EXPERIMENTAL INVESTIGATION OF PERFORATING MASONRY BRICK WALLS IN CENTER CORE REHABILITATION METHOD; DEVELOPMENT OF TECHNIQUES AND EQUIPMENT

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ABSTRACT

An advantageous method for retrofitting of brick unreinforced masonry buildings is center core. In this method vertical holes with given intervals are perforated through the brick walls to the footing and then reinforcing steel bars are embedded in the holes and grout will be injected finally to create bond strength between wall and bars. This method would not affect inner and outer appearance of the building; therefore it would be suitable for historical buildings. It could be also achieved without thorough evacuation of the building from residents and furniture. However, the difficulty of conducting such deep boreholes in weak and thin brick walls especially of older buildings remains a serious challenge in the method. So a practical investigation was designed to investigate the feasibility of the method and develop the techniques and equipment needed. This article aims to report the results of the experiment. However, the main contribution of the study has been finding new drilling techniques, designing and testing of the best suited drilling bit which is particularly appropriate for boring brick walls without deterioration and cracking.

INTRODUCTION

An advanced, advantageous method for retrofitting of un-reinforced masonry (URM) buildings is center core (CC). Center core strengthening system consists of a reinforced grouted core placed in the center of an existing URM wall. Coring a vertical hole from the top continuously through the wall into the existing footing will provide the core (Figure 1). Reinforcing steel bars are then embedded in these holes and grout would be injected finally to create bond strength between wall and bars. CC would not affect inner and outer appearance of the building (same as nondestructive methods), therefore it would be suitable for historical buildings. It could be also achieved without thorough evacuation of the building from residents and furniture because it can be done externally from the roof.

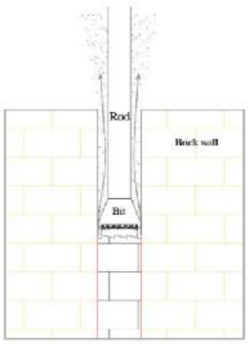

Figure 1. Boring process in Center core method

Since, CC is a newly introduced method mainly in the research phase, its related obscurities fall naturally into two parts. The first part encompasses analytical and experimental lateral load tests that would quantify the beneficial effects of CC operation. This part includes aspects such as the amount of seismic improvement of the method, design regulations, the resulting force-displacement characteristics of the retrofitted wall, in-plane and out-of-plane effectiveness of the method, spacing of bars, the size and grade of bars, the nature of the grout composition used to bond the bars and so on. A few researchers have investigated this part. Plecnik and Rao(1987) recommended field procedures for center core rehabilitation method. Breiholz(2000) suggested a design procedure for the method. Kehoe (1996) reported that the buildings rehabilitated with the CC technique sustained less damage than other UMBs in Northridge earthquake of 1994. Plecnik et al. (1986) made specimens rehabilitated with center core technique using various grouts. They did shear tests on these specimens and showed that specimens made with cement grout were generally weaker than specimens made with epoxy or polyester grouts. Abrams and Lynch (2001) used successfully the technique to double the resistance of URM wall in a static cyclic test. Some other researchers focused on retrofitting URM walls with post-tensioning tendons spaced at a regular interval. The selected retrofit technique incorporates vertical coring of URM walls same as CC to allow for the insertion of single post-tensioning tendons (Wight and Ingham, 2008). However, it must be emphasized that CC method requires much more profound studies until it becomes a promising retrofitting technique. This is the subject of a research currently under execution by the senior author and intended to be revealed in another paper.

The second part encompasses the feasibility and practicability study of the method. This part includes aspects such as effective techniques of perforating masonry brick walls in height without damaging walls, constructional methodology, drilling techniques and required equipment. Since, there was no previous experience of conducting CC in the region, serious doubts about the practicability of the method for a large number of buildings were encountered. An internet search did not reveal any serious investigation on this part either. Although, CC rehabilitation method based on perforating walls has been under consideration in recent years, the difficulties and uncertainties about deep perforating operation have made it infeasible. Iranian code of practice (2014) permits construction of only one or two-story masonry buildings, therefore, the target structures would be generally between three to seven meters high. The thickness of bearing brick walls are mostly between 20 to 40 centimeters. The difficulty of conducting such deep boreholes in weak and thin brick walls remains a serious challenge in the method. So a practical investigation is needed to investigate the feasibility of the method and develop the techniques and the required equipment. The focus of the present article is on the second part mentioned - finding special techniques of perforating holes in brick walls without destroying or cracking walls.

Figure 2. A vertical bore hole in a brick wall

Boring, drilling and coring are common practices in different fields of engineering. They might be done for site exploration in geotechnical or mining engineering, concrete, rock or wood sampling for material property tests, pit or tunnel digging and many other applications. There are many specifications, regulations and technical notes for each specific application. There has been done a lot of work to develop the related technology and equipment. However deep boring in thin old weak brick walls that is needed in CC method is a quite different process. It must be a deliberate and precise action to prevent damaging weak brick walls or finishing material. Only a very little deviation of the bit can be acceptable. There is little academic or practical research on this part. It might be owing to following reasons: a) CC is a new modern retrofitting method. b) Such researches may need costly practical experiments. Whatever the reasons are the uncertainties about CC implementation have prevented the widespread application of the technique. It is clear that successful and widespread use of CC would be completely dependent on revealing how it can be executed.

CENTER CORE METHOD

URM buildings are widely constructed in many countries. According to statistics, a significant number of existing buildings in many counties are masonry (Roy et al., 2013). This construction practice is widely used for following reasons: a) it is based on traditional masonry construction practice. b) It does not require highly qualified labor. c) It is cost-effective. d) It has a broad range of application. This construction type is addressed by codes of numerous countries.

Existing URM buildings, especially those constructed before the enforcement of enhanced seismic codes usually lack the necessary standards such as tie-columns and tie-beams. For this reason, they have long been recognized as the structures much vulnerable to earthquakes. Moreover, many old masonry applications are seldom properly designed and well supervised. While masonry does not exhibit measurable distress under gravity loading, its failure is widely reported even under moderate lateral loading. Such failures occur both in the load bearing and in the cladding masonry elements causing significant loss of lives and damages to properties (Dhanasekar, 2011). The loss of life attributable to their collapse during earthquakes is well documented and much of the structural damage produced by earthquakes was suffered by URM buildings. These buildings dangerously lack structural integrity mostly because of tie columns and tie-beams absence (Dhanasekar, 2002). Many structural components just rely on contact and friction to transfer gravity and lateral forces. Thus, beyond a certain threshold of seismic excitation, the various structural elements especially the brick walls risk to separate and behave independently during an earthquake. These buildings are vulnerable to flexural out-of-plane failure (Juan, 2000). Typically, walls especially the exterior ones may behave as cantilevers and fail in an out-of-plane manner. The unstable and explosive-like out-of-plane failure of URM walls can endanger the gravity-load-carrying capabilities of the walls and can seriously injure or kill occupants and passers-by. Excessive bending or shear may produce in-plane failures and familiar through-thickness cracks in masonry walls. In many cases, these more common cracks are overshadowed by simultaneous more spectacular type of failures, but nonetheless present (Drysdale,2005). For URM walls, in-plane shear failures are usually expressed by diagonal shear cracking . Fortunately until the shear cracks become unduly severe, the gravity-load-carrying capacity of walls is not jeopardized. However, in-plane shear cracking which can produce triangular cantilever wedges can therefore help precipitate out-of-plane failure of the weakened wall. In addition, in many facades having numerous window openings, spandrels and the short peers between them may also fail in shear. Flexural failure is also possible for those slender URM elements. Global structural failure can occur by slippage of the joists and roof beams from their supports. Many visible separations of walls and floors have been reported after earthquakes.

Center core rehabilitation method was introduced to obviate aforesaid barriers (ElGawady, 2004). In this method a vertical borehole is perforated from the top finishing to the base foundation and after embedding steel bars, is filled with filler grout. Depending on the thickness of the URM wall and the retrofitting requirements, the diameter of the bore may vary between 50 and 150 millimeters. The filler grout consists of a binder material (e.g. epoxy, cement, and polyester) and a filler material (e.g. sand). Grout penetration through the wall could create a homogenous and uniform system. The placement of the grout under pressure provided by the height of the core could provide a beneficial migration of the grout into all voids adjacent to the core shaft. The strong bonding of the grout to the inner and outer bricks provides a homogeneous structural element larger than the core itself. This reinforced homogeneous vertical column provides strength to the wall with a capacity to resist both in-plane shear and out of-plane bending. Flexural out-of-plane and in-plane shear capacity of the walls would be expected to increase noticeably. The purpose for strengthening out-of-plane forces is obviously to prevent the wall from falling in or falling out. Once a good wall diaphragm anchorage is accomplished, the reinforced core at the center of the section provides flexural capacity to add to the arching action capacity to keep the wall in place and in position to carry building vertical loads. The design strength of CC for out-of-plane flexure is based upon a yielding of the steel prior to any crushing of the masonry. The force developing the moment versus the flexural strength of the center core system will determine the spacing of the cores. In addition, openings, spandrels and the short peers could be retrofitted by this method. Because, the bars used in center cores can connect walls and the roof properly the danger of joists and roof slippage would be solved too. By CC method structural integrity of the whole building can be achieved. However, it should be emphasized again that the above sayings are mostly based on engineering judgments rather than certain research conclusions. The CC method requires much more analytical and experimental studies until it becomes a promising retrofitting technique.

BUILDING SELECTION

The difficulty of conducting deep boreholes in weak and thin brick walls without destroying or cracking walls is a serious challenge of center core method. Uncertainties about CC implementation have prevented its widespread application. It is clear that successful and widespread use of CC would be dependent on finding special techniques of perforating holes in brick walls without destroying or cracking them. Particularly for practical purposes of the project, this part must be investigated first. Therefore, a practical experiment was designed to investigate different drilling techniques and equipments. An old school located in Tehran was selected for the experiment. It is a three-story building aged about 50 years (Figure 3). Since the proposed drilling technique could be generalized, the selected building for the experiment needs to be studied under the most critical conditions such as:weak mortar,loose plaster and thin walls. The selected building had all the critical conditions mentioned.

Figure 3. View of the selected building

The experiment

To conduct the experiment five bore holes with maximum depth of seven meters were perforated in the selected building. Ten different drilling bits, two different drilling machines and several different stabilizers and guides were utilized in the experiment. Some important aspects can be summarized in brief. In general, the result of non-coring (NC) bit seems to be acceptable. A reason for deviation of the coring(C) bits could be the big cuttings of mortar and bricks. The big pieces of cuttings foul in bit teeth, bit contact surface or stabilizer and would deviate the bit. Therefore, the bits that produce tiny splinters would proceed on a straighter line. Two influential parameters in damaging the walls found to be: a) high air pressure which mostly happens near the bit and stabilizers locations, especially if the vertical seams between bricks are empty of mortar that would prepare a way to let air flow out; b) deviation or eccentricity of the bit and rods. The latter one would be more effective when the depth of bore and length of rod increases.

DESIGN OF THE BEST SUITED BIT

Bits are of coring or non-coring type. Each one has its own advantages and disadvantages in CC method. NC bit teeth are set in a circle round the bit. They penetrate in a straight line in the brick wall while the bit is turning round. They have a little contact surface. These characteristics lead to little deviation of C bits. This is a crucial parameter in boring brick walls in CC method. However, cores of NC bits are big cylinder-like pieces which cannot be taken out by air pressure. So the bit and core barrel should be pulled out from time to time. This slows down the process noticeably, especially in deep bores. In addition the necessity of use a core barrel with the same diameter increases air pressure when NC bits are utilized. C bits are faster than NC ones. However, more deviation or eccentricity from the straight line is expected. Some types of them produce big-sized cuttings that cannot be taken out easily by air pressure.

There are advantages and disadvantages with each of C and NC bits. None of them is perfectly suitable for boring brick walls. This fact occurs mainly because none of C and NC bits are designed for perforating brick walls in such a manner that is needed in center core method. They are originally made for coring or boring in soil, concrete, wood and so on. Deliberate deep vertical perforating in such a manner that is needed in CC needs a new design of bit type. Based on the gained experiences of the experiment, a new bit type particularly designed and manufactured for CC method is suggested. The newly designed bit is a combination of both of C and NC bits to have advantages of both while the disadvantages are dissolved. It is made of TC. In this design the coring bit teeth is installed in front. This part penetrates in the wall and cores. It would act like a guide which prevents bit deviation or eccentricity. Within a short distance the second part similar to a NC bit is present. The main duty of this part is grinding the produced core of the first part. The teeth on this part are of a shape and size to produce small splinters could be taken out easily by normal air pressure (Figures 4 and 5).

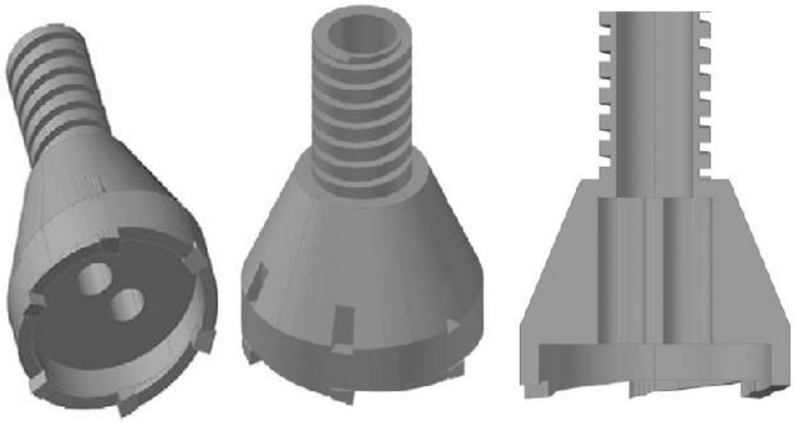

Figure 4. Three dimensional views of the newly designed coring & non-coring bit

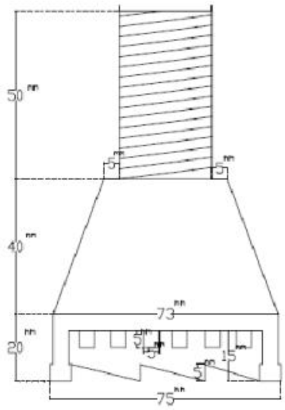

Figure 5.The newly designed coring & non-coring bit

The new manufactured bit (Figure 6) and stabilizer are utilized in a new bore experiment. The process started and after a very short time of drilling on the top cement-aggregate mortar, the process stopped to see the bit trace on the hard surface of cement mortar. As expected the coring part of the bit had penetrated in the surface and then the non-coring part ground the core.

Figure 6. The combined coring & non-coring bit

The results of the new coring & non-coring bit with use of a guide at the start point were perfectly appropriate. To see the bit performance the front bricks were removed at a part. The splinters were mostly of dust size. However some cuttings were larger due to rotation of the bit on weak mortar. No cracks happened in this stage at any part.The newly proposed bit which is a combination of C and NC bits is perfectly suitable in CC retrofitting technique. Its deviation from the straight line is negligible. It produces tiny splinters which could be taken out by a normal pressure of air flow. At this stage, by utilization of the new bit, application of the techniques developed in this experiment and notice to the experiences gained, perforating masonry brick walls in CC rehabilitation method would be easily practicable for brick masonry buildings.

CONCLUSION

Considering the experiences during the experiment presented in this paper, the following conclusions can be drawn;

1- Center core is a feasible method for retrofitting of brick masonry buildings. It is a suitable method for historical buildings and could be achieved without thorough evacuation of the building.

2- The bit type is a greatly influential parameter in successful boring process of a brick wall. Inappropriate selection of the bit type can result in damaging the wall or its finishing. Other effective parameters in damaging walls in CC method are: a) high air pressure which mostly happens near the bit and stabilizers locations, especially if the vertical seams between bricks are empty of mortar that prepares a way to let air flow out; b) deviation or eccentricity of the bit due to looseness of the rod connections, limp motor of the drilling machine and careless adjustment of the system. Whatever fewer pieces of rods are used in the system, the precision of boring would be higher.

3- Coring bits produce little deviation and this is their most important characteristic. In spite of high precision coring bits are not so fast due to several pull out of the bits for emptying the cores. This slows down the process noticeably, especially in deep bores. Necessity of use of a core barrel with the same diameter of the bit increases the air pressure when coring bits are used.

4- NC bits are faster than C ones. Rate of penetration with NC bits is high. However, these bits are not as precise as C bits. More deviation or eccentricity is expected when this type is used.

5- If NC bits are used, as the size of bit teeth increases, the deviation of the hole will increase. Larger cuttings lead to asymmetric engagement of the bit and cuttings and make changes in the axis of rotation. The teeth on the bit must be of the shape and size which can produce small splinters.

6- The most important result of this study is design and test of a new bit which is a combination of coring and non-coring bits. On the whole, this drilling bit contains a TC Coring bit which cores from the masonry walls. This part penetrates into the wall and cores. It would act like a guide which prevents bit deviation or eccentricity. In a short distance from the TC Coring bit, TC Non-Coring bit is installed. This bit crushes the cores and makes the cuttings ready for being removed from the hole as dust. The smaller the cuttings are the lower air pressure is needed to remove them. The results of the experiments showed that use of this innovative coring & non-coring bit was perfectly appropriate.

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