

Technical Notes 17 - Reinforced Brick Masonry - Introduction Reissued Oct. 1996

Abstract: The concept and use of reinforced brick masonry (RBM) has a long history. This Technical Notes documents the history of RBM. Recent and current code provisions are enumerated. Several applications of RBM show the variety of possible uses.

Key Words: applications, brick, constructions, history, reinforced brick masonry, reinforcement, research.

INTRODUCTION

Reinforced brick masonry (RBM) consists of brick masonry which incorporates steel reinforcement embedded in mortar or grout. This masonry has greatly increased resistance to forces that produce tensile and shear stresses. The reinforcement provides additional tensile strength, allowing better use of brick masonry's inherent compressive strength. The two materials complement each other, resulting in an excellent structural material. The principles of reinforced brick masonry design are the same as those commonly accepted for reinforced concrete, and similar formulae are used.

Brick masonry is one of the oldest forms of building construction, and reinforcement has been used to strengthen masonry since 1813. In the modern sense reinforced brick masonry in the United States is a relatively new type of construction, with specific design procedures and construction methods. These have been developed from experimental investigations beginning in the 1920's and with the experience of the performance of thousands of reinforced masonry buildings. These structures demonstrate the practicality and economy of the construction, and their performance confirms the soundness of the design principles. Figure 1 shows the Los Angeles Police Department, Devonshire Station, a reinforced brick structure, located 3 miles (4.8 km) from the epicenter of the Northridge earthquake. There was no structural damage and the building reportedly functioned as an emergency services coordination center following the 6.7 magnitude earthquake.



**Los Angeles Police Department, Devonshire Station
FIG. 1**

This Technical Notes presents the history of reinforced brick masonry with a review of recent research and applications. Other Technical Notes in this series provide information on the design of reinforced brick masonry including applications such as beams, lintels, and retaining walls.

HISTORY

Marc Isambard Brunel is credited with the discovery of reinforced masonry. He first proposed the use of reinforced brick masonry in 1813 as a means of strengthening a chimney then under construction. However, it was in connection with the building of the Thames Tunnel in 1825 that he made his first major application of reinforced brick masonry. As a part of the construction of this tunnel, two brick shafts were built, each 30 in. (760 mm) thick, 50 ft (15 m) in diameter and 70 ft (21m) deep.

The shafts were reinforced vertically with wrought iron rods 1 in. (25 mm) in diameter, built into the brickwork. Iron hoops, 9 in. (230 mm) wide and 1/2 in. (13 mm) in thickness, were laid in the brickwork as building progressed. The first shaft was built to a height of 42 ft (13 m) and then sunk by excavating soil from the interior, using what is now commonly known as the open method of caisson construction. The remaining 28 ft (8.5 m) of its height was added to the top of the shaft as it settled and was stabilized by underpinning.

In spite of unequal settlement of the shaft no cracks developed in the brick masonry. As a result, these cond shaft was built to its entire height of 70 ft (21 m) before it was lowered. Richard Beamish, in his Memoirs of the Life of Sir Marc Isambard Brunel [1], describes this construction and states that, after an unequal settlement of 7 in. (180 mm) on one side and 3 in. (76mm) on the other, "the surge was alarming, but so admirably was the structure bound together that no injury was sustained." Brunel continued the use of reinforced masonry and in 1836 constructed test structures in an effort to determine the additional strength imparted to the masonry by the reinforcement.

Other engineers became interested in this type of construction and in 1837 Colonel Pasley of the Corps of Royal Engineers conducted a series of tests on reinforced brick masonry beams and reported results comparable to those obtained by Brunel. Pasley's tests were designed to settle the prevailing argument as to whether the flat hoop iron used as reinforcement really strenthened brick beams.

Three beams were built, each 18 in. (460 mm) wide and 12 in (305 mm) (4 brick courses) deep, with a 10 ft (3 m) span. One beam was built without reinforcement, with the brick laid in neat cement. The second beam was also laid in neat cement, but this beam was reinforced with 5 pieces of hoop iron; two placed in the top mortar joint, one in the middle joint and two in the bottom mortar joint. The latter of these obviously carried most of the tensile stress. The third beam was reinforced in the same manner as the second beam, but the brick were laid in a mortar composed of 1 part lime and 3 parts sand. The first beam failed at a load of 498 lb (2.2 kN); the second beam carried 4723 lb (21.0 kN); and the third beam failed at between 400 and 500 lb (1.8 and 2.2 kN); thus settling the dispute. The results point out that bond between the brick, mortar and reinforcement develops when cement-based mortars are used.

As indicated by the placement of the reinforcement in Pasley's beams, the manner in which steel and masonry act together to resist forces was not completely understood at the time. The empirical formulae dereved from such tests could not be used to determine dimensions and reinforcement of structural members varying in cross section or span from those tested. However, the interest in reinforced masonry construction continued and, with the increased use of cement in mortar, additional tests were conducted.

One such test that received widespread publicity was a reinforced brick beam tested at the Great Exposition in London in 1851. The "new cement," commercially known as Portland Cement was used in the construction. This test was highly successful, and the publicity which it received resulted in the more widespread use of portland cement in several European countries and, to a lesser degree, in the United States.

N. B. Corson published an article in the July 19, 1872 issue of Engineering [5] in which he reviewed the data obtained from the Exposition's test beam, Brunel's test structures, tests of unreinforced masonry beams and arches, and the performance of a large number of masonry structures. From these data, Corson computed tensile stresses of unreinforced masonry and recommended an allowable tensile stress for use in the design of masonry lintels. This appears to be the first recorded technical discussion of the relation of tensile strength of masonry to mortar strength. However, it did not recognize the full effect of the metal reinforcement in increasing the tensile strength of a member.

The use of reinforced brick masonry continued to spread. The benefits of combining the tensile strength of iron or steel with the compressive strength of masonry was evident to those familiar with the potential damage of earthquakes. The Palace Hotel opened in San Francisco in 1875, covering a full city block, rising seven stories in height. The 3 ft (0.9 m) thick solid brick walls were reinforced by iron bands every few feet. These formed a "basket" that completely encircled the building. This is one of the few large structures that endured the 1906 San Francisco earthquake [2].

During the period 1880 to 1920, there was little recorded use of reinforced brick masonry and experimental investigations of this type of construction appear to have been practically discontinued.

In 1923, the Public Works Department of the Government of India published Technical Paper No. 38 [3], a comprehensive report by Undersecretary A. Brebner of extensive tests of reinforced brick masonry structures extending over a period of about two years. A total of 282 specimens were tested, including reinforced brick masonry slabs of varying thickness, reinforced brick beams, both reinforced and unreinforced columns, and reinforced brick arches. The tests reported by Brebner appear to be the first organized research program on inforced brick masonry and the data obtained provided answers to questions raised regarding this type of construction. This research marks the initial stage of the modern development of reinforced masonry.

Following Brebner's report and his statement of a rational design theory for reinforced brick masonry, its use increased, particularly in India and Japan. Both countries are subject to severe earthquakes, and buildings expected to withstand such shocks must be designed with relatively high resistance to lateral forces. Since structural steel and suitable lumber for concrete formwork were relatively expensive in these countries, engineers turned to reinforced brick masonry. It became standard construction for public and important private buildings, as well as for many types of engineering structures, such as retaining walls, bridges, storage bins and chimneys.

Brebner wrote in 1923 of reinforced brick masonry, "In all, nearly 3,000,000 ft² (279,000 m²) have been laid in the last three years." Skigeyuki Kanamori, Civil Engineer, Department of Home Affairs, Imperial Japanese Government, is reported in the July 15, 1930 issue of Brick and Clay Record [7] as stating, "There is no question that reinforced brickwork should be used instead of (unreinforced) brickwork when any tensile stress would be incurred in the structure. We can make them more safe and stronger, saving much cost. Further, I have found that reinforced brickwork is more convenient and economical in building than reinforced concrete and, what is still more important, there is always a very appreciable saving in time." Structures described by Kanamori include sea walls, culverts and railway retaining walls, as well as buildings.

Research in the United States, sponsored by the Brick Manufacturers Association of America and continued by the Structural Clay Products Institute and the Structural Clay Products Research Foundation contributed much valuable material to the literature on reinforced brick masonry. Since 1924, numerous field and laboratory tests have been made on reinforced brick beams, slabs and columns, and on full size structures. Fig. 2 is an example of a 1936 test to demonstrate the structural capabilities of reinforced brick masonry elements.



**Early Test of RBM Element
FIG. 2**

During this period, research was conducted on both reinforced and unreinforced brick masonry at the National Bureau of Standards, now the National Institute of Standards and Technology, and at practically all of the principal engineering colleges of the United States. As new data was developed through research, the erratic performance of some of the earlier reinforced brick test specimens could be explained and, one by one, the principal variables affecting the strength of reinforced brick masonry have been identified and, to large degree, evaluated.

In 1933 the Brick Manufacturers Association of America published Brick Engineering, Vol. 111, Reinforced Brick Masonry, by Hugo Filippi [6]. Regarding the uses of reinforced brick masonry, the author states, "Reinforced brick masonry is well adapted for use in the following types of structures, either wholly or in part: Buildings, Culverts and Bridges; Retaining Walls and Dams; Reservoirs; Sewers and Conduits; Tanks and Storage Bins; Chimneys and Circular Constructions; Abutments, Piers, Trestle Bents, etc.

"In the United States alone, during the past year and one-half, more than 40 individual jobs of reinforced brick masonry have been built, consisting of such distinctive types of construction as highway bridges, storage bins, industry track trestle piers, floor and roof slabs, beams, girders and long lintels. At the present time approximately 50 additional jobs are either under construction or under consideration in various parts of the country."

During the period referred to by Filippi, the development and use of reinforced brick masonry in the United States were in their early stages. A significant change in the use of RBM came after the 1933 Long Beach earthquake. It was realized that unreinforced structures were susceptible to major damage from earthquakes and that RBM could be used to save lives. Codes were developed that promoted the use of reinforced structures. Since that time thousands of such structures have been built and reinforced brick masonry construction has been adopted as standard practice for various types of structures in many areas.

RECENT RESEARCH

Research on reinforced brick masonry has continued. In 1984, the Technical Coordinating Committee for Masonry Research (TCCMAR) was formed for the purpose of defining and performing both experimental and analytical research and development necessary to improve structural masonry technology [9]. A unique aspect of this research was a phased step-by-step program of separate, but coordinated research tasks. Initial research on materials was used in later tests on assemblies. These led to tests of building elements and then the combination of wall and floor elements. The research culminated in a full-scale, five story structure subjected to dynamic loading in 1993. Much of the research led to the development of a limit states design procedure for masonry.

Interest in better utilization of brick masonry's high compressive strength has led to research in prestressed brick masonry. Knowledge about this form of reinforced brick masonry was increased by research in Great Britain. Research is currently underway in the United States, as is the development of design procedures.

BUILDING CODE PROVISIONS

Building codes first covered reinforced brick masonry in 1953 in the American National Standards Institute's A41.2 document [4]. Since that first code on RBM, other codes such as the Uniform Building Code and the Masonry Standards Joint Committee Code (ACI 530/ASCE5/TMS 402) have adopted provisions.

Most code provisions on reinforced masonry are based on allowable stress design (ASD). In ASD, the reinforcement in masonry is designed to resist all tensile forces. The reinforcement increases the masonry's shear resistance and may contribute to the compressive strength. The stress-strain relationship is linear at working loads and the strain is proportional to the distance from the neutral axis. Code requirements cover axial compression, flexure, and shear.

The Uniform Building Code has provisions for slender wall design, which is loosely based on strength design. A more comprehensive design method, known as limit states design is in development. Limit states design considers the actual performance of the materials as they undergo load and deformation. Significant changes in the state of stress, such as cracking of the masonry and yielding of the steel, are identified. The capacity, or strength, of the element at these limit states is compared to that required to resist the applied load. These code provisions are expected to provide a complement to ASD.

BASIC CONSTRUCTION PROCEDURES

The earliest method of placing reinforcement into brick masonry was simply to place iron or steel bars in mortar joints as the bricks were laid. Later the reinforcement was placed in collar joints between two masonry wythes and surrounded by mortar or fine grout.

Eventually the space between wythes was increased in width and filled with grout. Horizontal reinforcement and grout were placed as the outer wythes were completed. The next development was the "High Lift Grouting System" in which the brick masonry wythes are built up around the reinforcement and allowed to set for a minimum period of three days. Then grout is pumped into the space containing the reinforcement. This method was developed in the San Francisco area during the late 1950s. This double wythe reinforced brick masonry is shown in Fig. 3.



Double Wythe Reinforced Brick Masonry
FIG. 3

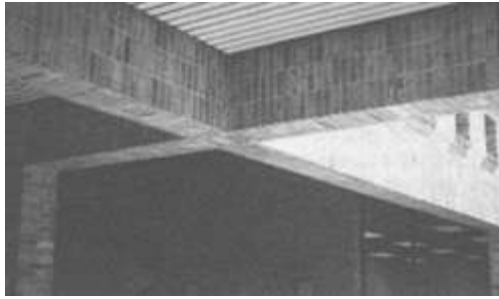
The most recent means of constructing reinforced masonry incorporates hollow brick. These units are manufactured with large open cells which align vertically when the units are laid. Vertical reinforcement is placed in the cells by laying the brick over or around the bars, or by threading the bar in after the brick are laid. Horizontal reinforcement is placed in bed joints or in continuous bond beams made by removing portions of the webs that connect the face shells. Spaces containing reinforcement are grouted in lifts of up to 5 ft (1.5m) to make grout pours of up to 24 ft (7.3m). Construction of reinforced hollow brick masonry is shown in Fig. 4



Reinforced Hollow Brick Masonry
FIG. 4

APPLICATIONS AND EXAMPLES

During the past 60 years, reinforced brick masonry has been used for the construction of a variety of structures. In those countries where labor costs are low, one of its principal uses has been for the construction of floor and roof slabs. However, in the United States, its most extensive use has been in the construction of vertical members, such as walls and columns. Since no forms are required for these members, reinforced brick masonry is competitive with reinforced concrete, and walls of minimum thickness and light structural members can be constructed at substantially less cost in reinforced brick masonry than in reinforced concrete. Reinforced brick beams and lintels allow the designer to achieve exposed brick on the underside of these elements as in Fig. 5.



Reinforced Brick Beams
FIG. 5

This provides a horizontal finished surface that matches the vertical surface. The idea of brick hanging upside down must be disconcerting. Some designers seem reluctant to use RBM construction for brick lintels or soffits. As demonstrated by tests since 1837, the bond of the mortar and grout to the brick holds the brick in place.

Structures of all sizes, from single story residences to 23 story buildings have been constructed of reinforced brick masonry as shown in Figs. 6 and 7.

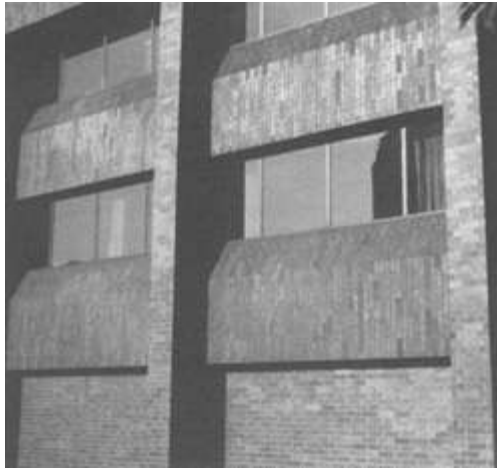


Reinforced Brick Masonry Single Family Residence, Ashbrun VA
FIG. 6



Reinforced Brick Masonry High Rise, Cleveland, OH
FIG. 7

The applications range from retaining walls to exterior cladding. The added tensile strength of the reinforcing steel opens the possibility for prefabricated brick panels. This method of design and construction is utilized frequently to achieve unusual shapes and bond patterns in brick masonry. See Fig. 8.



Reinforced Brick Masonry Panels
FIG. 8

SUMMARY

The use of reinforced brick masonry has been recorded for over 175 years. RBM construction has been adapted to a wide variety of applications throughout its history. Beams, column, pilasters, arches, and other RBM elements have been used in buildings, culverts, retaining walls, silos, chimneys, pavements and bridges. Continuing research on RBM results in more economical structures able to withstand all types of loading.

The information and suggestions contained in this Technical Notes are based on the available data and the experience of the engineering staff of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this Technical Notes are not within the purview of the Brick Institute of America and must rest with the project architect, engineer and owner.

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