World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

an initiative of
Earthquake Engineering Research Institue (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Adobe House

Report#	179
Last Updated	
Country	Chile
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Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John A, Martin & Associates, Inc. or the participant's organizations.

General Information

Building Type:	Adobe House
Country:	Chile
Author(s):	Claudia Alvarez Velasquez Matias Hube Ginestar Felipe Rivera Jofre Hernan Santa Maria Oyandenel David Hernandez Jara
Last Updated:	
Regions Where Found:	Adobe houses are mainly found in rural areas of the central regions of Chile. These represent 3% of the total number of houses in the country.
	Adobe houses are mainly found in rural areas of the central regions of Chile. These represent 3% of the total number of houses in the country and they are characterized for having a large mass and very small strength, particularly against out-of-plane forces. Adobe houses are used as single or multiple family dwellings and are one or two stories high with no basement floors. This type of construction exhibited very bad performance during past strong

Summary:	earthquakes (i.e. Valparaiso 1985, Maule 2010, Iquique 2014), causing a decrease in the number of adobe constructions through time. This type of construction is not included in the seismic building code of the country since it is considered to be highly vulnerable to seismic forces. However, it is allowed to build adobe structures following the requirements of the General Planning and Building Ordinance (MINVU, 2014a), and following a foreign seismic code for adobe. After the 2010 Maule earthquake, two standards were created with the requirements for intervention, renewal, retrofit or structural consolidation of adobe structures with heritage value. These standards are NCh 3332 (INN, 2013) and NTM 002 (MINVU, 2013).
Length of time practiced:	More than 200 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, unknown typeSingle dwelling
Typical number of stories:	1-2
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	Adobe houses can be found all over the country and are mainly found in rural areas of the central regions of Chile, representing

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	Adobe houses commonly have rectangular plan shapes despite there are no plan shape regulations in the codes. The rooms are divided symmetrically on both sides of the main axis, with a limited number of small openings for windows.Article 4.1.1 of the General Planning and Building Ordinance (MINVU, 2014a) establishes a minimum interior free height of 2.3 m for housing dwellings, except under beams, horizontal installations, and small areas under sloping roofs. Article 4.1.2 indicates that there should be at least one window in each room (bedrooms, living room and bathrooms) of the dwelling. In bedrooms, windows must have a minimum free horizontal distance of 1.5 m. For thermal requirements, and according to Article 4.1.10, maximum window area is limited based on the type of glass and the thermal zone where the structure is built.
Typical plan length (meters)	11m
Typical plan width (meters)	11m
Typical story height (meters)	2.2m
Type of Structural System	Masonry: Earthen/Mud/Adobe/Rammed Earth Walls: Adobe block walls
Additional comments on structural system	
Gravity load-bearing & lateral load-resisting systems	The vertical load-resisting system is earthen walls. Gravity loads from the roof construction itself (dead loads), live loads, wind or snow loads are transferred directly from the roof construction to the walls and then to the foundations. The lateral load-resisting system is earthen walls. The lateral stiffness is provided by the massive adobe shear walls. Generally, wall thickness is between 30 and 40 cm (Solar Hermosilla, 1975). Common dimensions of adobe bricks in Chile are 58 × 30 × 8 cm and 78 × 40 × 8.
Typical wall densities in direction 1	15-20%
Typical wall densities in direction 2	15-20%

Additional comments on typical wall densities	Adobe houses have a typical story height of 2.2 m, and a wall density of 20%.
Wall Openings	Adobe houses commonly have rectangular plan shapes despite there are no plan shape regulations in the codes. The rooms are divided symmetrically on both sides of the main axis, with a limited number of small openings for windows.Article 4.1.1 of the General Planning and Building Ordinance (MINVU, 2014a) establishes a minimum interior free height of 2.3 m for housing dwellings, except under beams, horizontal installations, and small areas under sloping roofs. Article 4.1.2 indicates that there should be at least one window in each room (bedrooms, living room and bathrooms) of the dwelling. In bedrooms, windows must have a minimum free horizontal distance of 1.5 m. For thermal requirements, and according to Article 4.1.10, maximum window area is limited based on the type of glass and the thermal zone where the structure is built.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Typically, no modifications are made to these houses.
Type of Foundation	Shallow Foundation: No foundationOther Foundation
Additional comments on foundation	Concrete strip footing are also used but with no reinforcement as it is shown in Figure 9.Foundation requirements such as dimensions, allowable soil contact stress, minimum area of reinforcement in spread foundations, which depends on the number of stories, and minimum buried depth of foundations, are specified in Title 5 Chapter 7 of the General Planning and Building Ordinance (MINVU, 2014a).
Type of Floor System	Other floor system
Additional comments on floor system	
Type of Roof System	Wooden structure with light roof covering
Additional comments on roof system	Roof consists of wooden beams or truss forming a pitched roof with gable ends. This wooden structure are required to be embedded in the earth wall and securely anchored (see Section 6.3 and Figure 14).
Additional comments section 2	

Figure 1.b Typical adobe houses in the city of Curepto, central Chile

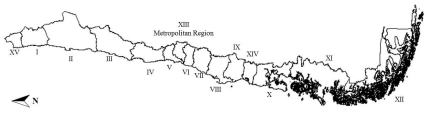

Figure 2. Map of Chile and location of the regions

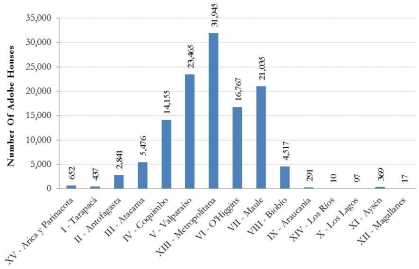

Figure 3. Regional distribution of total existing adobe houses in 2012 (INE, 2012)

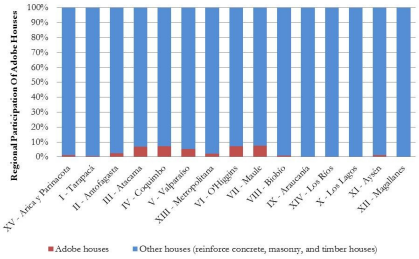

Figure 4. Regional participation of existing adobe houses in the total number of houses in 2012 (INE, 2012)

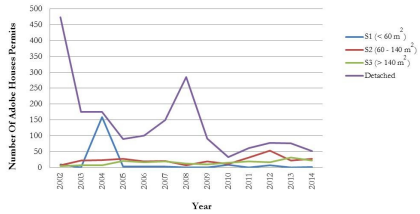

Figure 8. Number of adobe semi-adjoining and adjoining houses separated by plan area (S1, S2 and S3), and total detached houses approved for construction from 2002 to 2014 (INE, 2014)

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Adobe	1.64 to 3.75 Kgf/cm2No standard values available/ 58 * 30 * 8 cm or78 * 40 * 8 cm
Foundations	Concrete	170 Kg of cement per m3 of concrete
Floors		
Roof	Wood	Wood: depending on local quality.
Other		

Design Process

Who is involved with the design process?	Owner
Roles of those involved in the design process	
Expertise of those involved in the design process	Only local traditional knowledge is used in these constructions. The role of professionals such as engineers and architectures is minimal to none.

Construction Process

Who typically builds this construction type?	Owner
Roles of those involved in the building process	The builder/owner usually lives in these housing constructions.
Expertise of those involved in building process	Only local traditional knowledge is used in these constructions. The role of professionals such as engineers and architectures is minimal to none.
	A dry and flat terrain must be chosen to build the house. This field should be slightly raised above the surrounding terrain. Besides, the proximity to rivers, or areas with steep slopes should be avoided.Excavations must be at least 40 cm deep and 20 cm for gravel soil, and a width of 40 cm;

Construction process and phasing	foundations must be built with concrete of at least 170 Kg of cement per m3 and 40% of rock boulders. In order to avoid the erosion of adobe blocks closest to the ground, a plinth wall must be constructed, which can be built from concrete or masonry. Then the adobe wall can be constructed. The joints between blocks of adobe, both vertical and horizontal, are made with the same material of the adobe, and its thickness should be 2 cm. All bricks must be locked with a midblock overlap. The intersection of the walls must be orthogonal (Figure 12). As reinforcement in door and window openings, wooden lintels are embedded in the adobe walls (Figure 13).A continuous horizontal reinforcement called "crowning chain" is placed at the top of the walls, along all their length. It is constructed using two parallel 3 x 3 in timber pieces joined by 2 x 2 in transverse elements. This set constitutes a chain that must be assembled at the corners as shown in Figure 14 to prevent the walls from separating, and must be filled with the same material as the adobe bricks.Finally, the roof structure is mounted over the crowning chain.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	Adobe houses must follow the General Planning and Building Ordinance. The Ordinance indicates that there are two types of adobe structures (Article 5.3.1): a) type E, which are constructions with timber supporting structure, timber panels made of fibre-cement, gypsum plasterboard, and/or adobe wallboard partitions, and timber floors; and b) type F, which are adobe constructions, earth-cement or another light material bonded with cement, and timber floors. According to the Article 5.1.7 of the Ordinance, for both types, if the construction area is less than 100 m2 or occupancy load is less than 20 people, it is possible to not require a structural calculation and design, and only has to follow Title 5 Chapter 6. However, in Title 5 Chapter 6, adobe constructions are not included. Thus, in 2010 Ministry of Housing prepared a document that says that a structural analysis for adobe structures prepared by an engineer is always required (MINVU, 2010).Article 5.3.2 establishes that structures type F cannot have more than one story, and 3.50 m of height. Structures type E have to follow Art. 5.6.8, for timber structures, because of their wooden elements.
Process for building code enforcement	In Chile every structural design has to follow the seismic code NCh 433 (INN, 2009) and Decree DS 61 (MINVU, 2011), but for materials lacking of seismic standard, such as adobe, there are two options. First, it is required to prove through nonlinear cyclic tests that it has strength and ductility (following this seismic code) equivalent to those that have specific seismic standard (DS 61, 2011). Second, it is required to follow a foreign seismic code for this construction material (MINVU, 2010).After the 2010 earthquake, the standards NCh 3332 (INN, 2013) and NTM 002 (MINVU, 2013) were created to establish minimum requirements for intervention, renewal, retrofit or structural consolidation of existing earthen structures with heritage value, including those considered of adobe masonry.

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes

Additional comments on building permits and development control rules	The construction permits are regulated and given by the Municipalities. Each Municipality is in charge of the master plan of the zone or city. Additionally, a Municipality permit is required to expand or modify an existing structure. According to Article 5.1.6 of the General Planning and Building Ordinance, to obtain the permits for a project it is necessary to give the following documents to the Municipality Building Director:1) Application signed by the owner and the architect of the project with the following attached documents:- A list of all the documents and architectural drawings signed by the architect.- Statement of the owner indicating being the owner of the domain of the property.- Special conditions of the project.- All the professionals of the project.- A statement indicating if the project consults public buildings or not.- If the project has a favourable report of an independent reviewer and the identity of this reviewer.- If the project has a favourable report of a structural design reviewer and the identity of this reviewer.- A copy of the approval document if the project has an approved project draft.2) A copy of the current Certificate of Prior Information of the project.3) Unique Edification Statistics Form.4) Report of an independent reviewer, or the architect if the project consists of one house, one or more progressively build houses, or sanitary structures.5) Favourable report of the structural designs reviewer, if it corresponds.6) Certificate of feasibility of drinking water and sewerage issued by the sanitary company.7) Architectural drawings which must content exact location of the project, distribution of structures, drawings of each level, and every elevation drawing.8) Structural design and calculations according to the Article 5.1.7 of the Ordinance.9) Technical specifications of the items included in the project, especially those relating to compliance with fire regulations or standards of the Ordinance.10) Other documents.

Building Maintenance and Condition

Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	Typically, a house of this housing type is maintained by the owner(s). In general, there is no careful maintenance of adobe houses.

Construction Economics

Unit construction cost	A unit construction type F (see section 6.5 for definition) may cost 87-121 USD$/m^2, considering quality category Semi-Inferior to Regular (MINVU, 2014b), and its base appraisal unit value is 100 -184 USD$/m^2. This base appraisal value has to be modified by four factors dependent on the structure's location, special conditions of the structure, depreciation, and a commercial coefficient applicable to structures built in commercial zones (SII, 2013).
Labor requirements	
Additional comments section 3	

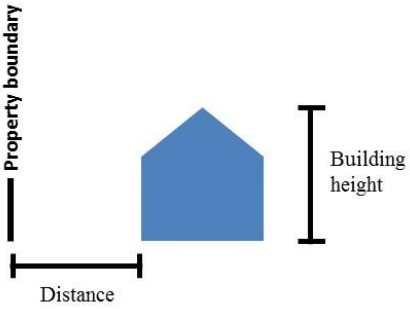

Figure 5. Distance between a structure and property boundary.

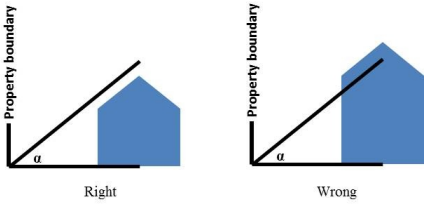

Figure 6. Angle that determines theoretical envelope.

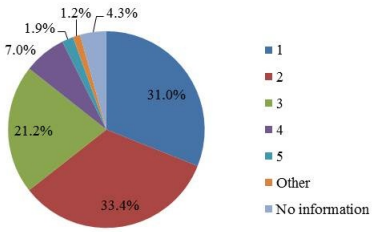

Figure 7. Number of bedrooms in adobe houses (INE, 2012)

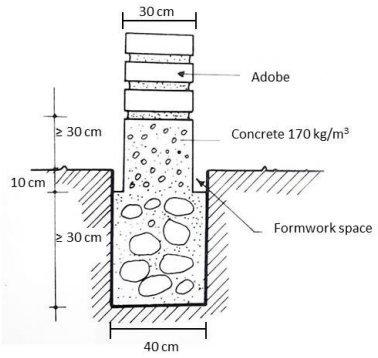

Figure 9. Required measures for strip foundations of adobe houses (Barrios, 1989)

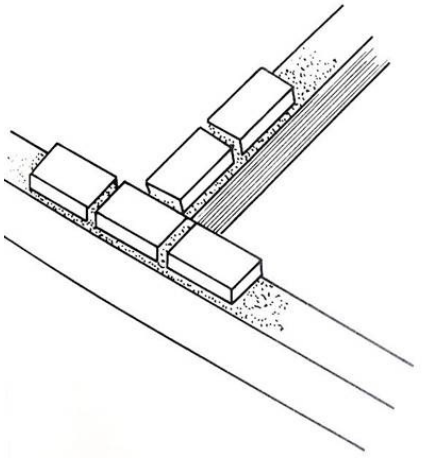

Figure 12. Orthogonal intersection of adobe walls: "T intersection"(Barrios, 1989).

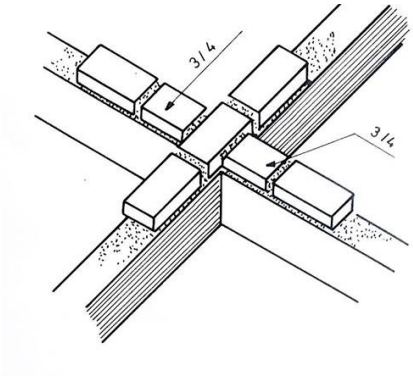

Figure 12. Orthogonal intersection of adobe walls: "Cross intersection" (Barrios, 1989).

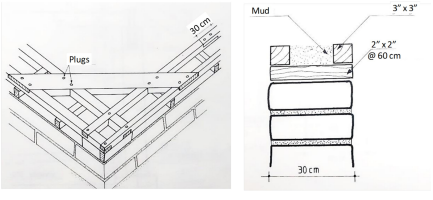

Figure 14. Crowning chain (Barrios, 1989)

Figure 13. Lintel above the door opening embedded in the adobe wall of an adobe house

Socio-Economic Issues

Patterns of occupancy	Typically, one dwelling is occupied by one family (father, mother and two to three children). The main function of the building is residential housing.
Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	<5
Additional comments on number of inhabitants	Each house typically corresponds to one housing unit. The number of inhabitants in a building during the day or business hours can be none. The number of inhabitants during the evening and night can be 2 or more. In average, there are 3 inhabitants per adobe house in Chile (INE, 2012).
Economic level of inhabitants	Very low-income class (very poor)Low-income class (poor)
Additional comments on economic level of inhabitants	The Ministry of Housing and Urbanism (MINVU) defines five categories of quality of residential structures: Superior, Semi-Superior, Regular, Semi-Inferior and Inferior (MINVU, 2014b). A total score of the structure, which is obtained considering design aspects, general characteristics, installations, and terminations, defines first to fourth quality categories. The Inferior category is assigned to social condominiums only. Social condominiums are built by the government for low income and vulnerable population. The ownership of the unit is given to 60% of the lowest quintile income families and they have the right to sell it after five years of use (Comerio, 2013). According to the Chilean Internal Revenue Service (SII), a house of 60 m2 (segment S1) may have an appraisal value between USD$5,977 and USD$11,069 depending if construction quality is classified as Semi-Inferior or Regular. To obtain an appropriate appraisal value, this value has to be modified by four factors: structure location, special conditions of the structure, depreciation, and commercial coefficient applicable to structures built in commercial zones. A 100 m2 house (segment S2) may have an appraisal value between USD$9,962 and USD$18,448 if construction quality is Semi-Inferior or Regular. For segment S3, a house of 140 m2 or more may have an appraisal value of more than USD$25,827 for a Regular construction quality (SII, 2013).According to the Ministry of Social Development (MDS) the average monthly working income for a family is approximately USD$1,000 (MDS, 2015). The minimum legal monthly wage for a person in Chile is USD$360. The average family monthly working income of the first decile is USD$102 per person. For the fifth and tenth deciles these working incomes are USD$617 and USD$3,680 per person, respectively.
Typical Source of Financing	Owner financedPersonal savingsInformal network: friends or relatives
Additional comments on financing	
Type of Ownership	RentOwn outright
Additional comments on ownership	This construction type is built following the system of self-construction. In some cases the house owners own the land.
Is earthquake insurance for this construction type typically available?	No
What does earthquake	

insurance typically cover/cost	
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	Earthquake insurance for this construction type is typically unavailable.Owners of residential real estates must pay annual territorial taxes, corresponding to 0.98% of tax appraised value if it is less than USD$117,648, and 1.143% if tax appraised value is more than that, plus an annual surcharge tax benefit of 0.025%. If tax appraised value of the residential real estate is less than USD$32,941, then it is exempt of contribution payments (SII, 2014).

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1939	Chillan, VIII Region
1960	Valdivia, XIV Region
1985	San Antonio, V Region
2010	Maule, VII Region
2014	Iquique, I Region

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	In 2010, the Maule earthquake left a total of 4 buildings on the ground, and approximately 50 buildings with demolition order. Some adobe structures in cities like Talca and Curepto experienced total collapse (see Figure 11).The 2014 Iquique earthquake (MW 8.2) was felt by more than a million people. The strongest seismic intensity occurred in Iquique (MMI VII), Arica (VII), and Tacna (VI). The earthquake generated a tsunami with maximum measured water run up of 3.15 and 4.4 meters above sea level at Iquique and Patache, respectively. There were more than 13,000 damaged houses in the affected area, mostly reinforced masonry dwellings. Adobe and masonry houses located in small towns were strongly affected by the main shock.
Additional comments on earthquake damage patterns	

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
Lateral load path	The structure contains a complete load path for seismic force effects	False

	from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	True
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	True
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	False
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	False
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	True
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	True
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	N/A
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	N/A
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	False
Wall Openings		True
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	False
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	False

Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	False

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	Lack of connection between walls.Walls with openings greater than the 30% of the total wall area.Poor lateral resistance, weak in out of plane directionCollapse of interior walls. Falling down of pieces and parts of adobe blocks from the face of the wall.General shear cracking of walls.Vertical separation of walls occurs at intersection of walls.
Earthquake-resilient features in walls	
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	The roof is poorly connected to the walls. If the walls move out of plane, the roof can collapse.
Earthquake resilient features in roof and floors	
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class	o					

Figure 10. Separation between adobe walls after the 2010 Maule earthquake in the city of Curepto

Figure 11.a Collapse of adobe houses in 2010 Maule earthquake in the city of Talca

Figure 11.b Collapse of adobe houses in 2010 Maule earthquake in the city of Curepto

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Not cracking or decoupling of structural elements (existing elements)	Static Structural Analysis with real parameters of the structure and materials. Design, Geometric (structural elements slenderness, maximum size of openings, location of openings, vertical braces) verification of the existing structure. If it is possible after all the verifications, repair, and if it is not, rebuild.
Cracking and decoupling of structural elements	Dynamic Structural Analysis with real parameters of the structure and materials. Design, Geometric (structural elements slenderness, maximum size of openings, location of openings, vertical braces) verification of the existing structure. If it is possible after all the verifications, repair, and if it is not, rebuild.

Additional comments on seismic strengthening provisions	For a new adobe structure a foreign seismic can be used for structural calculations and design a foreign seismic code (MINVU, 2010) and for intervention, renewal, retrofit or structural consolidation of existing adobe structures NCh 3332 (INN, 2013) and NTM 002 (MINVU, 2013) are used.
Has seismic strengthening described in the above table been performed?	Only after the earthquake of February 27, 2010.

Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	Repairs following earthquake damage.
Was the construction inspected in the same manner as new construction?	No
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Contractors hired by private/governmental institutions. Engineers and/or architects were involved.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	No subsequent earthquakes have affected that zone yet.
Additional comments section 6	

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