgado, Escamirosa, Domínguez y Arroyo, 2004).

Figura 3. Mapa de zonificación sísmica del centro histórico de Chiapa de Corzo, Chiapas



Fuente: Salgado *et al*. (2004)

Figure 3 shows the seismic zoning of the historic center of Chiapa de Corzo, Chiapas. According to the results obtained, the fundamental period of soil vibration in zone 1 (low hills) records values in a range from 0.10 to 0.25 seconds, while in zone 2 (substantially flat) the period is in the range from 0.25 to 0.50 seconds (Salgado et al., 2004).

Diagnosis of traditional adobe houses

In 2013, the inter-institutional team of researchers, integrated into the academic bodies CADU-UNACH and RGN-UAGRO, with the participation of students from both institutions, initiated the development of the research project Proposal of structural reinforcement for the consolidation of housing Traditional of the historic center of Chiapa de Corzo, Chiapas, which was funded by the SEP through Promep (Escamirosa et al., 2013). Through this, the diagnosis of the traditional houses of Chiapa de Corzo was elaborated, according to the typology offered by Ocampo (2003), which served to determine the risks of structural insecurity, overcrowding and unhealthiness that affect the health of low-income families. economic conditions that these structures inhabit. From the above, two houses (V1 and V2) located in zone 1 of the seismic zoning were selected (figure 3), whose adobe walls showed fissures and cracks in the intersections and in the openings of the doors.

Housing V1, according to its owner, Evangelina Montero Aguilar, is over 80 years old and is located on Miguel Hidalgo Avenue, corner of Tomás Cuesta Street. It was built on the basis of cyclopean-type masonry foundation, made with ball stone and sand-lime mortar, walls of adobe 40 cm thick and roof structure with round beams and wooden slats to support the roof of mud tile. In general, the house had several fissures at the intersection of the walls and at the foot of the doors, in addition to the absence of mud tiles on the roof of the main entrance (figure 4).

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Figura 4. Vivienda tradicional V1 de Chiapa de Corzo, Chiapas

Fuente: Elaboración propia

Housing V2 is located on Tomas Cuesta street, No. 80, between Alvaro Obregon and Miguel Hidalgo avenues, in the San Vicente neighborhood. According to its owner, Reyneria Moreno Cuesta, it was built by his father more than 70 years ago. It has constructive characteristics similar to the previous one, except for the thickness of the walls, which vary from 38 cm in the main facade to 30 cm in the rear facade. In addition, it is not covered with mortar, since it only has a thin layer of lime on the main facade that has served to protect the adobe from the outside environment. There are also fissures and severe structural problems in a head wall that is slightly collapsed; also, the wooden structure of the roof is in very bad condition (figure 5) (Escamirosa *et al.*, 2013).

Figura 5. Vivienda tradicional V2 de Chiapa de Corzo, Chiapas

Fuente: Elaboración propia

In October 2013, the evaluation of the earthquake-resistant capacity of housing V1 was started based on measurements of accelerograph performed in situ. The accelerograph records were stored in 3 orthogonal directions of 30 seconds each; later, with the analysis of the Fourier spectra in each record, the transfer function or spectral ratio was established, using the technique of Nakamura (1989). The data collected show that the fundamental periods of vibration in the face of possible seismic scenarios on average were high: 0.213 seconds in the ground and 0.151 seconds in the house, for which it was determined that the structure presents high seismic vulnerability, hence it represents a risk for its inhabitants. As additional data, the record of the period of vibration of the soil corresponds to zone 1 of the seismic zoning, since the value obtained is in the range of 0.10 to 0.25 seconds.

Proposal for structural reinforcement

From similar cases analyzed by Arroyo, Guinto, Sánchez and Corona (2010) in the state of Guerrero, a proposal for structural reinforcement was made with reinforced concrete membranes with electro-welded wire mesh on both sides of the walls. The proposal considered the conservation of functional spaces, the uses and customs of the inhabitants and the typology and urban image, among other aspects. The structural reinforcement of the two houses of adobe was carried out during the months of June to August 2014, and at the end of

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the works was presented to the delegation in Chiapas of the National Institute of Anthropology and History and to the municipal government of Chiapa de Corzo as an appropriate alternative to contribute to the conservation of the built heritage of the city, since it increases the levels of security before earthquakes, and, most importantly, it offers confidence and tranquility to its inhabitants (Escamirosa et al., 2014).

The previous works to the structural reinforcement consisted in extracting the doors and the mortar of both sides of the walls in the house V1 (figure 6); in the case of housing V2, the lime layer was removed. These tasks were carried out carefully to avoid major damage to the adobe.

Figura 6. Retiro de recubrimiento en la vivienda V1

Fuente: Elaboración propia

Next, the walls of house V1 were covered with a layer of cement-sand mortar, ratio 1 to 3 (average compressive strength of 227 kg / cm2), hand-launched, leveled and with a minimum thickness of 1 cm . Subsequently, the steel mesh (6x6 / 10x10, 6 "x6" grid with 10-gauge steel wires in both directions) was placed, with 60cm overlaps in the sections that were fastened to the walls from the following procedure based on the Complementary Technical Standards (NTC) (2004): a 30 cm grid was drawn on the walls, and at each intersection point drilling was done with a 5/16 "diameter drill bit; Through the hole, a wire was passed to hold

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the steel mesh on both sides of the wall. Then, a second layer of mortar was applied, just like the previous one, and a thin layer of cement-calhydrate, ratio 1:10, was placed to obtain the final finish on the walls, similar to the original caulking of the adobe houses. (figure 7). The works concluded with the application of the painting (figure 8) (Escamirosa *et al*., 2014).

Figura 7. Aplicación de las capas de mortero

Fuente: Elaboración propia

Figura 8. Vivienda tradicional V1 rehabilitada

Fuente: Elaboración propia

In house V2, unlike the previous one, the steel mesh was placed directly on the walls, without a previous layer of mortar (figure 9). Once the mesh was secured, the first layer of cement-sand mortar was applied with a minimum thickness of 1 cm, and after sufficient time of mortar setting (2 hours), the second layer was placed (figure 10).

Figura 9. Fijación del refuerzo en vivienda V2

Fuente: Elaboración propia

Figura 10. Aplicación de la capa de mortero

Fuente: Elaboración propia

Figura 11. Vivienda tradicional V2 rehabilitada

Fuente: Elaboración propia

In both houses were replaced the pieces of wood and damaged tiles of the roof; also, 30x30 cm ceramic tile was placed on the floors and, finally, the doors were installed and paint was applied on all the elements trying to preserve the typology of the traditional houses of Chiapa de Corzo (figures 8 and 11) (Escamirosa *et al*., 2014).

Method

The present investigation consisted of evaluating the seismic capacity of traditional dwellings with structurally reinforced adobe walls. The works carried out were placed in the study of environmental vibration to determine the fundamental vibration periods of the structure and to define the level of security of the houses after the structural reinforcement. In the measurements made in situ, an accelerographic sensor Physics Toolbox Accelerometer with Android system was used. The accelerographic records were in three orthogonal directions and lasted approximately 120 seconds each. Next, the Fourier spectra were determined for each record and in the evaluation of the periods the transfer function or spectral ratio was established with the technique of Nakamura (1989).

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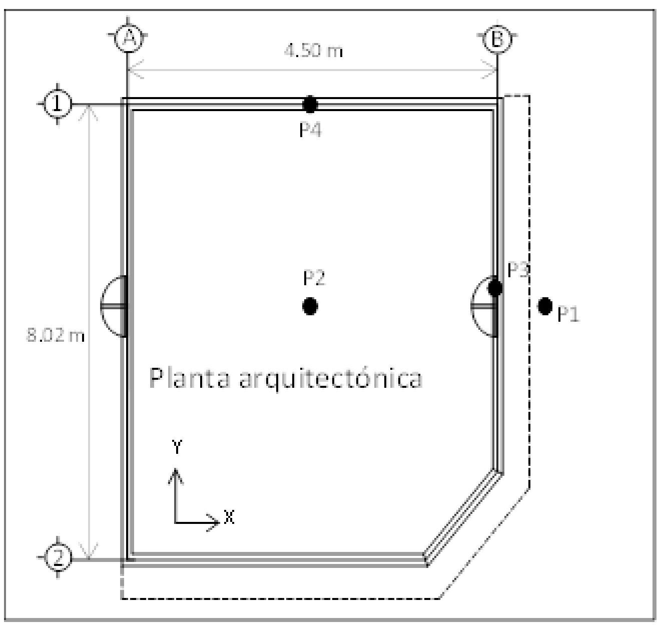
Presentation of the results

Case study: adobe housing V1

On October 2, 2014, measurements were taken with an accelerograph in each home. Housing V1, owned by Mrs. Evangelina Montero Aguilar, is located at the geographic coordinates of 16 ° 42 '37.99 "N and 93 ° 0' 44.63" W, on Miguel Hidalgo street, corner with Tomás Cuesta. Prior to the on-site measurement work, based on the architectural floor plan of the home, important points were established to obtain the records; P3 and P4 were located in the adobe walls defined by axes B and 1, respectively; P2 represents the geometric center and P1 corresponds to the floor of the housing site (figure 12).

Figura 12. Ubicación de los puntos de medición en V1



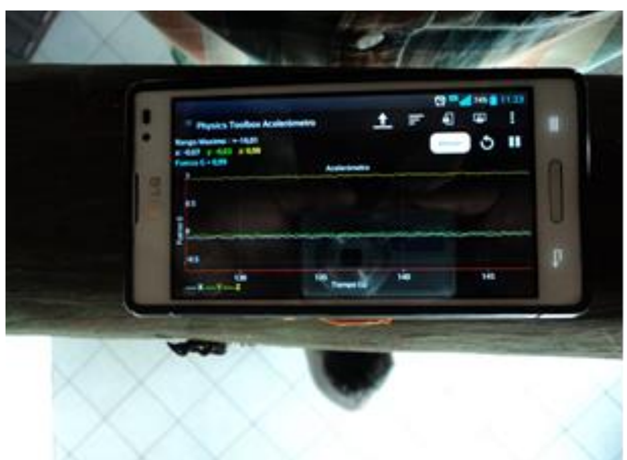
Fuente: Elaboración propia

Figure 13 shows the moment of measurement at point P2, while figure 14 shows the placement of the accelerograph on the point established on the wooden beam, which corresponds to the geometric center of the house.

Figura 13. Medición en punto P2

Fuente: Elaboración propia

Figura 14. Acelerógrafo con sistema Android



Fuente: Elaboración propia

Next, Figure 15 shows the transfer function in the house V1; the continuous function corresponds to the short-side direction X of the dwelling, and the dotted function to the function of the long-side direction Y. The functions were obtained by dividing the Fourier spectra calculated in each accelerometric record of the measurement points P2, P3 or P4 between the soil record P1. The quotient of said registers makes it possible to calculate the

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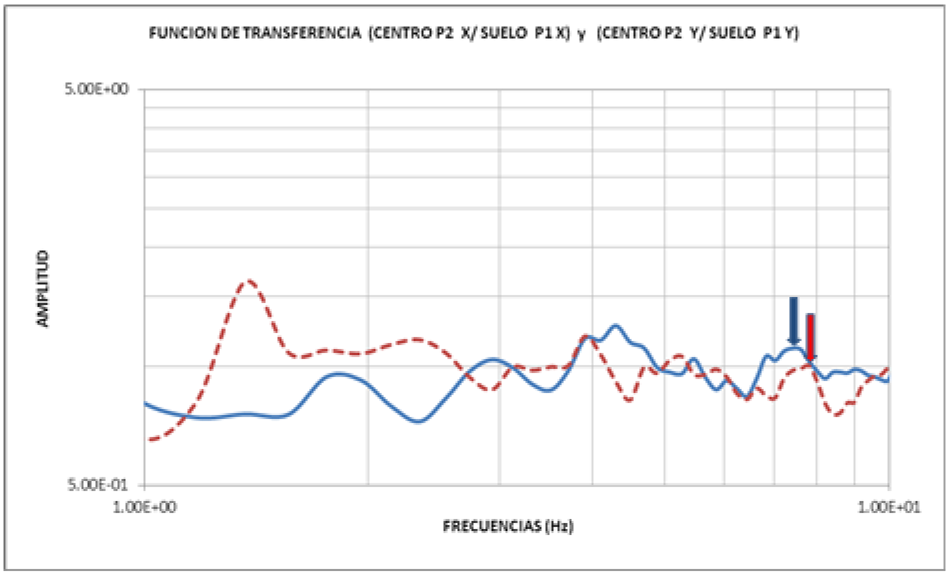
amplification of the response in P2, P3 or P4 with respect to that obtained in the soil (P1). Figure 15 shows the frequencies of greater amplification of spectral response recorded in the geometric center. Subsequently, the transfer function or spectral ratio was determined using the technique of Nakamura (1989). The average maximum value of the fundamental period was 0.135 seconds in the X direction, and 0.128 seconds in the Y direction (see table 1).

Figura 15. Función de transferencia de la vivienda V1 (línea continua-X, discontinua-Y)



Fuente: Elaboración propia

Case study: adobe housing V2

Housing V2, owned by Reyneria Moreno Cuesta, has the following geographic coordinates: 16 ° 71 '10.65 "N and 93 ° 0' 12.12" W, and it is located on Tomás Cuesta street no. 80. The measuring points, similarly, they were established in accordance with the architectural floor plan of the dwelling (figure 15); P3 and P4 were located in the adobe walls defined by axes 1 and 2, respectively; P5 on the B axis; P2 corresponds to the geometric center and P1 represents the ground (figure 16).

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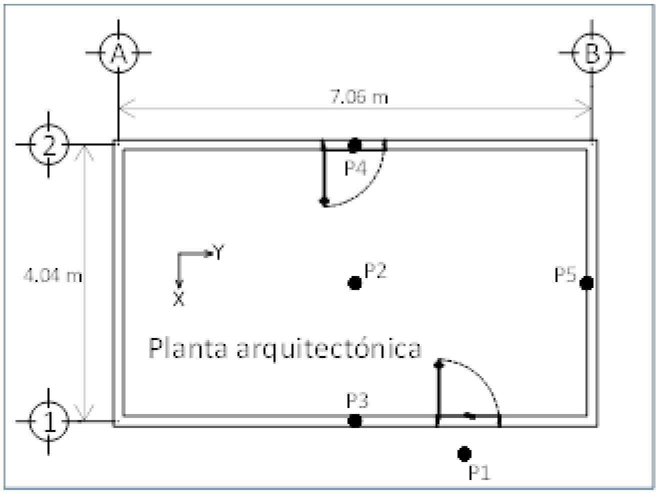
Figura 16. Ubicación de los puntos de medición en V2



Fuente: Elaboración propia

Figures 17 and 18 show the measurements made at points P5 and P3, respectively. The frequencies of greater amplification of spectral response were located in the direction parallel to the long side. The transfer function in the housing V2 is represented in figure 19; in this case, the functions were determined by dividing the Fourier spectra calculated from the accelerometric records obtained at point P4 between the record of P1 (the ground).

Figura 17. Medición en punto P5

Fuente: Elaboración propia

Figura 18. Medición en punto P3

Fuente: Elaboración propia

Figure 19 shows the frequencies of greater amplification of the spectral response of the housing V2, located in the direction parallel to the long side. The maximum average fundamental periods were 0.125 seconds in the Y direction, and 0.1191 seconds in the X direction (see table 1).

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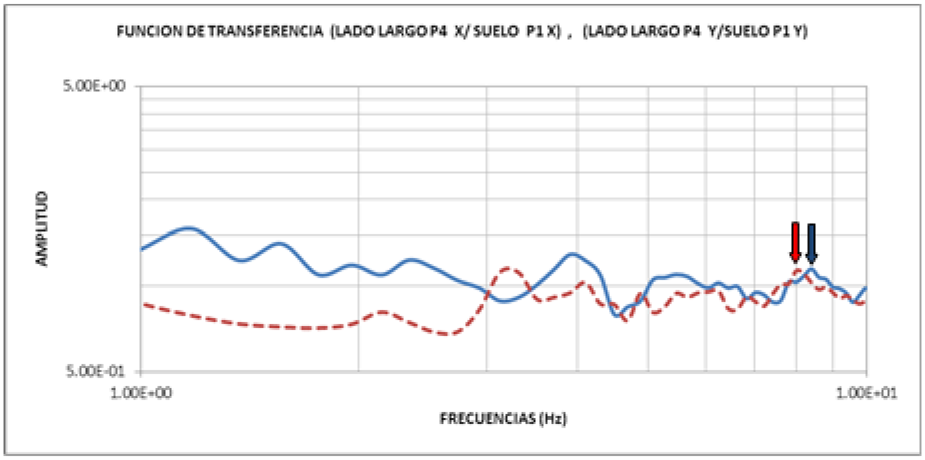
Figura 19. Función de transferencia de la vivienda V2 (línea continua-X, discontinua-Y)



Fuente: Elaboración propia

Discussion of results

The results obtained show that housing V1 presented the most critical fundamental vibration periods at point P2, corresponding to the geometric center. The maximum values were as follows: 0.135 seconds in the X direction, and 0.1280 seconds in the Y direction.

These results, established after the structural rehabilitation, show a significant reduction with respect to the maximum values obtained before the reinforcement performed; that is, the maximum values went from 0.151 to 0.135 seconds in the X direction, and from 0.142 to 0.128 seconds in the Y direction; likewise, the average fundamental periods calculated on the long side were reduced from 0.151 to 0.114 seconds in the X direction, and from 0.142 to 0.116 seconds in the Y direction; On the short side, the values went from 0.1506 to 0.1089 seconds in the X direction, and from 0.142 to 0.109 seconds in the X direction (see table 1).

In the case of housing V2, the critical vibration periods were located in the direction parallel to the long side, with maximum values of 0.125 seconds in the Y direction, and 0.119 seconds in the X direction (see table 1). It is important to mention that in this house the fundamental period of vibration was not determined before the structural rehabilitation; nevertheless, in the visual inspections carried out, it was observed that the adobe walls had a high deterioration condition.

Tabla 1. Resultados de la evolución de los periodos fundamentales de vibración de las viviendas

	Vivienda 1											
	Dañada						Reforzada					
	Dirección											
	Centro Geométrico		Lado largo		Lado corto		Centro geométrico		Lado largo		Lado corto	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Amplitud (cm)	29.66	7.90	24.4	3.27	5.54	17.5	1.11	1.00	1.01	1.04	1.09	1.18
Frecuencia (Hz)	6.641	7.031	6.641	7.031	6.641	7.031	7.422	7.813	8.790	8.594	9.180	9.180
Periodo (segundos)	0.151	0.142	0.151	0.142	0.151	0.142	0.135	0.128	0.114	0.116	0.110	0.109
	Vivienda 2											
	Dañada						Reforzada					
	Dirección											
	Centro Geométrico		Lado largo		Lado corto		Centro geométrico		Lado largo		Lado corto	
							X	Y	X	Y	X	Y
Amplitud (cm)	N. d.	N. d.	N. d.	N. d.	N. d.	N. d.	1.21	1.15	1.15	1.13	1.21	1.31
Frecuencia (Hz)	N. d.	N. d.	N. d.	N. d.	N. d.	N. d.	9.375	8.790	8.400	8.007	8.594	8.008
Período (segundos)	N. d.	N. d.	N. d.	N. d.	N. d.	N. d.	0.107	0.114	0.119	0.125	0.116	0.125

N. d. = No disponible

Fuente: Elaboración propia

On the other hand, it is important to note that the maximum fundamental vibration periods obtained in both dwellings, from the measurements made after the structural reinforcement (0.135 seconds in the V1 dwelling, and 0.125 second in the V2 dwelling), are close to the recommended values for homes considered structurally healthy, established in the scale of 0.08 to 0.12 seconds by Hernández, Meli and Padilla (1979), as well as in similar studies (Arroyo et al., 2010) carried out in housing in the state of Guerrero.

Figures 20 and 21 correspond to the images obtained from houses V1 and V2 one day after the earthquake occurred on September 7, 2017 in the state of Chiapas, which had a magnitude of 8.2 on the Richter scale. In the visual inspections carried out in both houses on September 8, 2017, it was observed that the reinforced adobe walls with flattened and electrowelded mesh did not show any damage, which shows that the behavior after the seismic loads occurred was satisfactory.

Figura 20. Imagen de la vivienda V1obtenida el 8 de septiembre de 2017 a las 18:20 horas

Fuente: Elaboración propia

Figura 21. Imagen de la vivienda V2 obtenida el 8 de septiembre de 2017 a las 18:25 horas

Fuente: Elaboración propia

Dynamic analysis of adobe housing. Numerical modeling

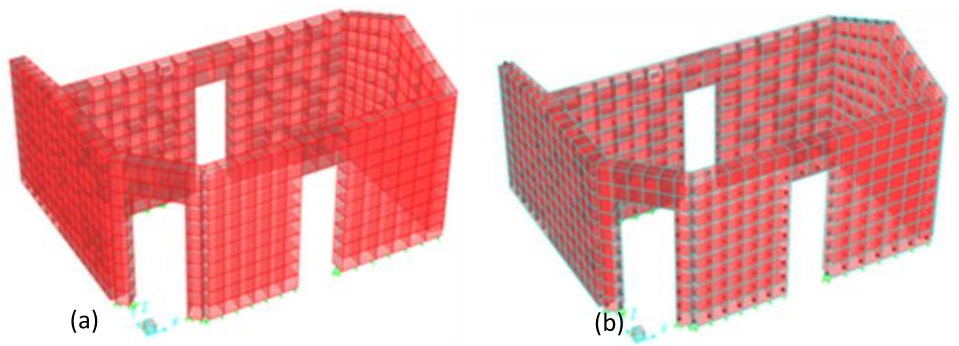
In order to study the dynamic behavior of the adobe house, the V1 housing was selected as the base model due to the relevance of its geometric and dynamic characteristics, since it presented a less efficient physical structural behavior than the V2 housing due to its configuration in " corner". Then, we proceeded to develop a three-dimensional analytical model representative of housing V1 with the finite element method to represent the conditions prior to and after the application of the reinforcement based on mortar flattened combined with electrowelded mesh.

The analytical model was developed in the non-linear SAP2000 program, professional version 17. To this end, thick-walled quadrangular elements with the capacity to support membrane and bending stresses and straight frame-type bars were used. The representation of the traditional adobe walls without reinforcement was made with thick-shell-like quadrangular elements 30 cm thick and with an average surface area of 1000 cm2 each.

In the case of housing V1 with reinforcement based on flattened with electrowelded mesh, were added, in addition to the previous elements, two layers of quadrangular elements that were attached to the element of adobe: one internal and one external. The two layers were modeled on thin shell-type elements, each 2 cm thick, and their nodes were fixed directly to the nodes of the adobe shells to simulate the presence and strength contributed to the wall by the flattened mortar. Similarly, the electrowelded mesh was modeled and a sandwich-like configuration was obtained. In total, this model required 522 quadrangular adobe elements, 1044 quadrangular mortar elements and 3096 frame-type bars to model the electrowelded mesh. In both cases, the base of the dwelling was considered supported, so that the walls did not have the capacity of rotation at its lower end. It is important to emphasize that to simplify the model we tried to model the approximate global behavior of the house, and not in detail, so the walls were not shaped by individual pieces joined with floor mortar, but by complete and continuous adobe panels.

The rigidity and the mass of the roof system were modeled with the application, respectively, on the upper edge of the walls, of diaphragm-like constrictions and concentrated loads equivalent to the weight generated by wooden bridges and wooden beams, as well as clay tiles. The models without reinforcement (a) and the reinforced with flattened mortar and welded mesh (b) are shown in figure 22. The characteristics of the materials used are shown in table 2.

Figura 22. Modelo original (a) y modelo reforzado con mortero y mallas electrosoldadas (b)



Fuente: Elaboración propia

Tabla 2. Características de los materiales empleados

Material	Módulo de elasticidad E (MPa)	Resistencia a la compresión axial (MPa)	Resistencia a la tensión axial (MPa)	Módulo de Poisson
Adobe	150	1.2	-	0.16
Aplanados de mortero cemento-arena (espesor 2 cm)	20,000	10	-	0.18
Barras de refuerzo electrosoldadas	210,000	540	540	0.21

Nota: Megapascal (MPa) = 10.2 kg/cm^2

Fuente: Elaboración propia

To perform the modal dynamic spectral type analysis, the parameters detailed in Table 3 were used.

Tabla 3. Datos empleados en el análisis modal espectral

Tipo de suelo	II (medianamente blando)
Factor de comportamiento sísmico, Q	1
Coeficiente sísmico empleado, C_s	0.8

Fuente: Elaboración propia

Results

The analysis allowed to define the following results: the house without reinforcement presented a fundamental period of vibration of 0.16 seconds in the X direction, which agrees with the period measured in situ (0.151 seconds); while in the reinforced housing with flattened and reinforcement mesh a fundamental period of 0.14 seconds was obtained in the X direction, which also agrees with the period measured in situ (0.135 seconds). This allows to corroborate that the flattened reinforced with mesh stiffened the behavior before seismic loads up to 13%; in addition, in the case of lateral displacements due to earthquake, these can be reduced by applying this reinforcement technique up to 8 mm, which means approximately 45%.

Tabla 4. Comparación de resultados: vivienda sin refuerzo y reforzada con aplanados y malla

Vivienda de adobe V1	Periodo fundamental de vibración (segundos)	Desplazamiento lateral (mm)	Esfuerzos cortantes en el adobe (MPa)
Sin refuerzo	0.16	18.0	0.35
Reforzada con aplanados y malla	0.14	10.0	0.62

Fuente: Elaboración propia

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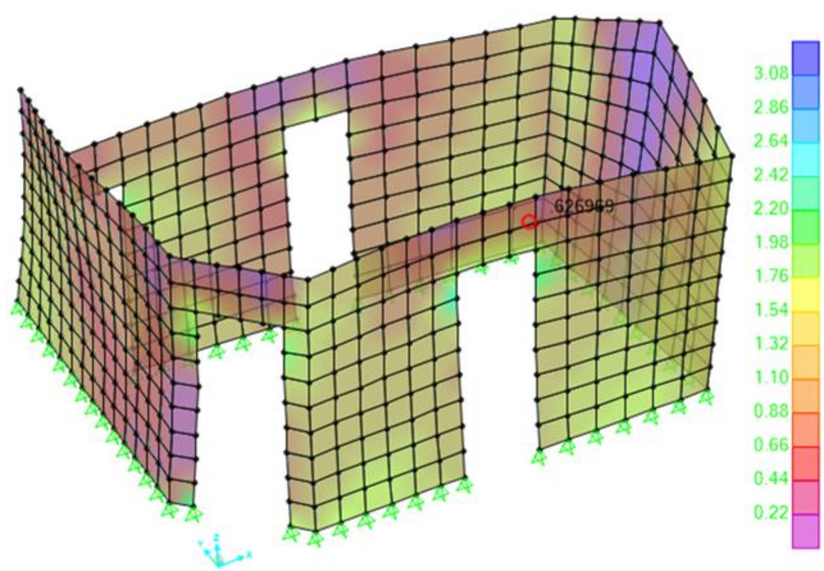
In the case of diagonal tension stresses, the results indicated in table 4 and figure 23 confirm that even when the reinforcement provided by the mesh flattens produces an increase in the shear stresses in the adobe, mainly in the corners of openings of doors, this is not counterproductive, since the efforts are absorbed by the mesh, which limits the damage in the flat and, mostly, in the adobe. In this way, the model allowed establishing that the mesh has an important role of protective structural jackets that not only provides rigidity to the system, but above all ductility.

Figura 23. Distribución de esfuerzos cortantes (combinación gravitacional + 100 % sismo transversal + 30 % sismo longitudinal)



Fuente: Elaboración propia

Conclusions

The reinforcement applied to the adobe walls of housing V1, made with mortar flattened combined with electro-welded mesh, significantly reduced the maximum value of the fundamental period of vibration; this allowed the housing to acquire greater rigidity and the adobe walls to be strengthened and its flexibility diminished.

On the other hand, the results obtained with the application of the three-dimensional analytical model representative of housing V1 -developed with the finite element method to analyze the behavior before seismic loads in conditions prior to and after the reinforcement of the adobe walls- indicate that the values of the fundamental periods of vibration of the house were reduced approximately 13%; also, the study shows that lateral displacements caused by seismic effects can be reduced up to 45%.

This shows that the adobe walls of traditional dwellings structurally intervened with mortar, cement-sand and reinforced with electro-welded mesh stiffened their behavior in the face of the effects of seismic movements of a certain magnitude as occurred in the state of Chiapas. September 2017. Undoubtedly, the presented proposal offers benefits, among them, the increase in the security of the low-income families that live in the houses and the conservation of the built heritage of the city of Chiapa de Corzo, Chiapas.

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