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Strengthening Masonry Structures with Retro-Reinforcement

Consolidation de constructions de maçonnerie au moyen de barres d'acier

Verstärkung von Mauerwerkbauten durch nachträgliche Bewehrung

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SUMMARY

Retro-reinforcement, a cost-effective method of increasing the tensile strength and ductility of existing masonry using stainless steel reinforcement, is briefly described. Recent experience shows that such reinforcement can be installed with very little disruption to the users of the structure and that it is possible to avoid any noticeable alteration to the original masonry finishes. Although retro-reinforcement has been used mainly to rehabilitate low-rise buildings and arch bridges, it is also likely to be suitable for improving the impact resistance of masonry and as a seismic retro-fit technique.

RÉSUMÉ

Le "rétro-renforcement" est une méthode rentable qui permet d'augmenter la résistance à la traction et la ductilité des maçonneries existantes au moyen de barres en acier inoxydable. Des expériences récentes montrent que ce renforcement peut être installé sans perturber outre mesure les utilisateurs du bâtiment et en évitant toute modification apparente des finitions de la maçonnerie originelle. Quoique le "rétro-renforcement" ait été, jusqu'ici, principalement utilisé dans la rénovation de bâtiments à hauteur limitée et de ponts en arc, il est probable qu'il puisse également améliorer la résistance à la flexion de la maçonnerie, sous l'effet de chocs et servir de technique pour augmenter la résistance aux séismes.

ZUSAMMENFASSUNG

Die nachträgliche Bewehrung ist eine kosteneffektive Methode zur Steigerung der Zugfestigkeit und Duktilität bestehender Mauerwerke durch Edelstahlbewehrung. Neueste Erfahrungen zeigen, dass eine solche Bewehrung bei minimaler Störung der Benutzer eingebaut werden kann und dass es möglich ist, jegliche wahrnehmbare Veränderung der Originalmauerwerkfassaden zu vermeiden. Obwohl die nachträgliche Bewehrung bisher hauptsächlich für die Renovierung niedriger Bauten und Bogenbrücken verwendet wurde, ist es wahrscheinlich, dass sie sich auch für eine Verbesserung des Mauerwerkschlagwiderstandes und als eine seismische Nachrüstungstechnik eignet.

1. INTRODUCTION

Engineers have been using reinforcement to improve the performance of masonry for many centuries. The Romans used iron cramps in molten lead to fasten stone blocks together or to tie stone facing to rougher masonry backing [1]. During the Italian Renaissance (1420-1580), iron tie rods and chains were used to resist the thrust in vaulted masonry construction and iron anchors were used to tie floors to masonry walls. Also, by this time, it had become common practice in many parts of Western Europe to use various iron components to tie masonry blocks together. One of the earliest recorded examples of the use of iron bar reinforcement in a masonry structure was by Soufflot who used a variety of horizontal, vertical and diagonal iron bars to strengthen the portico of Sainte Geneviève (the Panthéon) in Paris between 1770 and 1772 [2]. In the UK, Sir Marc Isambard Brunel used hoop iron to reinforce the caissons for the Wapping to Rotherhithe tunnel beneath the River Thames in London in 1825. The success of this project led Brunel to carry out a programme of testing of reinforced brickwork between 1835 and 1838. Initially he carried out load tests on a series of reinforced brickwork beams; this was followed by the construction of two semi-circular reinforced brick arches cantilevering from a prototype bridge pier. The use of reinforcement in the arches precluded the need for costly centering and falsework. Around the time of Brunel's tests, C.W. Pasley carried out similar tests on reinforced brickwork beams constructed with different mortar types. The results demonstrated improved performance with mortar containing a cementitious binder instead of lime [3]. By the turn of this century, the development of Portland cement and improvements in the performance and production of steel led to reinforced masonry being eclipsed by the emergence of reinforced concrete construction. Nevertheless, reinforced masonry continued to be used, notable examples being the Sidwell Street Methodist Church in Exeter, England and the Church of St.Jean de Montmartre in Paris, designed and built between 1900 and 1906 by the French structural engineer Paul Cottancin [3,4].

Much of the development of reinforced masonry followed the widespread damage to masonry buildings caused by seismic activity. As a result of the earthquake in Lisbon on 1 November 1755, timber members arranged in the form of a cage or *gaiola* were built into masonry walls to improve their seismic performance. A similar internal timber frame was also proposed for masonry buildings in Calabria, Italy following a series of earthquakes in 1783. Iron was suggested as an alternative to timber and it was eventually adopted as the principal reinforcing material in Southern Italy after a series of strong tremors struck the region in 1854 [2]. A great deal of credit for the development of seismically-resistant reinforced masonry construction must go to Sir Alexander Brebner, the Chief Engineer to the Government of India, who, between 1918 and 1923, carried out an extensive experimental study leading to the widespread use of reinforced masonry construction for slab and wall construction in buildings, culverts and bridges. Such structures were found to perform very well in the 1934 Bibar earthquake which prompted the extensive use of reinforced masonry in the reconstruction of Quetta (in what was then Northern India) following the devastating earthquake of 1937 [3,5]. In the USA, in spite of the poor performance of many unreinforced masonry buildings in the 1906 San Francisco earthquake, reinforced masonry only became recognised as an acceptable form of earthquake resistant construction after the 1925 Santa Barbara and 1933 Long Beach quakes and the earlier successes in India. It is now used fairly extensively in many of the seismically active regions of the world, particularly for low to medium rise building construction.

It is clear from the above brief review that many generations of engineers have recognised the potential benefits of building some form of reinforcement into new masonry construction. It should also be possible to strengthen or improve the performance of *existing* plain masonry structures by installing reinforcing bars, retrospectively, in regions where tensile stress is likely to develop or where it is desirable to introduce a measure of ductility. This paper describes a method of installing reinforcement into existing masonry structures hereafter referred to as "***retro-reinforcement***".

2. RETRO-REINFORCEMENT

The different stages of retro-reinforcing an existing masonry structure are summarised as follows:-

a) Any existing covering such as external render, plaster, vegetation or dirt that has accumulated on the surface of the structure is removed to expose the masonry.

b) Grooves or slots up to 10mm thick are cut into the mortar bed joints of the masonry; for repairs to brick masonry walls, the grooves are usually 50 - 70 mm deep. Although the use of a power disc cutter is often adequate for most repair work, in some cases it is necessary to exercise more control over the depth of cut. Equipment capable of achieving this with the added benefits of reduced dust emission and improved operator handling has been developed by Proprietary Reinforcement Engineering of England who are specialists in this type of work.

   In any case, 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. In some cases, for example when repairing severely deteriorated arches or other spanning members where the reduction in structural integrity caused by the cutting of grooves is a major concern, it is necessary to install the reinforcement in comparatively narrow band widths and to provide temporary support to the adjacent masonry.

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

d) Dust and debris are removed using compressed air or by washing with clean water.

e) A layer of cementitious 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. When injecting grout into a groove cut into a soffit, or where the existing masonry contains many voids, the use of low pressure mechanical pointing equipment is recommended.

f) 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. Stainless steel helical rod or flat strips of stainless steel may be used instead of reinforcing bar.

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

h) Additional bars, rods or strips 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.

i) 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.

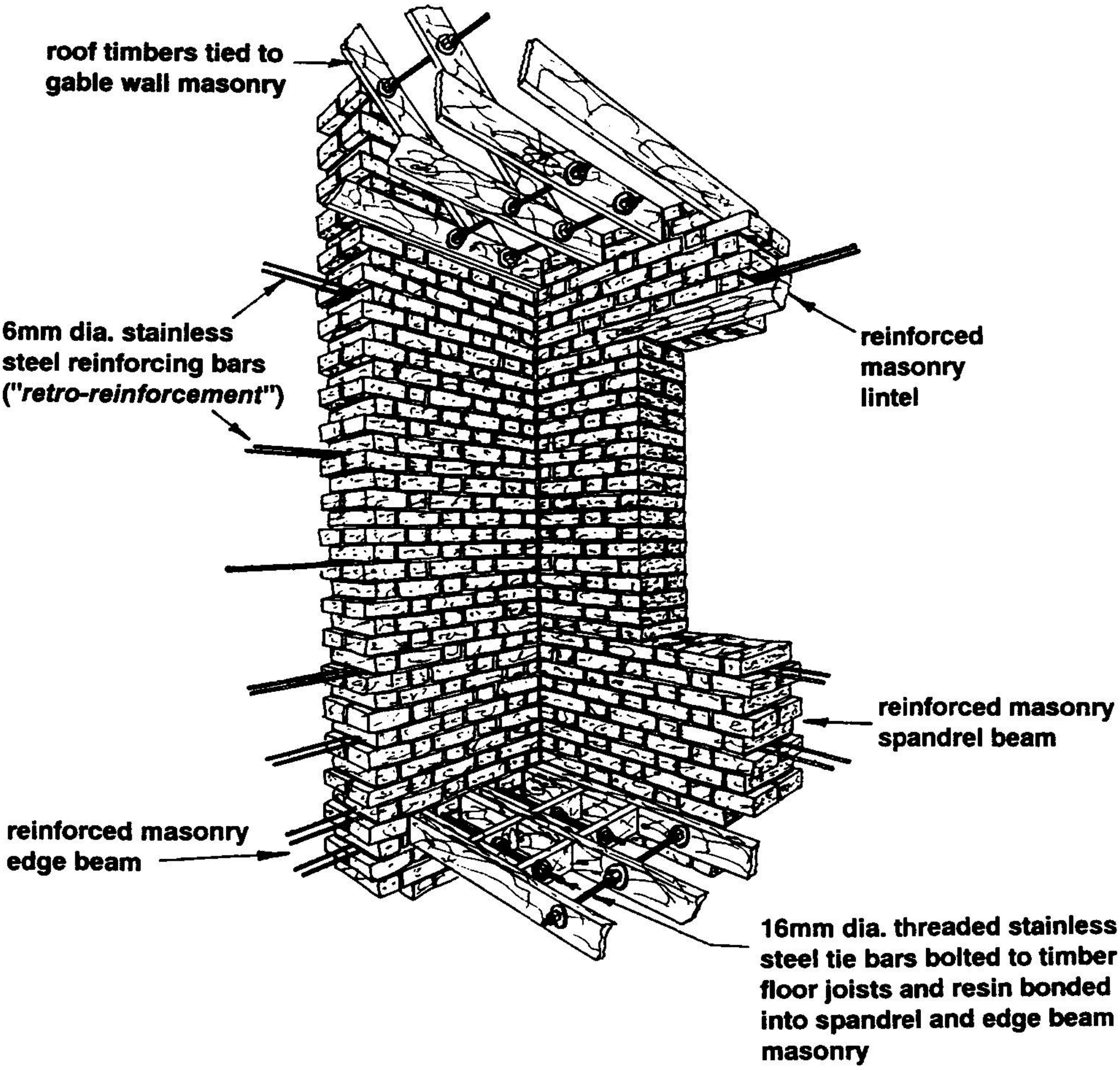

Fig. 1 Typical retro-reinforcement repairs to low-rise masonry construction

To date, retro-reinforcement has been used mainly to repair low-rise masonry buildings; a general example is given in Figure 1. Usually, the steel reinforcement is installed in the bed joints of regularly coursed brick or stone masonry. Although this is the simplest form of retro-reinforcement and is the easiest to disguise, it is possible to install diagonal and vertical bars in masonry structures using a similar approach.

3. 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 must also 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. Although retro-reinforcement is a very versatile technique, it is not a solution to ***all*** masonry repair and strengthening problems. 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. 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. Typical examples include building structures either damaged by or at risk from seismic activity, blast effects or other forms of impact loading. The technique has also been successful for the repair and strengthening of short span masonry arch bridges.

When designing or specifying any form of repair or strengthening works it is not only very important to correctly diagnose the cause of deterioration or cracking but also to determine the effects of the proposed remedial works on the behaviour of the complete structure. 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.

4. SUMMARY

Retro-reinforcement has already proved to be an effective and economical means of repairing and strengthening existing low-rise masonry buildings of historical interest [6]. 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 impact damage.

5. ACKNOWLEDGEMENT

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