RETRO-REINFORCEMENT OF EXISTING MASONRY STRUCTURES

Stephen W. Garrity

1. ABSTRACT

Retro-reinforcement, a cost-effective method of installing stainless steel bars in existing masonry, is described with the aid of a case study. The technique has been developed as a repair for cracked masonry and as a means of increasing the tensile strength and ductility of an unreinforced masonry structure. Although retro-reinforcement has been used mainly to strengthen the masonry walls of low-rise buildings, it may also be suitable for improving the blast resistance and seismic performance of buildings, for repairing damage due to these effects and for repairing and strengthening masonry arch bridges.

2. INTRODUCTION

Before the turn of this century, unreinforced masonry was used extensively as the principal structural material for many different forms of building, civil and military engineering work. Many of these structures are still in use today as historical monuments or, as is often the case, they form an important part of a nation's commercial and domestic infrastructure. In spite of prolonged exposure to wind, rain, frost attack, atmospheric pollution and large variations in temperature and humidity together with the damaging effects of inadequate drainage and waterproofing, excessive ground movements, scour, increased loading or a major change of use, many of these structures remain in comparatively good condition. In some cases, however, a lack of planned maintenance has resulted in an increasing number of old masonry structures that are suffering from severe deterioration, cracking and a consequent reduction in strength.

Keywords: Strengthening; Reinforced Masonry; Masonry Bridges; Seismic Retrofit; Blast Resistance.

1Lecturer, Department of Civil Engineering, University of Bradford, Bradford, West Yorkshire, England. BD7 1DP.
In modern construction, where the use of structural steel and reinforced and prestressed concrete prevails, unreinforced masonry tends to be specified as a non-structural cladding or as a structural material for low rise buildings. In comparison with earlier forms of masonry construction, modern brickwork or blockwork structural elements are slender and are built using cementitious mortars that are stronger but more brittle than the hydraulic lime mortars of old. As a result, modern masonry construction has cracked where there has been inadequate provision for moisture and thermal movement, where insufficient support has been provided over door or window openings in walls or where the foundations have been unable to accommodate large ground strains. Common sources of the latter are the effects of coal and mineral extraction, localised scour due to the failure or leakage of water mains or drainage pipes and ground water variations in clay soils susceptible to shrinkage and swelling.

In some cases it is necessary to strengthen and increase the ductility of existing unreinforced masonry structures to improve their performance when subjected to seismic activity or large magnitude loading from hurricanes or typhoons. Similar measures are required for masonry structures thought to be likely targets for terrorist bombing or other forms of blast loading. There is also a need to rehabilitate damaged masonry following an explosion or an earthquake. Clearly, unreinforced masonry structures near the epicentre of an earthquake or the source of an explosion are likely to be beyond repair, however, more remote structures may have sustained comparatively minor damage that can be repaired and strengthened for the future.

Several different repair and strengthening techniques have been developed to solve the problems described above. When carrying out refurbishment work, engineers and architects are usually faced with constraints such as the widespread reduction in public expenditure, the importance of minimising any disruption to industry, an increasing awareness of the historical importance of many masonry structures and the need to reduce maintenance costs. Hence, as well as providing the required structural integrity, a repair or strengthening method ideally should:

- be cost-effective.
- be quick and simple to install.
- not create structural distress in other parts of the structure.
- cause minimum disruption to the users of the structure.
- not be visually obtrusive.
- be serviceable and durable.

This paper describes a versatile repair and strengthening system, hereafter referred to as retro-reinforcement, that may satisfy some or all of the above criteria. A case study and a number of possible uses for the technique are also briefly considered.

3. RETRO-REINFORCEMENT

The different stages of retro-reinforcement, a method of installing reinforcement in existing masonry, are summarised as follows:
i) Any existing covering such as external render or plaster is removed to expose the masonry.

ii) Grooves or slots are cut into the mortar bed joints of the masonry using a power disc cutter, see Figure 1. The grooves may be up to 10mm thick and, for brick masonry, are typically about 50 - 70mm deep. Sufficient mortar should remain in place to support the existing bricks or blocks. In some cases, dislodged bricks or stones must be reinstated before continuing with the repair.

iii) The interior of the existing masonry is carefully inspected to assess its condition. It may be necessary to grout up any large voids present; the characteristics of the hardened grout should be compatible with the existing masonry.

iv) Dust and debris are removed using compressed air or by washing. The use of water to clean out the grooves is dependent on the type of grout used (see "v", below). With a cementitious grout, wetting the groove will promote hydration of the cement at the grout/existing masonry interface and thereby improve the bond. If a polyester or an epoxy grout is used the groove should be kept dry.

v) A layer of grout is then injected into the back of the groove using a manually operated gun; the grout should also be firmly pressed into the groove to ensure maximum compaction. Various grout types can be used; generally a cementitious grout consisting of Ordinary or Sulphate Resisting Portland Cement with natural sand fillers and an expanding agent to compensate for any likely shrinkage is used. The compressive strength of the grout after three days is typically between 10 and 15 N/mm²; 28 day strengths are usually between 30 and 45 N/mm². In some cases pozzolanic fillers such as pulverised fuel ash (pfa), air entrainers and waterproofing agents such as Styrene Butadiene Rubber (SBR) have been used. With certain types of masonry it may be necessary to use weaker grouts, however sufficient binder is required to ensure composite action. Where much higher early strengths are required, as is the case with repairs necessary to stabilise a structure in advance of the main works, more expensive chemical grouts such as acrylics, polyesters or epoxy resins may be used.

vi) A length of 6mm diameter ribbed stainless steel reinforcing bar is then pushed into the layer of grout. Care is taken to ensure that the bar is fully surrounded by grout. Usually grade 304 austenitic stainless steel is used, however, grade 316 steel can be used where exposure to chloride salts is likely. This reinforcement has very similar mechanical properties to high yield carbon steel commonly used for reinforced concrete construction in the U.K. As an alternative, stainless steel helical rod or thinner stainless steel wire may be used.

vii) A second layer of grout is then injected over the reinforcing bar.

viii) Additional bars are inserted, as required, and encapsulated in grout. In a 50-70mm deep groove, it is usual to insert only two bars and the outer 15mm is left free of grout for repointing.

ix) The grout is left to cure and the sawn grooves are repointed with mortar to match the existing masonry. In many cases special sands or pigments must be used in the repointing mortar to obtain the required finish.
It is assumed that any works necessary to stabilise the ground or strengthen the foundations have already been carried out.

Figure 1. Grooves cut into the bed joints of a brickwork wall. Note the provision for lapped reinforcement and the large crack at the left hand edge of the building.

Figure 2 gives details of the usual range of repairs that are necessary for most old low-rise masonry buildings. The reinforcement, which can usually be installed from the inside or the outside of the building, is commonly used in the following three ways:

1. To form deep beams thereby allowing the masonry to span over window or door openings or across softened regions of ground.

2. To repair cracks where further movement is unlikely.

3. To form edge beams within the masonry so that the external walls can be tied to the timber roof and floor plates. This not only provides additional stability to the external walls but also considerably improves the robustness of the building.

In the diagrams and photograph shown in this paper, steel reinforcement is installed in the bed joints of regularly coursed brick or stone masonry. This is the simplest form of retro-reinforcement and is the easiest to disguise. Diagonal and vertical bars have also been installed in masonry walls using the same technique. The procedure is as described above except that, where it is necessary to hide the evidence of the repair work, the line of the proposed bar is marked on the wall first and any bricks or similar sized stones on the line are carefully removed before cutting the groove for the reinforcement. These are replaced when the bars have been grouted in place.
Figure 2. Typical uses of retro-reinforcement in old masonry buildings.

4. CASE STUDY - RETAIL PREMISES - GRAVESEND, KENT, ENGLAND.

This structure was built about 150 years ago with a timber roof and floors supported on solid walls built in Flemish bonded London stock bricks with hydraulic lime mortar. It is a three storey terraced property with a traditional Victorian front elevation comprising
moulded blocks, frieze and pilasters. It is currently used as a men's clothing shop or store and is located in the main shopping area of Gravesend.

Many years ago, when the building was converted into a shop, a spine wall that originally divided the front of the ground floor area into two rooms was removed and replaced by a steel beam. As a result, there was a redistribution of load to the external walls causing the defects summarised in Figure 3, below. In addition, a survey of the building revealed that the frieze appeared to be laterally bowing away from the front wall, there was extensive vertical cracking of the external walls and diagonal cracking in the internal walls on the first and second floors. The ground floor construction appeared to be in relatively good condition indicating that the foundations were adequate.

Figure 3. Case study - front elevation showing the main defects

Initially, the architect for the scheme considered that the only realistic way to refurbish the building was to demolish and completely rebuild its front elevation. It was estimated that such work would cost in the order of £40,000 and that the business would have to close for a period of about 4 months. In the event, using the retro-reinforcement technique, it was possible to retain the existing front elevation and strengthen the
complete structure by installing ties and stainless steel bars similar to those shown in Figure 2. Furthermore, the refurbishment work, including restoration of the internal and external finishes, was completed in only 4 weeks at a cost of £16,500 with no major disruptions to the business.

5 DISCUSSION

The principal advantages of retro-reinforcement are that it is both simple and quick to install. Furthermore, the repairs and resulting disruption are kept to a minimum because the engineer can target specific regions of the structure where the reinforcement is needed. In some cases the reinforcement can be installed entirely from the outside of the building and it may only be necessary to evacuate the rooms immediately adjacent to the walls undergoing repair to prevent any imposed loading that might impair the development of full bond between the grout and both the reinforcement and the existing masonry. The noise of the disc cutter and the dust created during groove cutting also must be taken into account when planning repair work of this type.

Another important feature of retro-reinforcement is that it does not cause any noticeable alteration to the original appearance of a structure, particularly if the reinforcement can be installed in the bed joints of the masonry. Also the addition of reinforcement does not significantly increase the self weight of the structure. This can be a major advantage when repairing old and historic buildings built on poor foundations. Where adequate end anchorage can be provided, the reinforcing bars can be post-tensioned to improve the shear strength of the masonry. The technique can also be used to repair or strengthen unreinforced or lightly reinforced concrete structures; decorative anti-carbonation coatings or similar could be used to cover and further protect the repair.

Although retro-reinforcement is a very versatile technique, it is not a solution to all masonry repair and strengthening problems. Its main uses are likely to be where there is a need to provide or increase continuity in a masonry structure and where greater tensile strength and ductility are required. It may not be the most appropriate repair system to use where the mortar joints are very thin; although the bricks or blocks could be cut, it would be difficult to disguise the repair work.

The cause of deterioration or cracking must be correctly diagnosed and the effects of the proposed remedial works on the behaviour of the complete structure must be carefully considered and taken into account when designing or specifying any form of repair or strengthening works. In some cases, retro-reinforcement will only be appropriate if used in conjunction with other remedial work such as pre-grouting of the masonry. Where cracking has been caused by excessive movement of the foundations, it is usually necessary to stabilise the ground or relieve some of the load from the foundations to minimise the risk of further gross deformation.

With retro-reinforcement, as with all refurbishment, it is essential that the work is carried out with care. Even though the technique is very simple and therefore there is reduced scope for error, to ensure maximum composite action it is important to remove dust and debris from the grooves cut into the existing masonry and to accurately batch and mix the grout materials.
The installation of steel reinforcement into existing masonry structures as a form of repair is not new. For many years, masonry structures have been repaired or strengthened by grouting steel reinforcing bars into a criss-cross network of pre-drilled holes; in the U.K. this type of repair is commonly known as stitching. This technique is mainly suitable for old masonry structures of fairly massive construction such as bridge piers, arches, tunnels, churches, cathedrals and ancient monuments rather than modern slender masonry walls. Although not always the case, for maximum structural efficiency it is usually preferable to install reinforcement at or near to the surface of the damaged masonry, as is the case with retro-reinforcement. With the stitching technique, the repair must be deep enough to ensure that adjacent reinforcing bars cross over each other; this is likely to produce a large increase in the stiffness of the repaired masonry that could cause distress elsewhere, particularly if movement occurs subsequent to the repair. In spite of this, stitching is likely to be the preferred method for deep repairs and both stitching and retro-reinforcement would probably be necessary when repairing large masonry building and engineering structures.

6. POSSIBLE USES OF RETRO-REINFORCEMENT

6.1 Repair and Strengthening of Masonry Arch Bridges

It is estimated that about 40% of the U.K.'s bridges are of masonry arch construction, most of which are well over 100 years old. Although the majority of these structures are in good condition, some are in need of repair and strengthening because of the problems highlighted in the introduction to this paper. The main defects found in masonry arch bridges include cracking of the arch barrel, ring separation, detachment of the spandrel walls, settlement induced cracking of the abutments and vehicular collision with the parapets[1,2,3]. It may be possible to overcome some or all of these problems without noticeably altering the appearance of the bridge, significantly increasing the load on the foundations or causing prolonged disruption to traffic by selectively reinforcing critical parts of the bridge. These might include the regions of the arch barrel where hinges are likely to form under collapse conditions, intermittent lengths of the parapets and spandrel walls and the cracked sections of abutments and piers. The barrel could also be reinforced transversely to resist any tensile stresses caused by lateral pressures on the spandrel walls or bending effects due to imposed loading. It may be possible to extend this reinforcement to connect the spandrel walls to the arch barrel, however, the influence of this on the structural behaviour of the arch needs to be thoroughly investigated before adopting such a measure. The use of retro-reinforcement should keep the cost of repair to a minimum because full width/full length repairs such as saddling or load relieving slabs can be avoided. Furthermore, it is anticipated that in most cases the reinforcement can be installed around existing services thereby precluding the need for expensive service diversions.

6.2 Seismic Retrofitting of Unreinforced Masonry Structures[4]

The use of reinforced masonry for low to medium rise buildings constructed in some countries where there is a significant risk of seismic activity is now common practice. It therefore follows that the seismic resistance of similar structures built of unreinforced masonry could be improved by installing steel reinforcement using the technique
described in this paper. As mentioned earlier, retro-reinforcement could also be used to repair and strengthen unreinforced masonry buildings that have suffered comparatively minor damage in an earthquake.

It is also widely accepted that the response of a building to seismic activity can be improved by providing greater structural continuity between the masonry walls and floors. This can be achieved using a detail similar to that shown in Figure 2. Moreover, seismic performance can be improved by reducing the plan eccentricity between the centres of mass and stiffness of the walls of a building. One way of doing this is to use retro-reinforcement to convert non-structural walls into structural members and to improve the connection between the walls and the floors. In addition, the risk of damage or worse from non-structural elements that become unstable during an earthquake, such as parapet walls, can be considerably reduced by installing retro-reinforcement.

Retro-reinforcement may be an economically viable and effective alternative to some of the other forms of seismic retrofit such as the use of internal steel frames or jackets, coating walls with gunite (or shotcrete) or fibre reinforced render, crack injection, grouting or prestressing. As far as the author is aware, retro-reinforcement has not been used as a retrofit technique other than as a means of inserting horizontal stirrups into existing slender masonry columns[4, paper 3].

6.3 Armouring Existing Masonry Structures Against Blast Effects

Although structures may be subjected to blast effects from various sources, a principal concern of many engineers is the need to restrict damage and loss of life resulting from explosions caused by terrorist activity. This is currently a major concern in the U.K. where, since 1969, there have been almost 15,000 explosions caused by terrorists. Most of these have occurred in Northern Ireland. Recent experience in the U.K. has shown that masonry structures or infill panels in concrete or steel framed buildings are particularly vulnerable to the effects of a bomb or mortar attack. Such explosions can generate dynamic pressures of up to 150 - 200 kN/m² or more with a duration of a few milliseconds; in urban areas, reflection effects can magnify these pressures by a factor of between two and twelve.

The response of buildings to blast loading is dependent on many factors such as the proximity and the explosive strength of the bomb or projectile, the amount of venting, the degree of ground shock, the reflection of the blast waves and the robustness of the building. The robustness of unreinforced masonry buildings can be improved by using retro-reinforcement to strengthen load-bearing and non load-bearing masonry walls, to introduce redundancies into the structural form, to increase the ductility of the masonry elements and to improve the structural continuity between the walls and the roof and floors. Retro-reinforcement could also be used not only to repair masonry damaged by blast effects but also to provide increased protection against further attack.

The general principles described above have been known for many years. However, research is required to study the effectiveness of retro-reinforcement as a means of armouring masonry structures against terrorist attack as there is currently little detailed design guidance available. Earlier research work is either classified and therefore unavailable or it is not directly relevant having concentrated on the blast resistance of
infill panels[5,6] or brickwork buildings subjected to lower magnitude effects caused by gas explosions[7].

7. SUMMARY

Retro-reinforcement has already proved to be an effective and economical means of repairing and strengthening existing low-rise masonry buildings. Experience to date shows that such reinforcement can be installed with very little disruption to the users of the building and that it is possible to avoid any noticeable alteration to the original masonry finishes particularly where reinforcement is installed in the bed joints of regularly coursed masonry. The technique also offers considerable potential for the repair and strengthening of masonry arch bridges, seismic retrofitting of low to medium rise masonry buildings and the armouring of masonry structures against blast damage.

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9. REFERENCES