ADOBE CONSTRUCTIONS. BASIS FOR A SEISMIC RESISTANT CODE

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S U M M A R Y

Basis for a Seismic Resistant Code are presented, using data obtained from tests performed at the Pontificia Universidad Catolica del Perũ laboratory.

Tests have been carried out over a period of six years, allowing us to draw some general conslusions regarding types of materials to be used, different ways of placing the reinforcement elements and stress distribution for a wide variety of relatively simple adobe structures.

This information is presented in the form of general guidelines to be used for design and construction purposes.

B A C K G R O U N D

Many countries have been looking into the convenience of standarizing adobe constructions. Peru, a country located within a seismic region, has opted for the inclusion of a chapter regarding that kind of constructions as part of its seismic-resistant code.

In April 1977, a National Building Code (1) was approved, which took into account this fact. Nevertheless, no results from the research work carried out before that date (2) and after (3, 4, 5, 6) have been yet incorporated into it.

S C O P E

Results reported in this paper can be used for design and construction purposes of adobe and "tapial" (*) walls, as well as being a reference for brick, artificial or natural stone and soil-cement masonry using mud mortar.

Adobe constructions with and without reinforcement are considered, the rural or urban nature of the building being determined by the type of material used as reinforcement elements. When dealing with urban buildings, enriched mortars will be considered as one of the possible reinforcement materials.

M A T E R I A L S

1. Units

A) Types of Units

No size restrictions are imposed upon units employed in structural

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(*) Local term applied to walls made out of compacted mud.

elements of masonry, but it is advisable to use 1:1:3 to 1:4:8 parallelepipeds for both the adobe and tapial. Units should be well compacted and used only after a one-month drying period.

As for the mixture composition employed for the preparation of the units, the following is recommended:

- The basic components will be water, clay, silt and sand. Particles below 0.002 mm will be considered clays, those between 0.002 and 0.02 mm. silt and the ones between 0.2 and 2 mm, sand. A small percentage (up to 5% in weight) of gravel can also be allow ed in the mixture.
- Clay content must be between 10 and 20% in order to assure plasti city and prevent fissures during the drying stage.
- Silt and clay content should be similar, but the total content of both must be kept below 30%; the rest being sand with or without additional components such as straw, fine gravel, dung or others.
- The inclusion of straw is recommended, as long as it does not exceed 1% in weight.
- The use of agglometates is also advisable. A 1:4 gypsum or cement/mud ratio can be used to increase the quality of the units.
- It is also advisable to incorporate bituminous emulsions to the mixture (stabilized adobe) in order to preserve the construction from humidity and erosion. Normally, 1.5 - 2.0% (on a dry weight basis) of RC-250 asphalt. (7)

b) Compressive Strength

The compressive strenght will be determined by testing shaped cubes, the size of which will be equal to the shortest dimension of the adobe unit.

For design purposes, the compressive strength (R_o) is chosen in such a way that 80% of the specimens tested exceed R_o. A safety factor of 2.5 is then applied to that value, so:

$$R_o^* = 0.4\, R_o$$

When tests are carried out using prismatic specimens:

$$R_o = R_\lambda \sqrt{\lambda}$$

where : λ = slenderness (largest/smallest dimension)

$1 \leq \lambda \leq 6$

R_o = compressive strength for $\lambda = 1$.

The size effect for cubical specimens can be considered to be negligible

If no experimental data is available, values indicated in Table No 1 can be used (*).

(*) Data obtained from test performed on ordinary adobe at the Pontificia Universidad Catòlica del Perù laboratory.

2. Mortars

Mortars can be classified into two groups:

- Type I (Sand and agglomerates based)
- Type II (Soil with or without agglomerates)

a) Type I. Mortar

- Its compressive strength (ASTM C109) should not be lower than 25 Kg/cm^2.

- For cement sand mortars, the volumetric ratio should be within 1:3 and 1:12.

- For cement lime or gypsum sand mortars, the volumetric ratio between agglomerates and inert constituents should be between 1:2.5 and 1:8.

- The amount of water to be used is the minimum allowing full joints within the masonry.

NOTE: The mortar quality is associated to its bond with the units. The use of the compressive strength as an indicator has been adopted for practical reasons only (8)

The above mentioned limits have been established in relation with the bond because of the behaviour observed during the tests performed.

b) Type II. Mortar

- This type of mortar is to be used only in rural dwellings or temporary buildings.

- Mortars with compressive strength lower than 25 Kg/cm^2 will be considered in this category.

- The mortar composition must meet the same requirements as the adobe units.

- The water quantity must be the minimum required to obtain a workable mixture

Masonry joints are to be considered the critical zones, consequently, utmost care should be taken wirh them.

3. Reinforcement

Due to the adobe constructions fragility, use of reinforcement is recommended to ensure ductility, monolithism and eventually, resistance.

The use of the following materials is suggested:

a) Rural Construction (Mortar Type II)

Cane Arundo Phragmites type, in plain stripes very certain number of rows (from 2 to 4), tied at their ends and placed in every wall. Joints at the top and bottom levels of each span will be reinforced, trying to keep these levels at a uniform height.

Additionally, it is possible to include vertical canes, tied to the horizontal reinforcement, placed in a central plane between the adobe units and surrounded by mortar, greatly increasing the ductility of the construction. The cane employed should be subjected to some preservation treatment before being used as reinforcement.

Wood Placed in span lintels and collar beams above the walls. In both cases, this reinforcement will be tied with wire to the wall foundations. The lintel can be tied to the collar beam.

Wire Placed vertically or in a St. Andrew cross arrangement, fixing the collar beam or lintels to the foundations giving ductility to the structure. It is recommended to stress the wire when placing it.

b) Urban construction (Mortar Type I)

Steel. Reinforcing steel bars, forming vertical or horizontal elements of reinforced concrete, avoiding contact with mortars containing gypsum.

Steel mesh embedded in mortar plaster and joining collar beams with foundations can also be used.

Agglomerates

Cement, gypsum or other agglomerates forming enriched mortars.

4. Masonry

a) Thickness of joints

The thickness of the joints will be 20 mm for mortars type II, and 15 mm for mortars type I, with 50% allowance for both.

b) Compressive strength

The masonry compressive strength (R^*_m) can be determined experimentally; alternatively, reference values given in Table N°2 can be used.

- Pile tests using materials to be employed in the building:

If possible, piles should be formed by the number of bricks required to obtain a slenderness coefficient of 4. However, 4 unit piles can be used, since it has been observed that for adobe, results show very small variations when the number of joints is above 3 and they are practically independent of the slenderness of the pile being tested. Special care should be taken to maintain the verticality of the specimen. The drying period of the mortar of the pile should be at least one month, the strength of the piles increasing with the drying period (± 50% during the first year).

The nominal strength (R^*_m) will be considered to be 40% of the value exceeded by 90% of the piles tested. ($R^*_m = 0.4\ R_m$).

The minimum number of piles to be tested will be 6, and under no circumstance a value of $R_m^* > R_o^*$ should be considered.

- If no adobe pile tests are available, the reference values of Table N°2 can be used.

c) Shear Strength

The masonry shear strength (C_m^*) can be determined experimentally, or the reference values given in Table N°2 can be employed.

- Shear test with materials to be used in construction.

  Specimens will be small walls having a length/height ratio of about 1.7, loadet laterally at 2/3 of its height, with or without simultaneous compression load. Length by height product of specimen should be around 1 m^2. Drying period for the test pieces should be around one month.

  The nominal shear strength (C_m^*) should be considered to be 40% of the specimen strength (C_m) the latter being the value exceeded by 90% of the specimens tested. (C_m^*) = 0.4 C_m).

  The minimum number of pieces to be tested will be 12, using three different levels of simultaneous compressive load (4 specimens/load level).

  The sear strergth (C_m), will always be calculated as a lineal function of the acting compressive stress:

$$C_m = a + b\ \sigma_m$$

  Experimental results have shown that this value should be multiplied by a scale factor (in order to take into accound full scale walls) $\alpha = 2$. C_m will be calculated multiplying a and b by this value of α .

  Only 70% of the gravitational forces will be considered when calculating $_m$, due to the eventual simultaneous action of the inertia forces associated to vertical accelerations present during an earthquake. Additionally, only half of the wall weight will be considered to determine the average height of the critical section.

- If no shear tests are performed, reference values shown in Table N°2 can be used for design purposes.

d) Tensile Strength

For design purposes, tensile strength across the joints will be considered to be nigligible.

e) Modulus of Elasticity

The modulus of elasticity of the masonry can be determined experimentally, but if this is not possible, the following values can be used:

Mortar Type I : E = 5000 Kg/cm^2 or 1000 R_m^*

Mortar Type II: E = 1700 Kg/cm^2 or 680 R_m^*

The modulus of elasticity increases with the drying period of the test piece. For short loading periods, a 50% increase in the value of E is recommended.

f) Modulus of Rigidity

A value of $G = 0.4\ E$ is suggested.

5. Design and Construction guidelines

Stresses on different elements can be determined using elastic analysis, considering that no tensile stresses are present across the masonry joints.

Due to the complex distribution of stresses within the assemblage of walls with or without spans, the possibility of a detailed elastic analysis is discarded for practical reasons. On the other hand, the elastic behaviour of material is only accomplished at a very low level of stresses, producing early and unpredictable redistributions of stresses in the structural element joints as well as around the spans.

6. Structural System

Adobe houses should be compact, with a high density of walls sharing the support of the roof weight; rooms should tend to be square shaped, with very small spans centered in the middle of the walls. The architectural distribution must be in accordance with this scheme.

7. Forces Distribution

Usually, wood or cane is used for the roof of these buildings and the possibility of obtaining rigid diaphragms with these materials can be a difficult and expensive task. In order to overcome this difficulty and guarantee an acceptable behaviour of the structure as a whole when subjected to seismic forces, walls aligned along the direction of the seismic action should resist the shear stresses and those normal to it should be capable of resisting the seismic forces by flexure.

The distribution of shear forces will be made according to the zones of influence on each longitudinal wall, considering its mass plus the corresponding fractions of the transverse walls and roof masses. If rigid roofs are present, seismic forces will be distributed according to the relative stiffness of the different walls. In all cases, roofs should be made as light as possible.

The effects of the gravitational loads will be distributed by areas of influence on each wall, according to the structural scheme of the roof.

8. Dynamic Analysis

An adequate aproximation level is considered to be obtained if a quasistatic analysis is carried out, using the recommendations given by the National Building Code.

For the purpose of using the spectrum, the fundamental period (T), can be calculated considering the building as an assemblage of two subsystems: one formed by the transverse walls (which is dominant) and the other formed by the longitudinal walls, so that:

$$T = (T_e^2 + T_s^2)^{1/2}$$

T_e and T_s periods for the longitudinal and transverse walls can be obtained using the static deflection method.

The rapid degradation of the material will provide flexibility to the system, thus decreasing the value of the intertial forces initially assumed.

The ductility reduction factor (R_a) given by the National Building Code will be 1.5, 2.0 or 2.5, depending on the type of reinforcement used (horizontal cane, steel wire or cane mesh respectively).

9. Desingn of longitudinal walls

The strength C_m^* will be used over the critical cross section of each wall (subtracting the spans if that is the case). Part of the transverse walls cross section canbe included (anly if they are present at both ends), this extra area being equal to 25% of the length of the shortest wall or five times the thickness of the longitudinal wall multiplied by their respective thickness (whichever is smaller).

10. Transverse Wall Design

The method of yield lines is recommended, based on the permanent action of a (gravitational) flexure resistant moment through the wall cracks or using the expressions obtained by that method, modified by empirical evidence.

The study of these walls defines the spacing of the bracing walls, the length of which must not be shorter than:

$$l_o = \frac{chl}{2}$$

where : l_o = bracing wall length

c = seismic coefficient employed
h = wall height
l = length of the main wall

The thickness of the bracing wall will be the same or larger than the main wall.

For pre-dimensioning purposes, the maximum distance between bracings can be considered to be:

$$d = 2.5 \frac{b}{ch} \qquad d \leq \frac{4}{3} h$$

11. Foundations

To minimize the seismic efets, the adobe constructions should only be founded on solid soils. (σ admissible ≥ 3 Kg/cm^2)

A C K N O W L E D G E M E N T S

The Author wishes to express his gratitude to all those persons involved in the different research programs from which the information for this paper has been taken.

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NOTATION

λ = Safety factor for admissible stresses.
R_o = Nominal value of the compressive strength for cubical test pieces (value exceeded by the 80% of the specimens tested).
R_o^* = Value of reduced compressive strength (λ = 2.5), to be used in design for admissible stresses.
$R\lambda$ = Value of compressive strength for slender test pieces.
λ = Slenderness coefficient of test pieces (largest/shortest dimension $\geq$ 1).
R_m^* = Value of reduced compressive strength for masonry, to be used in design for admissible stresses.
R_m = Value of compressive strength for masonry piles with 1:4 slenderness, (minimum 4 adobes) exceeded by 90% of the specimens tested.
T_f^* = Value of reduced tensile strength by flexure for the units (λ = 2.5)
T^* = Value of reduced tensile strength (Brazilian test) in cylindrical specimens of 15 x 30 cm (λ = 2.5).
C_m^* = Value of shear strength for the masonry wall, exceeded by 90% of the specimens tested.
C_m = Value of shear strength for the masonry, to be used in design for admissible stresses.
σ_m = Compressive stress acting on the masonry ($\sigma_m < R_m$) (Kg/cm^2)
E = Modulus of Elasticity (Kg/cm^2)
G = Modulus of Rigidity (Kg/cm^2)

TABLE N° 1

Admissible Resistance of Units

- Reference values of results obtained on adobe tests:

Compression (cubes)	$R_o^* = 0.4\ R_o = 5$ Kg/cm^2
Tension by flexure (units)	$T_f^* = 1.3$ Kg/cm^2
Tension (Brazilian Test)	$T^* = 0.3$ Kg/cm^2

NOTE: These values may be increased by 20%, if the mixtura contains 25% or more cement or gypsum (on a dry volumetric basis).

TABLE N° 2

Admissible Resistance of Masonry

- Reference values of results obtained on adobe pile tests.

Compression

	Mortar Type I :	$R_m^* = R_o^*$
	Mortar Type II :	$R_m^* = 0.5\ R_o^*$

Shear

	Mortar Type I :	$C_m^* = 0.08 + .48\ \sigma_m$(Kg/cm^2)
	Mortar Type II :	$C_m^* = .040 + .24\ \sigma_m$(Kg/cm^2)