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Techniques used to repair seismic-resistant masonry walls

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ABSTRACT: The western region of America, is affected by local and subducted earthquakes. At present the majority of its buildings are low with reinforced framed masonry walls. This type of building technique affect capacity, stiffness and resistance of these buildings. The Grupo de Construcciones Antisísmicas (Antiseismic Building Group) belonging to Facultad Regional Mendoza, Universidad Tecnológica Nacional has included studies aimed at the recovery of seismic-affected structures in its research programs. In this paper, various repair techniques developed for seismic-resistant masonry, 1:1 laboratory tests and comparisons referred to costs and reliability are included.

1 INTRODUCTION

One of the challenges of the structural seismic-resistant engineering corresponds to decision after earthquake opposite to damaged resistant masonry: to repair or to tear down?

In the answer to this alternative will interfere with technical, economic, social an even political factors.

The earthquake-damaged masonry structures are most problematic elements for restoring because they are non-homogeneus elements.

Repairing or strengthening methods are used so far empirical and they are applied on basis of accumulated experience.

The research planning on the repaired masonry structure behaviour is carried out at the Facultad Regional Mendoza, Universidad Tecnológica Nacional (Republic of Argentine). One of its aims is the evaluation of various repair techniques developed for the region. These techniques allow to recover or to increase the masonry resistance which are verified through 1:1 laboratory tests.

2 CRITERIA FOR REPAIRING OF MASONRY

To choose the most adecuate technique for repairing structure masonry we must be have the following information:

1. regional seismic level
2. mechanical properties of constitutive materials, and
3. dynamic characteristics of structural system.

From the point of view of seismic-resistant it is desirable to attain, in repaired structures, the same original resistance as much as in project or in structural behaviour of the system (resistance, stiffness and ductility). For this purpose, it is neccesary to identify the mechanisms of failure of the masonry structure and to know the authentic results by means of laboratory tests of the selected technique.

Table 1. Mechanical properties of used materials

Material	Value	Units
Cement mortar		
Compressive strength	103	kN/m2
Reinforced concrete		
Compressive strength	170	kN/m2
Elastic modulus E	180 000	kN/m2
Poissons modulus	0.2	-
Tensile steel strength	6 770	kN/m2
Elastic steel modulus E	1 802 060	kN/m2
Units of masonry: ladrillón		
Compressive strength	87	kN/m2
Flexural strength	31	kN/m2
Elastic modulus E	35 000	kN/m2
Shear modulus G	5 580	kN/m2
Resina epoxi		
Compressive strength	600-700	kN/m2
Flexural strength	200	kN/m2
Density	1 200-2 000	kg/m3
Mastic epoxi		
Compressive strength	900	kN/m2
Flexural strength	300-400	kN/m2
Density	1 700	kg/m3

3 METHODOLOGY OF RESEARCH

The original lateral bonded masonry is tested to horizontal static cyclic loads (to equal seismic action) up to failure (which remain firm the structure).

In this damage state, the structure is repaired with different techniques and it is tested at the same level of load.

The conclusions about the used repair technique is obtained with the comparison of the two tests.

4 REPAIR STUDY TECHNIQUES

To evaluate the behaviour, the regional seismic resistant structural pattern (lateral bonded masonry or extra-reinforced masonry) calls for the repair of both masonry and reinforced concrete. The mechanical properties of used materials are shown in Table 1.

4.1 Repairing of masonry

1. Technique N°1: massive ordinary ceramic bricks (non-standarized units 0.09x0.18x0.30 m).

Used materials: for closing cracks ($5x10^{-3}m$) cement Portland grouted is used (volume doses 1:3) and for strengthening wall we must use romboidal wire mesh, anchor tie ($5x10^{-3}m$), wire ($3x10^{-3}m$), reinforced steel mesh # ($4x10^{-3}m$ diameter at 0.40 m interval in vertical and horizontal direction) and cement coating.

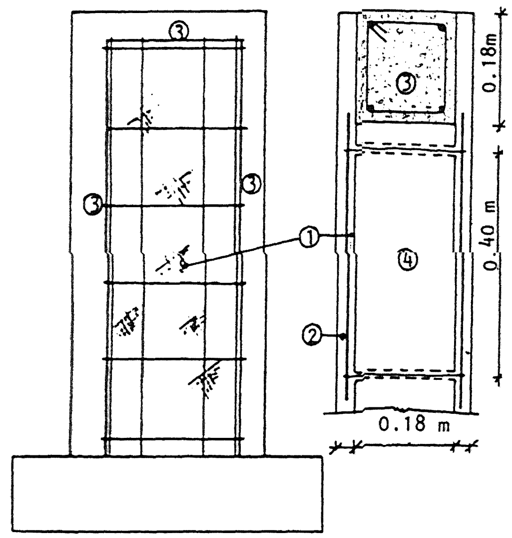
The following items are used for the repairing method:

1. Cleaning of cracks with pressure air and water.
2. Placement of injection tubes and inject cement grout throughout both sides of the wall.
3. Placement square anchor ties 0.40 m througtout the wall thickness.
4. Placement of wire in the anchor tie with cement grout until this runs out of the opposite side.
5. Placement romboidal wire mesh on to both sides of the wall and then a layer of cement grout is applied.
6. Placement reinforced steel mesh on to both sides of the wall, then connected to anchors.
7. Application of a layer of cement coating of the minimun thickness possible.

In figure 1 are shown the details of the technique N°1.

2. Technique N°2: massive ordinary ceramic bricks (non-standarized units 0.09x0.18x0.30 m).

Used materials: for closing cracks ($5x10^{-3}m$) epoxi mastic is used.



References:

① Romboidal wire mesh

② Cement coating

③ Reinforced concrete

④ Masonry

Figure 1. Details of repairing masonry wall Technique N°1.

The following items are used for repairing method:

1. Cleaning of cracks with pressure air and water.
2. Placement epoxi mastic into cracks of masonry wall.

3. Technique N°3: blocks with vertical cells (standarized 0.18x0.18x0.40 m, net section is 40% of the gross section).

Used materials: for closing cracks ($5x10^{-3}m$) cement Portland grout is used (volume doses 1:3) and for substitution of the blocks cement mortar is used.

The following items are used for the repairing method:

1. Cleaning of cracks with pressure air and water and removing cracked blocks.
2. Moistening both sides of the wall and filling up cracks with grout.
3. Placement cement mortar into masonry holes.
4. Application of a layer of cement coating of the minimun thickness possible.

Original masonry wall

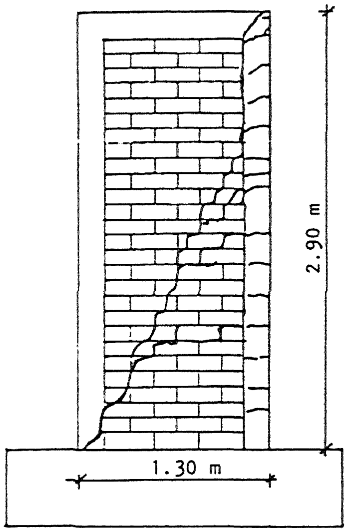


Figure 2. State of damage of original and repairing masonry wall (Technique N°1).

Repairing masonry wall

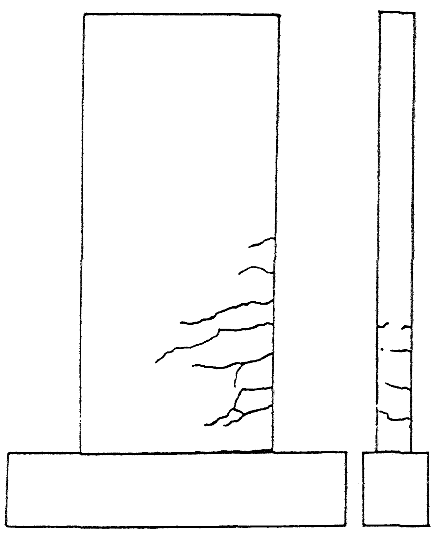


Figure 2. State of damage of original and repairing masonry wall (Technique N°1).

4.2 Repairing of reinforcing concrete

For closing cracks for consolidation of injection tubes and crack injection resina epoxi is used.

The following items are used for the repairing method:

1. General cleaning of affected surface.
2. Placement of the injection tubes.

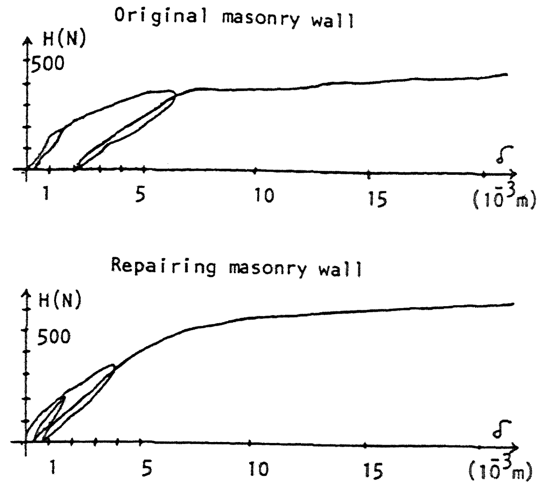


Figure 3. Comparison of the lateral load and lateral displacements hysteresis loops for laboratory tests (Technique N°1).

3. Closing cracks and verification of losses.
4. Injection cracks with resina epoxi.

6 RESULTS

6.1 Results of technique N°1

In figure 2 is shown the cracking state of original and repairing masonry wall.

- In figure 3 is shown the comparison of the lateral load and lateral displacement hysteresis loops for both tests.

In table 2 are given the results of laboratory tests.

Table 2. Results of technique N°1 laboratory tests.

Item		Primitive wall	Repaired wall
Shear modulus G	kN/m2	3 136	3 184
Stiffness	N/m	9 450	8 890
Shear stress	N/m2	992	954
Maximun shear	N/m2	2 095	2 070
Absorption of energy	J	6.2×10^{-2}	4.8×10^{-2}
Ductility factor		2.1	2
Costs	u$s/m2	-	13.5

6.2 Results of technique N°2

In figure 4 is shown the cracking state of original and repairing masonry wall.

In figure 5 is shown the comparison of the

Original masonry wall

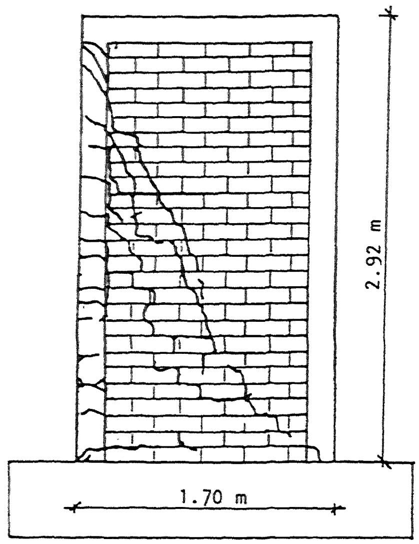


Figure 4. State of damage of original and repairing masonry wall (Technique N°2).

Repairing masonry wall

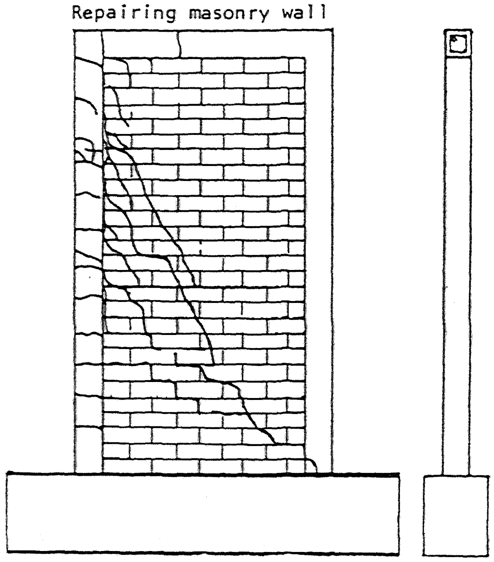


Figure 4. State of damage of original and repairing masonry wall (Technique N°2).

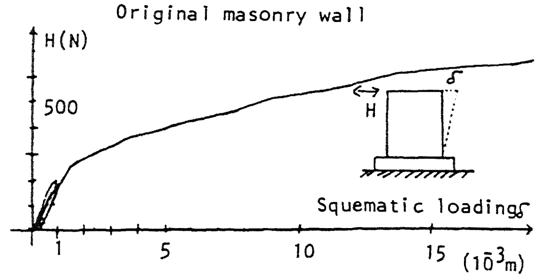
lateral load and lateral displacement hysteresis loops for both tests.

In table 3 are given the results of laboratory tests.

Table 3. Results of technique N°2 laboratory tests.

Item		Original wall	Repaired wall
Shear modulus G	kN/m2	3 864	676
Stiffness	N/m	16 120	2 670
Shear stress	N/m2	1 334	580
Maximun shear	N/m2	2 510	2 010
Absorption of energy	J	3.9×10^{-2}	8.9×10^{-1}
Ductility factor		2	5
Costs	u$s/m2	-	23.7

Original masonry wall



Repairing masonry wall

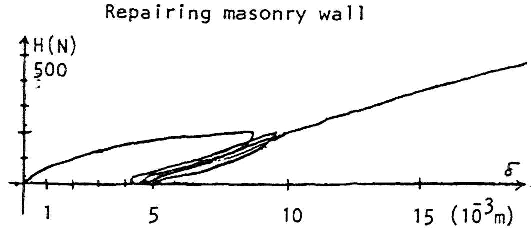


Figure 5. Comparison of the lateral load and lateral displacements hysteresis loops for laboratory tests (Technique N°2).

6.3 Results of technique N°3

In figure 6 is shown the cracking state of original and repairing masonry wall.

In figure 7 is shown the comparison of the lateral load and lateral displacement hysteresis loops for both tests.

In table 4 are given the results of laboratory tests.

7 CONCLUSIONS

7.1 Conclusions for technique N°1

1. Shear resistance between original and repaired wall makes no difference.
2. The cracking state of the repaired wall it is concordant with the state loading and the used construction system.
3. The repaired wall stiffness is equivalent

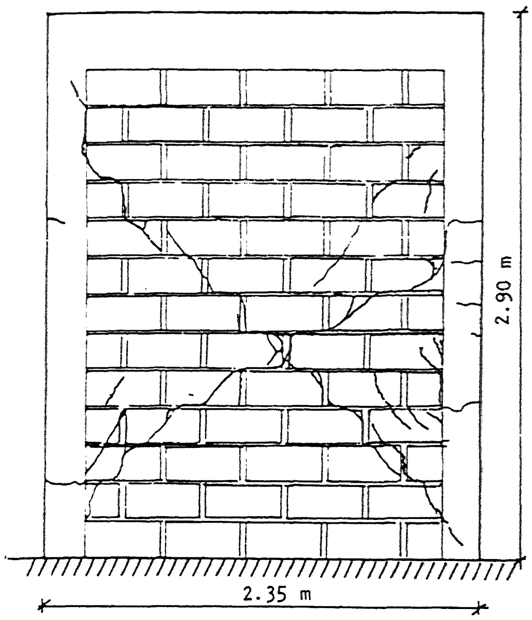


Figure 6. State of damage of original and repairing masonry wall (Technique N°3).

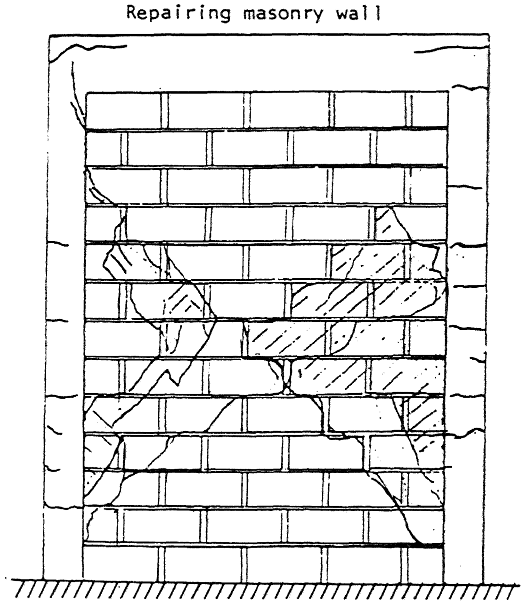


Figure 6. State of damage of original and repairing masonry wall (Technique N°3).

to the primitive stiffness although there is a change in the dimensions of the panel.

4. The energetic analysis shows that the repaired masonry wall behaviour is equivalent to panel without strengthening.

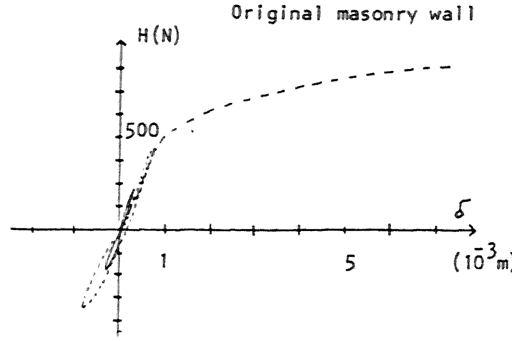


Figure 7. Comparison of the lateral load and lateral displacements hysteresis loops for laboratory tests (Technique N°3).

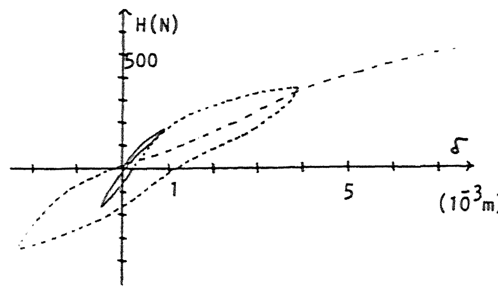


Figure 7. Comparison of the lateral load and lateral displacements hysteresis loops for laboratory tests (Technique N°3).

5. This proposal is consistent with the state of art of construction and the seismic-resistant design. It is allowed, in the west Argentine region, to find one solution which does not require specialized workmanship with lower cost and acceptable structural response.

7.2 Conclusions for technique N°2

1. Repaired wall shear resistance is less than original wall shear resistance.
2. The cracking state of the repaired wall is acceptable only under vertical static loads.
3. The repaired wall stiffness is less than the primitive wall stiffness.
4. The energetic analysis shows that the repaired masonry wall behaviour has a great deformability under horizontal loads because the epoxi mastic is an elastic solid.
5. This proposal is not consistent with the seismic-resistant design.

Table 4. Results of technique N°3 lab tests.

Item		Original wall	R
Shear modulus G	kN/m2	4 252	
Stiffness	N/m	24 310	
Shear stress	kN/m2	740	
Maximun shear	N/m2	1 480	
Absorption of energy	J	4.5×10^{-2}	2
Ductility factor		2	
Costs	u$s/m2	-	

7.3 Conclusions for technique N°3

1. Repaired wall shear resistance is less than original wall shear resistance.
2. The cracking state of the repaired wall it is concordant with the state loading and the used construction system.
3. The repaired wall stiffness is less than the primitive wall stiffness.
4. The energetic analysis shows that the repaired masonry wall behaviour is equivalent to brittle wall, with a great deformability and pulling-out of the used blocks.
5. This proposal is not consistent with the seismic-resistant design.

7.4 Final conclusions

Although the repairing techniques in the west Argentine region, has been investigated since 1985, it is well to indicate that the technique N°1 is the minor cost than the other techniques, it has the maximun security and it has little application. The technique N°2 is the most expensive and it is recommended as cosmetic repairing. As the technique N°3 is the most used in the region, the laboratory tests show its poor behaviour and thus is not recommended.

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