# SEISMIC CAPACITY EVALUATION AND RETROFFITING OF ADOBE CONSTRUCTIONS

**Raúl VERA[1], Angel ALBITER[2] And Sandra MIRANDA[3]**


## SUMMARY

In the present work a methodology to evaluate seismic capacity of adobe constructions is proposed, this methodology is based on laboratory test results, damage observation in recent earthquakes and reported information. This methodology is proposed for vulnerability studies in rural areas due to its simplicity and also can be used for select a retrofitting techniques. The application of this methodology for estimate the seismic vulnerability of a small village located in the central region of Mexico is also shown.


## INTRODUCTION

The us[1]e of adobe as a construction material is very common in developing countries, principally on rural areas where lot of constructions has been built using this material. These kind of structures generally do not count with an appropriate structural design which consider climatic conditions, quality control in the pieces elaboration, local seismicity, etc.

During an earthquake occurrence, for moderate intensities still, has been reported several damages in this kind of structures, due not only to poor mechanical properties of materials and its deterioration for weather features, but also, to structural defects like: walls with considerable high, large walls without reinforce, etc.

Despite of this problems, this material is very used mainly due to its low cost against other constructive techniques, also this material is suitable for be used in self construction, besides this, the growing of environmental conscience to use non industrialized materials.

## BEHAVIOR OF ADOBE STRUCTURES

n spite of structural problems that adobe presents, this material is widely used in Mexico. The majority of the people which use adobe for built, do not count with an adequate structural design, resulting constructions with low stability against earthquakes and lot of human an material losses during this events.

Periodically the pacific coast of Mexico is hit by earthquakes with Mercally magnitude around 6.5 These earthquakes have been caused important damages in adobe construction. In some places up to 80% of the adobe construction have been suffered structural damages. The main damages are vertical cracks in the intersection of perpendicular walls.


[1] *Facultad de Ingeniería, Universidad Autónoma del Estado de MéxicoCerro de Coatepec s/n, Ciudad Universitaria, Toluca, Mé*
[2] *Facultad de Ingeniería, Universidad Autónoma del Estado de MéxicoCerro de Coatepec s/n, Ciudad Universitaria, Toluca, Mé*
[3] *Facultad de Ingeniería, Universidad Autónoma del Estado de MéxicoCerro de Coatepec s/n, Ciudad Universitaria, Toluca, Mé*

When a seismic event occur, lateral forces are taken mainly for walls aligned with the movement land direction , due to its high stiffness and resistance on their plane, however for low intensity movements still, vertical cranny in the intersection of perpendicular walls appears due to flexion perpendicular to the wall plane.

Once the perpendicular walls are separated and if the roof system is not a rigid diaphragm, the pieces of the wall work independently and try to fall down by the inertial forces perpendicular to their plane, this phenomena is increased by the lateral reaction transmitted by the cover. When the ceiling give restriction against lateral displacements, shear failures occurred. [2].

Some characteristics that improve the behavior of this kind of structures against seismic solicitations are:

1. Light structures
2. Absence of critical points of stress concentration
3. Symmetric distribution of resistant elements
4. Continuity in shapes and volumes
5. Uniformity in stiffness and mass distribution
6. Suitable wall´s connection
7. Existence of rigid diaphragm
8. Enough resistance to support stresses
9. To limit the story drift

## SEISMIC CAPACITY EVALUATION OF ADOBE STRUCTURES

Since it has been commented, there are many adobe buildings founded on seismic zones and those are dispersed in a big zones, all of this, combined with the low economic level that the owners shows, hard to make an accurate analysis of each construction.

Looking for help to the solution, a methodology to evaluate this kind of structures proposed, looking for an easy application not needing capacitated people, this is possible limiting the objective of this method to estimate the structure confidence again the common failure patterns, skipping materials with different features of the usual and non conventional structuring, though it does not injure the stability of the building and difficult the evaluation.

This work is focused to find simple expressions that allow predict the behavior of a adobe structures against shear failure and perpendicular flexion to the wall plane, because these kind of failure are the most common, though in case of risk the structure stability.

The structure safety is related with the indicator of structural behavior (Io) that has to be determined per each of the type of given failures, being the minor which shows the vulnerability level esteemed for the structure.

## SHEAR REVISION

When the earthquake is acting parallel to its plane, the structural wall has to support the shear force that could be estimated by an static analysis as: [2]

$$V_u = cW/Q \tag{1}$$

Where:

$V_u$ - Share force produced by the earthquake c - Seismic coefficient

*Q* – Seismic ductility factor. Because the material has low ductility, it can be considered as one.

*W* – Structure weight, that it can be calculated by

$$W = Aw + 0.6(\Sigma L_x+\Sigma l_y)\ \gamma H\ t \qquad (2)$$

Where:

A- Floor area of the building

w- Weight of the cover per unit of area, that it could be estimated according by:

Light covers w = 50 $kg/m^2$

Ridge tile covers w = 250 $kg/m^2$

Concrete slabs w = 500 $kg/m^2$

(3)

$\Sigma L_x,\Sigma l_y$ - Total length of walls on x and y direction, without walls that its length is inferior of 1.3 m

$\gamma$ – volumetric weight of the adobe

H – Media height of the building

t – Wall thickness

The share force that resist the structure for each direction can be calculated with the contribution of all parallel walls with the seismic direction. The share resistant for each direction can be given by:

$$V_r = v_r\,\Sigma li\ t \qquad (4)$$

Where:

$V_r$ – Shear resistant force

$v_r$ - Shear resistant stress

$\Sigma li$ –Longitude of walls in the study direction. The walls with longitude smaller than 1.3 m will not be considered.

t – wall thickness

The security level of the construction against this failure pattern could be associated with the ratio between shear resistant force and shear acting force.

$$Io = v_r\,\Sigma li\ t\ /\ c\ W/Q = v_r\,\Sigma li\ t\ /\ [Aw+0.6\ (\Sigma lx+\Sigma ly)\ \gamma\ H\ t] \qquad (5)$$

For typical adobe construction in Mexico we can consider the volumetric weight of the adobe as 1800 $kg/m^3$, and doing $L_1$ and $L_2$ the smaller and bigger value of $\Sigma L_x$ and $\Sigma l_y$ respectively, the equation (5) results:

$$Io = \frac{10\ v_r\,\Sigma L_1\ t}{c[Aw/1000 + H\ t\ (L_1 + L_2)]} \qquad (6)$$

**FLEXURAL MOMENT REVISION.**

The flexural moment per unit of longitude in the adobe walls intersection could be estimated as:

$$Mu = c\ w_m\ x^2 / Q\ k \qquad (7)$$

Where:

$w_m$ – the total weight acting in a unitary length of the wall

x – the small value of H or L/2

k – coefficient to consider the restriction in the top of the wall, it could be consider as 20 in non reinforced structures.

The bending resisting moment at the critical zone could be estimated as:

$$M_r = f_t\ S \qquad (8)$$

Where:

$f_t$ = The bending resisting stress

S = Elastic section modulus; $S = t^2/6$

The security level of the construction against this failure pattern could be associated with the ratio between bending resistant moment and bending acting moment:

$$Io = (f_t\ t^2/6) / (c\ w_m x^2/Qk) \qquad (9)$$

The total weight in a unitary length of the wall could be estimated as:

$$w_m = \gamma\ t + wB/2 \qquad (10)$$

Where:

$\gamma$ – Volumetric weight of the adobe

*w* – Roof weight per unit area

B – Building dimension in the earthquake direction

If we consider the volumetric weight of the adobe as 1800 kg/m$^3$ the equation (10) results:

$$Io = \frac{K\ f_t\ t^2}{6cx^2\ (1800\ t + w\ B/2)} \qquad (11)$$

The smallest value of Io is reached from the maximum value of x.

## CORRECTION FACTORS

The above indexes are evaluated considering a construction with simple structural system, without important eccentricities, with good quality materials and without damage by natural features. The common constructions generally do not satisfy this hypothesis, this makes difficult to estimate accurately the security level of the structure.

To maintain the simplicity of the methodology, it is proposed to estimate approximately, the influence of materials quality, their damage by natural features and problems with their structural configuration.

For get this, a factor to reduce the structural behavior index is proposed, this factory try to include the reduction in the security level due to material deterioration by inclemency, irregularity on the structural system and bad quality of materials. The assessment of the construction is done by a view inspection using the deterioration regularity and quality factors.

<u>Deterioration factor</u> (Fd)

*Fd* = 1.0 – When the structure is not deteriorated

*Fd* = 0.8 – When the structure presents low deterioration

(less than 20% of the material is deteriorated)

*Fd* = 0.6 – When the structure is too much deteriorated
(12)

(more than 20% of the material is deteriorated or the adobe is saturated)

<u>Regularity factor</u> (Fr)

*Fr* = 1.0 – When the structure is regular

*Fr* = 0.8 – When the structure has small irregularities

(The irregularities represents less than 20% of the dimension of the construction)

*Fr* = 0.6 – When the structure is irregular
(13)

(The irregularities represents more than 20% of the dimension of the construction)

<u>Quality factor</u> (Fc)

*Fc* = 1.0 – When the quality of the construction is good

*Fc* = 0.8 – When the quality of the construction is regular

*Fc* = 0.6 – When the quality of the construction is bad
(14)

The correction factor (FR) can be estimated as:

$$FR = Fd * Fr * Fc \qquad (15)$$

Finally the vulnerability level of the construction is represented by the vulnerability index (I) as:

$$I = Io * FR \qquad (16)$$

When the value of vulnerability index is equal to 1.0, the mechanical elements acting in the structural members are equal to their resistance. Then when the vulnerability index has values equal or bigger than 1.0 indicate that the structural behavior expected for the construction is acceptable, in other case the structural properties of the construction should be improved. For those constructions in which the vulnerability index has values near to 1.0 is recommended to use a more accurate methodology.

## RETROFITING TECHINQUES.

In the present work only the most common retrofitting techniques used in Mexico will be discussed.

Addition of reinforced concrete beam in the top of the walls, this procedure confine the walls and restricts the independent movement of the perpendicular walls, increasing the flexural moment resistance of the elements. The shear resistance is not increased remarkably.

This retrofitting technique usually is combined with the addition of reinforced concrete columns, but this practice raises the retrofitting coast and substantially not provide additional advantages.

In order to consider the increase in the flexural moment resistance, the k coefficient used in equation (7) could be taken as 5.

Addition of steel mesh and cement mortar in both sides of the wall, this is the most effective retrofitting technique. The substantial amount in shear and flexural moment resistance is obtained, and also is effective to protect the adobe against environmental agents. The main disadvantage of this option is its relatively high cost.

The shear resistant stress ($v_r$) can be increased in 2.0 kg/cm2 and the k coefficient can be considered as 3.0.

Addition of tensile steel bars, the effects of this technique are similar to addition reinforced concrete beam, but is less effective, however, the installation of tensile bars is simple and during the retrofitting works, the building function is not affected. In this case the coefficient k can be considered as 10.

To select the suitable retrofitting Technique it is possible to apply the evaluation methodology assuming the parameters for a selected reparation method, if the vulnerability index adopt an adequate value, The retrofitting technique could be used.

## APPLICATION OF THE METHODOLOGY

The proposed methodology has been applied in a small village called “Chapultepec, Méx”, to estimate the seismic vulnerability. The study place is located on hard soil and in a moderated seismic risk zone. A seismic coefficient equal to 0.16 was used.

39 structures were checked , the majority of them have habitation function, with one or two rooms, regular plant shape, rock masonry foundation and roof formed by ridge tile supported by a wood structure.

For all the cases the shear failure was not expected, nevertheless for the 44% of the constructions, the vertical cracking intersections is expected.

In two cases the addition of steel mesh and cement mortar was recommended, for the other cases the addition of reinforced concrete beam in the top of the walls was selected.

## CONCLUTIONS

This methodology offers an alternative to estimate the vulnerability of adobe construction with typical characteristics of rural zones of Mexico, where there are lot of losses caused by earthquakes and due to the low economical conditions application of other techniques is not possible.

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