UNB
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RETROFIT OF UNREINFORCED MASONRY BUILDINGS: THE STATE-OF-THE-ART

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ABSTRACT

The vulnerability of unreinforced masonry buildings to impaired performance is a serious problem facing structural engineers today. Unreinforced masonry (URM) walls usually constructed from bricks or blocks and in some older buildings from cut stone, were designed primarily to resist gravity loads with little or no consideration for lateral loads. Although URM buildings perform satisfactorily under service loads, there is evidence that they may suffer serious damage under high lateral loads such as earthquake inertia forces. Besides seismic loads, URM buildings may require upgrading due to abnormal loads, environmental loads, or other causes of deterioration. Several techniques have been found to be effective in retrofitting masonry buildings. However, what is appropriate for one building may not necessarily be appropriate for another. The selected method must be consistent with aesthetics, function, and the strength, ductility, and stiffness requirements.

This paper reviews and discusses the limitations of the most commonly used field retrofitting techniques namely: repointing, grout and epoxy injection, anchoring and tying, overlays, bracing, internal reinforcement, external reinforcement, post-tensioning, and base isolation. Experimental investigations on retrofitting of URM structures are also reviewed. In light of the presented review, it is clear that a successful retrofit strategy requires a full understanding of the expected response mechanisms of the rehabilitated URM structures and how retrofit measures can alter the complete building response. Axial loads, height to width (or thickness) ratios, boundary conditions, diaphragm behavior, and connections between components tend to govern the response of URM structures and play important roles in guiding the choice of the appropriate retrofit strategy.

Key words: Unreinforced Masonry, Retrofit, Repointing, Injection, Anchoring, Overlays, Reinforcement, Post-tension, Base Isolation.

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INTRODUCTION

According to current estimates (Matthys, 1989), more than 70% of the existing inventory of structures worldwide are masonry. Most were designed and built prior to the development of "engineered masonry structures" and may not be able to satisfy the requirements for horizontal forces. Even most of them were designed to earlier building codes, which have been proven to be incomplete or even insufficient. These buildings include many of those with historical interest and are often protected by cultural conservation laws.

Demolition and replacement of these old masonry structures is not generally feasible due to the magnitude of the effort and the cost of new construction. Consequently, large retrofitting programs are currently underway in many countries especially seismic and hurricane areas. The North America continents' involvement in retrofitting and preserving URM buildings is relatively recent in comparison to the efforts expended on 17th to 20th century structures throughout Europe (Matthys, 1989). A literature survey shows a significant effort and success record in Yugoslavia, Czechoslovakia, and Italy.

Different terminology is unconsciously used interchangeably to describe the process of applying structural measures to increase the service life of the structures. By definition (Tomazevic, 1999), "repair" refers to restoring but not increasing the original performance of the structure after damage has occurred. Alternatively "strengthening" or "upgrading" encompasses technical interventions in the structural system to improve resistance by increasing strength and ductility. Strengthen the structure before damage occurs is one form of retrofit which may also involve upgrading. Repair, strengthening or rehabilitation after damage has already took place is often also called "retrofit".

Various retrofitting techniques have been developed for existing URM buildings. Some involve damage analysis and engineering judgment, and have never been actually verified. Others, have been verified either in the laboratory or under real loading such as earthquakes. The type and quality of masonry materials and the structural layout are critical criteria in choosing the retrofit method.

This paper reviews the most common techniques that used in retrofit of existing URM buildings. Experimental investigations carried out to study retrofitting of URM structures are also reviewed.

MOST COMMON RETROFIT TECHNIQUES

Repointing

Repointing is the process of removing deteriorated mortar from the joints and replacing it with new mortar. Mortar joints may spall or erode over time due to freeze-thaw cycles or water drainage paths or the joints may not have been well filled. Also, differential movement may cause debonding and separation cracks along the joints. In most cases, deteriorated mortar joints can be repaired by repointing.

It is recommend (Drysdale et al., 1999) that joints be racked or ground backed to a depth of two times the joint height with a minimum of 13 mm from the intended mortar surface. The fresh mortar, matching the original material as closely as possible, is placed in layers and tooled when thumb print hard. The new mortar should match as closely as possible the existing mortar in color, texture, and physical properties.

As a general rule, if the pointing is firm, intact and not eroded more than 13 mm, it should be left as is (London, 1988). The following criteria was suggested to be used in judging whether joints need repointing:

- Open joints: the mortar is deeply eroded (more than 13 mm) or has fallen out.
- Cracked joints: hairline cracks or larger have formed in the mortar.
- Separated joints: the masonry and the mortar do not adhere, resulting in a crack or a gap between the two, or the mortar is setting loosely in the joint.

Repointing, when properly done, restores the visual and physical integrity of the masonry. Improperly done, repointing not only detracts from the appearance of the building, but may cause physical damage to the masonry units themselves. For a masonry wall, to absorb the inevitable slight movements, including variations in temperature, settlement of the building and vibrations, the mortar joints must be somewhat weaker than the masonry units. Otherwise, the masonry units become the weakest part of the wall, and slight movements would cause the brick or stone to crack or spall. If repointing mortar is too strong, line loads are created along the new mortar to masonry unit interface. They may also tend to be more impermeable to moisture than the masonry units and thus prevent drying through the joints; moisture movement then is concentrated in the units, leading to damage of the masonry (London, 1988).

Grout and Epoxy Injection

Grout can be injected into walls to anchor other components or to strengthen and stiffen a wall by solidly filling hollow units or open cavities. This technique has worked well for historic masonry structures and can be more effective if masonry is prewetted (Drysdale et al., 1999). It is important to ensure complete filling and avoid later shrink-back as water is absorbed from the grout whether using a non-shrinkage grout, epoxy or polymer modified grout. Injection of low viscosity epoxy was found (Hamid et al., 1994) to be effective in repairing cracks as small as 0.13 mm. An epoxy mixture consists of epoxy adhesive as a binder and various fillers such as sand or cement can be used for economy for cracks wider than 6.4 mm. The shear strength of test specimens injected by polyester/sand was found to be the same as specimens injected by epoxy/sand. The disadvantages of epoxy injection include inadequate penetration, improper curing of epoxy, presence of cavities, and sensitivity of epoxy adhesive to temperature. Experience (Drysdale et al., 1999) has shown that the effectiveness of injection depends on the compatibility of physical, chemical, and mechanical properties of the original masonry and the injected material.

Recent research (Kingsley, 1995) has shown that properly designed cementitious grouts can be injected into URM walls to fill cracks ranging from 0.08 mm thickness to voids of 12 mm and larger. Used in combination with retrofit anchors, injection can ensure composite action of URM walls, and restore the integrity of previously damaged walls. Since grouts are cement based and can be custom designed for each application, continuity and compatibility of the grout with the existing materials can be optimized. Design of grout injection schemes must take account of increased wall mass, as well as nonstructural consequences of grouting, such as chemical interaction with surrounding materials and altered paths for moisture in the wall.

Some old masonry walls were constructed from two outer leaves of uncoursed stones or uncoursed stones mixed with bricks and a rubble inner infill of smaller pieces of stones often incorporating many voids. Injecting cementitous grout is an efficient method of strengthening such walls (Tomazevic and Anicic, 1989) by binding loose parts of the wall together into a solid structure. Grout is injected through tubes in holes drilled between the stones to a depth of at least half of the wall thickness at 0.5 to 1.0 m intervals. A fast setting mortar can be used to fix the tubes and seal surface cracks between stones, if the surface is not plastered.

Modena (1994) investigated injecting URM walls with mortar through holes drilled to two-thirds the wall thickness after sealing cracks. Low pressure was applied starting from the bottom of the wall. Reinforced injection was another technique investigated. It is similar to the injection technique; however, the holes are more frequent, longer, and inclined through the wall thickness as shown in Figure 1. Steel bars are inserted in every injection hole to create a mesh to ensure local connections between intersecting walls and, in whole wall, to increase strength in compression and in tension.

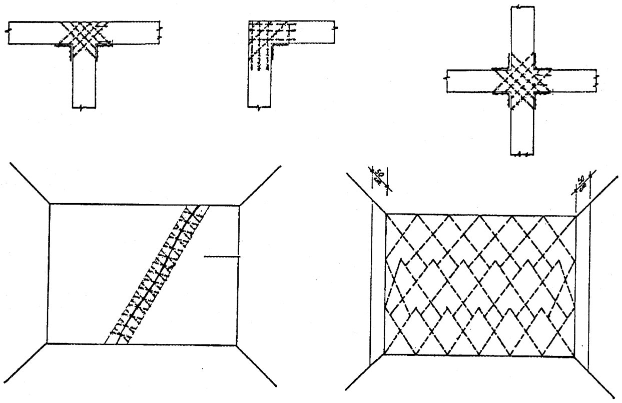


Figure 1: Distribution of Reinforced Injections in Damaged URM Walls. (Modena, 1994)

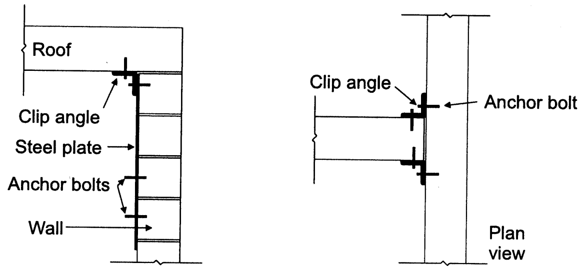
Manzouri et al. (1996) studied the effectiveness of different repair and retrofit techniques to identify suitable grouting materials and procedures for retrofit of URM. Development of analytical tools to evaluate the performance of masonry structures before and after retrofit was included. Eleven tests were conducted on four shear walls in their original condition and also after they were damaged and repaired with different methods. Three walls were solid walls having identical geometries and a height to width ratio of 0.6 while the fourth had an opening in the center to represent an open front wall.

The retrofit techniques studied included grout injection and the introduction of steel reinforcement. The tests showed that the injection of cementitious grout accompanied by the repair and replacement of localized damaged areas with similar materials can restore the original strength and stiffness of URM walls. However, in the absence of large voids or cracks grout injection by itself is not expected to be very useful in enhancing the strength.

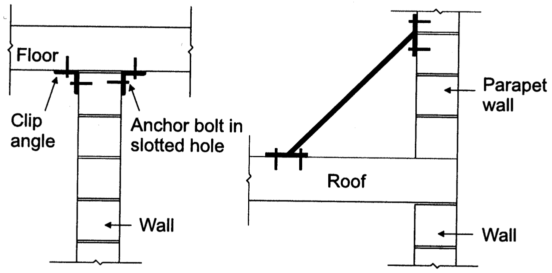
Anchoring and Tying

A fundamental detail for all retrofit procedures is the connection of walls, floors, and roof with anchors designed for tension and/or shear. This process serves to stiffen the individual structural elements, and encourage composite behavior of the structure as opposed to independent response of components. Tying elements together also has the advantage of damping the individual component response. In particular, stiffening and/or damping the response of diaphragms can significantly reduce the out-of-plane displacement demands on the URM walls. The use of RC and steel ties and beams tends to make the existing masonry act as confined masonry in the sense that tensile resistant uni-dimensional members are introduced either horizontally or both horizontally and vertically which allow the entire wall or portions of it to act as a truss element.

Failure to properly anchor floors and roof to walls limits their stability under lateral out-of-plane loading and limits the ability of the floor or roof system to transmit lateral in-plane loads to the wall to provide overall building stability. Collapse of improperly anchored URM walls is commonly found in earthquake damaged masonry buildings. Except where grouting-in of anchors to simulate original construction is possible, drilled-in retrofit bolts, expansion anchors, or epoxy sock anchors are used for mechanical connection. Steel angles or other joining elements are normally required to effectively transfer force from one structural component to the next as shown in Figure 2. In general, the most critical aspect of the design is to adequately anchor the bolts in the masonry and to ensure adequate stiffness. Wall anchorage is relatively expensive and, while disruptive to occupants, it provides more hazard reduction value than many other retrofit techniques.



(a) Hold Down of Roof (b) Intersecting Walls



(c) Floor to Wall (d) Bracing Parapet

Figure 2: Tying and Anchoring of Masonry Walls. (Drysdale et al., 1999)

For composite or multiwythe solid walls, tensile and shear strength are the main requirements. In this case, anchor bolts or similar through-the-wall devices can serve the purpose at low cost. Alternatives are combinations of internal anchors with nut and washer on the end. Large shear bolts can be used to tie masonry walls to roof and floor diaphragms (Drysdale et al., 1999) where installation consists of drilling a 64 mm hole and dry-packing a steel bolt to a depth of 200 mm into an unreinforced masonry wall. Grouting can be done with either a Portland cement drypack material or any commercially available non-shrink grout.

Investigations carried out in Yugoslavia during the 1980's (Tomazevic and Anicic, 1989) aimed at improving the seismic resistance of URM structures. Prototypes were built and tested under shaking-table excitations then repaired by different tying techniques and retested. One technique was tying the walls together by means of steel tie-bars, placed on either side of the walls at floor level and anchored at the ends of the walls on steel plates. Although, this technique did not prevent the vertical cracks at the joints between walls, it prevented the separation and collapse of transverse walls even when, the longitudinal wall started to collapse.

A brief review of the relevant aspects of the Italian experience during and after the Friuli and Basilicata-Campania earthquakes in repairing and upgrading URM buildings has been presented by Modena (1989 and 1994). The most simple and effective technique applied to connect intersecting URM walls was to place steel rods at every floor level and mechanically anchor them to plates or other steel devices. This method is preferred in cases where the surfaces of the wall must be preserved as is common in restoration of monuments and historic buildings. Another technique is connecting the walls with stiffened floors. This can be done either by nailing steel ties directly to the girders or to the stiffened slab and anchor them to the external face of the wall with steel fasteners, or by creating a composite section of the existing roof and a newly cast thin RC slab.

Overlays

When covering masonry with a surface layer is acceptable, use of an external reinforcing overlay can be an effective retrofitting technique for existing URM buildings. Ferrocement is the most common overlay producing an orthotropic material consisting of high-strength cement mortar, 13 to 25 mm thick, and reinforced with layers of fine steel wires in the form of a mesh; steel volume ratio ranges from 0.5 to 5% (Drysdale et al., 1999). The layer has a high tensile strength ranging from 3.5 to 13.5 MPa depending on the reinforcement amount, mesh type, and orientation.

Schotcrete has been also used to strengthen and repair masonry walls. When steel is used, plaster is first removed from the wall. Mortar is removed from the joints between the masonry units, 10-15 mm deep, and the cracks are grouted. After cleaning the surface, the first layer is applied. The reinforcing mesh is then placed and connected to the wall by means of steel connectors in pre-drilled holes. Then, the second layer is applied such that the total thickness of coating does not exceed 30 mm (Tomazevic, 1999).

Recent experiments (Albert et al. 1998, Ehsani and Saadatmanesh 1996, and Triantafillou 1998) have shown the effectiveness of advanced composite overlays in repair and strengthening of URM walls. Flexibility in the choice of fibre and matrix materials, fibre orientation, and fibre mat thickness allow for highly customized design. The process is still subject of investigation, and questions regarding long-term durability and fire-resistance remain to be addressed. Fibre glass reinforced laminates were used to strengthen small scale models of hollow concrete masonry to study the effect of strengthening on strength under in-plane loading (Hamid et al., 1994). The test results showed that the capacity of the strengthened specimens is double that of unstrengthened specimens for compression test and splitting tensile test.

The effect of strengthening URM walls by different overlays has been experimentally investigated both in laboratory and in situ. The test results (Tomazevic, 1999) showed significant improvement in the lateral resistance as shown in Table (1). The results indicated the importance of adequately anchoring of the overlay to the existing masonry. If the connection does not prevent splitting, the overlay separates from the wall and buckles at the occurrence of cracks.

Table 1: Effect of Overlays on the Lateral Resistance of URM Wall. (Tomazevic, 1999)

Type of Masonry		Type of Reinforcement	Resistance (kN)		Multiplier
Unit	Mortar		Original	Strengthened	
Brick B20	M 0.4	Steel	34	118	3.5
Brick B10	M 0.3	Steel	47	167	3.6
Block B7.5	M 5.0	Steel	128	167	1.3
Brick B20	M 7.2	Ferrocement	276	693	2.5
Brick B15	-	CFRP	299	426	1.4

Following the 1994 Northridge earthquake, a fiber composite fabric was epoxy bonded to the walls (Ehsani et al., 1996) of two masonry buildings in southern California. It proved to be the most cost-effective alternative to repair both of these damaged buildings. The test results indicated that retrofitting of masonry structures with composite fabrics is very efficient for increasing the flexural and shear strength and ductility when the strength of the fabric controlled the mode of failure.

Bracing

Bracing by attaching additional structural members to URM wall can be structurally effective for resisting lateral loads due to earth or wind pressure or seismic acceleration. Typically the additional member is placed vertically to span between top and bottom supports. If the additional steel section, reinforced masonry or concrete pilaster or buttress is designed to resist the entire lateral load transferred by the masonry wall, compatibility of deflection frequently dictates that the masonry will have to crack horizontally (Drysdale et al., 1999). Therefore, spacing of the braces may be limited by the ability of the masonry to span horizontally to transfer load to them. This type of bracing can have a negative impact on appearance and space utilization but installation on the interior face of the existing wall is generally preferable.

In 1995, Schwegler investigated ways to increase the system ductility and generate uniform crack distribution over the entire surface of the multistory shear wall. In one method, Carbon fibre (CFRP) sheets were bonded diagonally to 3.6x2.0 m masonry shear walls and anchored in the adjoining ceiling and floor slabs. In another method, shear walls were strengthened by a conventional woven polyester fabric applied to the entire surface but not anchored in the adjoining concrete slabs.

Cyclic horizontal loading showed that the resistance of the strengthened walls depended strongly on the configuration and type of strengthening material. The eccentricity arising from strengthening only one face of the wall was found to have a negligibly small effect on the bearing resistance of the shear wall. The earthquake resistance was increased by a factor of 4.3 when CFRP sheets were used and by a factor of 1.4 when the woven polyester fabric was used.

Internal Reinforcement

Internal reinforcing is a rather simple and efficient technique for retrofitting URM walls. It is actually a new version of an ancient technique. Ordinary steel reinforcing bars and, in some cases, tensioned tendons are inserted in holes, up to 60 mm in diameter and 50 m long, drilled in the URM wall thickness parallel to its plane. The holes are injected usually with cement mortars. This retrofit improves in-plane and out-of-plane flexural behavior of the wall and the connection between orthogonal walls at their intersections but may require replacement later due to corrosion.

This practice was wide-spread in Italy following the Friuli earthquake of 1976. However, it came under considerable criticism for its use in cultural monuments since it is an entirely irreversible intervention. It should be noted that introduction of reinforcement may change the basic mechanisms of response dramatically, and must be considered very carefully as a potential strengthening measure. For example (Kingsley, 1995), excess vertical reinforcement can cause a pier, which otherwise would have had a semi-ductile rocking response, to fail in shear.

Plencik et al. (1984) investigated factors influencing the strength of a multi-wythe unreinforced brick masonry wall after being strengthened with internal reinforcement. Reinforcing bars were placed in 51 to 127 mm diameter core holes and fixed in position using unfilled/filled epoxy, sand-filled polyester, and grout. URM walls of a building in Raleigh, North Carolina were strengthened by this technique. Panels and prisms were cut out of these walls for testing. The strengths for panels loaded cyclically for resistance to in-plane shear increased by 56% to 111%. Large diameter cores provide a greater area of grout to resist in-plane shear forces. The results for sand/polyester and sand/epoxy grouts were found to be similar for the same volume ratio. The greater the resin content the greater the shear strength. Specimens strengthened with cement grout were generally 30% weaker than specimens strengthened with sand/polyester or sand/epoxy grouts. The use of polyester was recommended over epoxy due to the much higher cost of epoxy.

External Reinforcement

Steel plates and angles have been attached to the surface of masonry walls to strengthen unreinforced or inadequately reinforced walls. In some cases, the URM wall may be simply considered as a platform for the steel and strength calculations can be done considering only this steel to be effective. The enhanced strength and ductility of this retrofit scheme has merit for out-of-plane bending of masonry walls due to seismic loading.

Albert et al. (1998) examined the out-of-plane flexural resistance of URM walls strengthened with externally applied FRP. Twelve walls reinforced with various types of FRP were tested as simply supported beams standing on one end subjected to two out-of-plane line loads. The test results showed that strength and ductility of wall specimens were significantly increased when strengthened with FRP. The type of fiber reinforcement and its amount affected the overall stiffness of the specimen. The layout of the fiber reinforcement had more impact on local joint strain than the overall behaviour. The introduction of axial load increased the stiffness of the masonry and reduced the stiffness of the fiber reinforcement. Although the stiffness of masonry was reduced by cyclic loading, the original load deflection envelope was maintained.

In 1998 Triantafillou analyzed the short-term strength of URM walls, strengthened with externally bonded CFRP laminates under monotonic out-of-plane bending, in-plane bending, and in-plane shear, all combined with axial load. Experimental testing of standard masonry wall specimens under various loading conditions showed that the increase in bending capacity is quite high. Achievement of full in-plane flexural strength depends on proper anchorage. Short development lengths and/or the absence of clamping may result in premature failures through peeling-off of the FRP laminates beneath the adhesive. The in-plane shear capacity of the FRP-strengthened walls was found to be quite high especially in the case of low axial load.

Post-Tensioning

URM walls that develop tension due to either in plane or out-of-plane bending can be strengthened using prestressing steel to create axial compression in the wall and increase the bending moment required to produce tension. Internal prestressing has been used successfully to increase strength and provide ductility to existing URM structures. Where cavity or cell space is sufficiently open to permit placement of prestressing strands or bars, wall openings are required to install anchors and bearing plates unless bond in grout at the base of the wall is used to provide end anchorage. Post-tensioning was found to increase the strength of the unstrengthened walls by a factor of two (Hamid et al., 1994).

Ganz (1991) described a system consisting of a tendon and anchorages. At the lower end of the tendon, a self-activating dead-end anchorage is placed in a cast-in-situ concrete element. The stressing anchorage is located at the upper end of the tendon. Low relaxation 7-wire 15 mm diameter strands are placed in a galvanized steel duct prepared in 1.0 m length segments. Paying due attention to the anisotropic material properties of masonry, post-tensioned masonry walls can be designed similarly to post-tensioned concrete.

Although post-tensioning masonry walls proved to be an effective technique in strengthening URM structures, post-tensioning masonry walls using FRP in a cold environment is not recommended due to the high losses in the prestressing force. Lissel et al. (1998) investigated the effect of low temperatures on the losses of four prestressed CFRP tendons used to post-tension a 3 m high diaphragm wall. On a theoretical basis, cooling in a Canadian winter will cause a large reduction in the prestress force compared to steel tendons. This has been verified experimentally by monitoring the losses. The diaphragm wall was also tested in flexure to cracking. Due to the differences in the coefficients of thermal expansion, the changes in the prestress level in a wall prestressed with CFRP tendons are opposite to changes experienced by walls prestressed with steel tendons. It was found that for masonry, a temperature drop below that at which the CFRP were prestressed results in a prestress loss.

Base Isolation

Base isolation represents a valid strategy for the reduction of seismic risk of URM buildings. This method can be advantageously applied in cases of strategic buildings where feasibility of the structure must be guaranteed in emergency situations and the contents represent an economical or cultural value to be safeguarded. Seismic rehabilitation by conventional techniques does not prevent the damage of structural and non-structural elements. Large cyclic deformations dissipate the energy transmitted from the ground at the expense of partial or total damage. Base isolation provides the energy dissipation mechanism at the base and drastically reduces the ductility demand from the superstructure. However, introducing base isolators under existing buildings is perhaps the most physically and economically dramatic intervention applied to date (Kingsley, 1995). The difficulties of construction and the complexity of engineering an isolated structure make base isolation a technically challenging solution that should not be undertaking casually. It should be noted also that not all existing buildings are equally candidates for base isolation.

Base isolators are very stiff in the vertical direction in order to transfer gravity loads, but are flexible in the horizontal direction, thus isolating the building from the horizontal components of seismic forces. Base isolation of the structure will shift the fundamental period of vibration of the structure to a range outside of the predominant energy content of earthquakes and significantly reduce the level of force experienced by the building. To be economically retrofitted with such a system, a building must substantially meet the following criteria (Bailey, 1987):

- The building's shape must be suitable. The height should be less than the width, so uplift is not a major problem. Squat bulky buildings are more suitable than high-rise. This is because their period is in the range most likely to benefit from base isolation.
- The building site must allow the building to move relative to the ground without interference from adjacent structures.
- The difficulty or expense of repairing non-structural damage in an unisolated condition should be substantially more than that anticipated in isolated structure.

CONCLUSION

Successful retrofit strategies require a full understanding of the expected response mechanisms of the retrofitted URM structures and how retrofit measures can alter the complete building response. Axial loads, height to width (or thickness) ratios, boundary conditions, diaphragm behavior, and connections between components tend to govern the response of URM structures and play important roles in guiding the choice of the appropriate retrofit strategy. Based on the literature surveyed and test results of the experimental investigations reviewed the following conclusions can be drawn:

- Deteriorated or unsatisfactory mortar joints can be repaired by repointing. When properly done, repointing restores the aesthetic appearance of the building and improves weather resistance and structural performance.
- Experience has shown that the effectiveness of the injection technique depends greatly on the compatibility of physical, chemical, and mechanical properties of the original masonry and the injected material.
- Test results show that grout injection can ensure composite action of URM walls and restore the integrity of previously damaged walls.
- Injection of low viscosity epoxy was found to be effective in repairing cracks as small as 0.13mm. Nonetheless, this technique requires high expertise to avoid the problems that might arise from improper application such as inadequate penetration, improper curing, presence of cavities, and sensitivity of epoxy to temperature.
- Although wall anchorage is relatively expensive and also disruptive to occupants, it provides more hazard reduction value than most other techniques. The most critical aspect of the design is to properly anchor the bolts in and ensure adequate stiffness.
- The use of an external reinforcing overlays can be an effective retrofitting technique for existing URM buildings but adequate anchoring of the overlay to the existing

masonry is necessary.

- Although bracing by attaching additional structural members to the surface of masonry wall can be structurally effective, it can negatively impact appearance and space utilization.
- A rather simple yet efficient technique to retrofit URM buildings is converting them to reinforced systems by the introduction of reinforcing bars into holes drilled in the walls or alternately applying the bars externally to the wall surface.
- Internal prestressing has been used successfully to increase strength and provide ductility to existing URM buildings. The effect of creep and loss of prestressing force may limit the application of this technique especially in old structures.
- Base isolation represents a valid strategy for the reduction of the seismic risk of URM buildings. It should be noted that this technique is an energy dissipation rather than a structural measure.

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