

Modern Brickwork Highway Structures

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Clay brickwork is set to reemerge as a major structural material with the growing emphasis on designing aesthetically pleasing highway structures with low maintenance costs. This paper addresses the use of clay brickwork construction for new highway structures such as earth retaining walls, short-span arch bridges and bridge abutments, piers, parapets, and wingwalls. The performance of existing masonry structures is appraised, the principal design requirements for new brickwork structures are identified, and recent research and development is summarized. Two recently completed bridges with major elements of structural clay brickwork construction are described in brief.

Many of the canal and railway structures built in Britain during the eighteenth and nineteenth centuries, such as earth retaining walls, viaducts, arch bridges, and tunnel linings, were of unreinforced clay brickwork construction. Although most of these structures have been under very severe exposure conditions for long periods, many are still in service. They have needed comparatively little maintenance, in part due to the inherent durability of many types of well-fired clay brick. Although clay brickwork and other forms of masonry such as dressed stone and concrete bricks and blocks now tend to be used merely as cladding, a number of structurally efficient, cost-effective forms of masonry construction developed in the last 30 years are likely to be suitable for new highway structures.

The aim of this paper, therefore, is to investigate the viability of clay brickwork construction for new high-

way structures such as earth retaining walls, short-span arch bridges and bridge abutments, piers, parapets, and wingwalls. The following aspects of brickwork construction are considered:

1. Critical review of existing brickwork highway structures,
2. Design requirements for new brickwork highway structures,
3. Plain or unreinforced brickwork,
4. Reinforced brickwork,
5. Prestressed brickwork, and
6. Case studies of Foxcovert Road Bridge and Kimbolton Butts Bridge.

EXISTING BRICKWORK HIGHWAY STRUCTURES

If highway and bridge engineers are to consider clay brickwork for use as a structural material, they must develop modern designs that retain the benefits of old forms of brickwork construction but overcome the limitations. Some understanding of the limitations may come from a critical review of the construction and performance of existing arch bridges such as the one shown in Figure 1, which is typical of nineteenth century construction in the United Kingdom. Different aspects of the performance of such bridges are reviewed.

Materials

Most brick arch bridges were built using weak hydraulic or semi-hydraulic lime mortar, with little or no at-

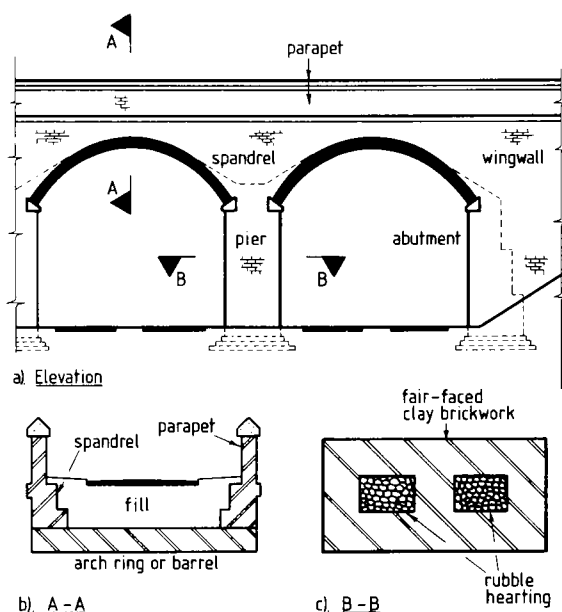


FIGURE 1 Typical brickwork arch bridge details: (a) elevation, (b) A-A, (c) B-B.

tempt to protect the joints from rainwater leaching through the fill material from the carriageway above. Although such mortars are capable of accommodating movements due to changes in the ambient conditions and small amounts of differential settlement, they are prone to deteriorate from the effects of frost, and lime can leach out of the mortar, leaving unsightly calcium carbonate deposits on the exposed faces of the brickwork. As a result, the bricks have tended to become debonded from the mortar, causing a severe reduction in the tensile strength. Furthermore, the aesthetic quality of some structures has been reduced considerably by lime staining and fungal growths on damp patches of brickwork. Other less common causes of deterioration include abrasion from wind and water, salt crystallisation damage, and the effects of the expansive reaction between cements and sulfates in groundwater or polluted air.

As far as clay bricks are concerned, there have been relatively few problems. The main form of deterioration has been the progressive degradation of the exposed faces of some bricks due to freeze-thaw action, although this has not occurred where the bricks have remained relatively dry or where well-fired, low porosity engineering bricks have been used.

The Arch

The inherent strength of the voussoir arch ring or barrel is well known (1); where distress has occurred it has

often been due to failure of the abutments or piers resulting either from scour or from the excessive settlement typical of shallow, inadequate foundations (2). There can be little doubt that most arch bridges built today would not suffer from such problems because of the vast improvements both in ground investigation techniques and in foundation design and construction.

Although the curved profile of the arch undoubtedly contributes to its aesthetic appeal, the low headroom close to the supporting abutments or piers of highway overbridges can result in "bridge bashing," that is, damage from tall vehicles. In addition, flooding can occur where arch bridges span watercourses, because the bridge creates an increasingly greater obstruction to flow as the water level rises.

As many of the proposals for new brickwork highway structures are for vertical elements of construction, it is appropriate to consider the wingwalls, parapets, spandrels, abutments, and piers of arch bridges in more detail.

Wingwalls and Spandrel Walls

These walls are subjected to horizontal earth pressure from the fill material placed at the ends and over the top or extrados of the arch ring. In addition, the spandrel walls and, to a lesser extent, the wingwalls stiffen the outer edges of the arch ring. The combined effects of lateral pressure and the central portion of the arch ring deforming under the action of live loading can lead to cracking and eventually partial collapse, as the wingwalls and spandrel walls become separated from the rest of the structure (3,4). This behavior is, again, indicative of brickwork's low tensile strength and is often exacerbated by rainwater leaching through the fill material into the mortar joints (5), as described above.

The craftsmen of the past were certainly aware of brickwork's very low and sometimes unreliable tensile strength. To overcome this, they usually built very thick wingwalls and spandrel walls, the aim being to provide sufficient dead weight to counteract any flexural tension caused by the lateral earth pressure. As this philosophy was also used when designing and building masonry earth retaining walls, it is not surprising that some of the solid brickwork walls built by Victorian railway engineers to support the sides of deep cuttings were well over 2 m thick in places.

Parapet Walls

The principal function of the parapets of any highway bridge is to contain a vehicle collision in as safe a manner as possible. In the case of masonry parapets, it is

very difficult to quantify the impact resistance because of the very complex behavior of unreinforced masonry when subjected to high rates of loading from a non-rigid body such as a vehicle. In order to assess the behavior and strength of masonry parapets when subjected to vehicle impact the County Surveyor's Society of the United Kingdom recently funded a research program that included a series of full-scale vehicle impact tests on masonry parapets at the Motor Industry Research Association in Nuneaton, England (6); all the tests were carried out in accordance with Appendix E of BS 6779 (7). Although most of the tested masonry parapets adequately confined the test vehicle, the research indicated that some existing walls may need to be modified to minimize the safety hazard caused by the masonry projectiles produced immediately after impact.

Piers and Abutments

Although usually of solid masonry, some piers and abutments were built with an outer skin of fair-faced stone or clay brick masonry with a low cost rubble infill or hearting (8).

As the compressive stress due to the vertical loads acting on a pier or an abutment of an arch bridge tends to be greater than the flexural tensile stress produced by the lateral forces, the masonry is generally in a net state of vertical compression throughout. Therefore, provided that the compressive stress is small, the piers and abutments can remain in an uncracked and stable condition for many years. As with the wingwalls and spandrel walls, piers and abutments were usually of massive construction to ensure sufficient dead weight to maintain the masonry in a net state of compression.

Lime mortars were used extensively in brickwork construction. The compressive strength of such mortar was invariably an order of magnitude lower than that of the bricks. Hence, it is very likely that the compressive stresses in the bricks of existing structures are very low, which may explain why there have been very few collapses resulting from compression failures. Where piers and abutments have failed, it has usually been as a result of tensile stresses or instability caused either by scour, excessive ground movements, or the effects of severe overloading produced by modern traffic.

Construction

The arch rings of masonry bridges were constructed in-situ on temporary centering. This was usually of timber construction and often consisted of an elaborate array of interconnected diagonal members, which was necessary to provide a stiff platform on which to build the

arch. Invariably the installation of centering was very time consuming and often fraught with delays arising from the combination of inclement weather and the complexity of construction.

As noted previously, most vertical structural elements of arch bridges were of massive construction to provide stability. As a result, arch bridge construction was very slow and very labor intensive, sometimes involving huge numbers of bricks: the 544-m-long, 27-arch Victorian railway viaduct in Stockport, England (9), is thought to consist of some 22 million bricks.

Taking into account the slow, labor-intensive construction methods and the difficulties experienced with the construction of centering, it is not difficult to appreciate why there was a decline in the use of masonry as stronger alternative materials such as cast iron, wrought iron, structural steels, and reinforced concrete were developed.

Workmanship

Judging by the results of many highway schemes that have involved the use of brick clad reinforced concrete it is clear that, with adequate supervision, very high quality brickwork can be achieved.

An advantage of brickwork is that the main construction defect, namely poorly filled mortar joints, can be detected by visual inspection. With reinforced concrete construction, durability depends on ensuring that the permeability of the surface zones of concrete is reduced as much as possible in order to provide the maximum protection to the steel reinforcement. This is achieved by using well compacted concrete with a relatively high cement content and a low water:cement ratio; surface porosity is further reduced by good curing. In practice, however, it is difficult to check the porosity and permeability of the concrete because the capillary pores in the cement paste, which permit the ingress of chloride ions and other deleterious substances, are microscopic. Hence, although the finished concrete may appear satisfactory to the naked eye, there is no way of easily checking that the quality of the cover concrete is adequate without carrying out in-situ permeability measurements. In short, it is not possible to visually inspect the concrete for quality. The water:cement ratio of the mortar in brickwork construction, however, does not have the same influence on durability, and only very inaccurate batching and poor mixing of the mortar constituents is likely to cause major problems in the future.

DESIGN REQUIREMENTS FOR NEW BRICKWORK HIGHWAY STRUCTURES

All structures must be strong, stable, robust and safe. Taking into account the points raised in the critical re-

view and the experience gained from the deterioration of some reinforced concrete structures, the additional requirements of new brickwork highway structures are summarized below.

Construction Methods

Construction methods must be simpler and quicker than in the past and must involve less labor and materials. Mortars in which the principal binding agent is ordinary portland cement rather than lime should also be used, as the rate of strength gain is conducive to ensuring the rapid construction times required by most clients.

Structural Form

Judging from the problems that occur with old arch bridges, it appears that major improvements need to be made to the laterally loaded structural elements, namely the parapets, spandrels, and wingwalls. To improve structural performance and reduce construction times and cost, it is necessary to adopt more efficient forms of construction that make optimum use of brickwork's relatively high compressive strength but overcome its inherently low tensile strength. It is therefore suggested that reinforced or prestressed forms of brickwork construction be used as alternatives to the massive forms of construction used in the past.

Compressive Stresses

Although modern cement-based mortars are much stronger than lime mortars, in order to reduce the risk of overstressing the bricks, a low compressive stress limit should be used when designing new brickwork structures.

Durability

New brickwork structures must be durable and easy to maintain. In particular, where any steel is used in construction, it is necessary to minimize the risk of corrosion caused by chloride attack from deicing salts and other sources. More durable mortars are preferable to the lime-based mortars of old, which were very prone to weathering and erosion.

A durable combination of bricks and mortar that is resistant to frost and chemical attack therefore must be specified. The guidance given in BS 5628: part 3 (10) recommends the use of frost resistant clay bricks with

a low soluble salt content; such bricks are defined as "durability designation FL" in BS 3921 (11). In addition, brick specifications should include a maximum water absorption of about 10 to 12 percent and a minimum compressive strength of about 50 MPa. Where the brickwork is likely to remain saturated for long periods, the use of bricks with a lower water absorption may be necessary.

The most appropriate mortar mix for highway structures will generally be a weigh batched 1:1/4:3 OPC:lime:sand mix (ASTM type M). Some engineers recommend the use of a styrene butadiene rubber (SBR) latex additive in the proportion of 6 litres of SBR per 50 kg of OPC. The SBR acts as a bonding and waterproofing agent, and may help reduce lime staining of the mortar joints and facilitate the removal of graffiti. New brickwork highway structures must be adequately waterproofed and drained to reduce the risk of deterioration from freeze-thaw action.

Aesthetics

Brickwork highway structures must be aesthetically pleasing. In addition to providing adequate waterproofing and drainage to prevent the occurrence of damp patches and the growth of unsightly fungi, measures must also be taken to minimize the risk of efflorescence and lime staining.

Movement

Cement mortars, which often contain a non-hydraulic lime plasticizer, are used exclusively in new construction; such mortars are much more brittle than their hydraulic lime-based predecessors. As a result, with modern brickwork construction it is essential to provide joints capable of accommodating movements due to moisture and thermal effects.

Cost

Brickwork structures must be cheaper to construct than brick faced concrete structures. Many engineers are familiar with reinforced concrete design and construction and are, perhaps, reluctant to use alternatives. Although some engineers may accept that clay brickwork structures can have very low whole-life costs, the prospect of initial cost savings is probably necessary to motivate most to consider brickwork as an alternative to structural concrete. New forms of plain, reinforced, and prestressed brickwork have been developed, which may

satisfy some or all of the above criteria and are therefore worth further consideration.

PLAIN OR UNREINFORCED BRICKWORK

Plain brickwork is commonly used for the stems of low-rise earth-retaining walls. To provide the necessary stability against overturning, walls up to 1 m high may need to be up to 665 mm (three bricks) thick. In the last 30 years, more structurally efficient alternatives to the solid brickwork wall have been developed, as discussed below.

The Cellular or Diaphragm Wall

Although the diaphragm wall was originally developed as an alternative to the brick-clad steel or concrete frame for tall single story buildings (12), it has also been used for earth retaining walls (13). It consists of two wythes or flanges of brickwork linked by brickwork webs to form a series of interconnected I-sections. Separation of the leaves of brickwork by the webs considerably increases the second moment of area of the wall, with a very small increase in the amount of brickwork; hence the cellular wall is much more structurally efficient than the solid wall. The cellular spaces in the brickwork can be filled with selected fill material or lean mix concrete to increase stability, and a pleasing effect can be created by topping the fill with plants.

Brickwork-Faced Reinforced Soil

This is a form of reinforced earth where the soil reinforcement is built into the bed joints of a brickwork wall. As with other forms of reinforced earth, the facing material, in this case the brickwork, is likely to be very lowly stressed. Indeed, its principal role is that of a durable protective cladding that also retains the edges of the soil mass. It must also be capable of resisting any localized earth pressures created during the compaction of the fill material.

This form of construction was probably first used in the United Kingdom by highway engineers from West Yorkshire County Council, England, following trials in 1977. Later, research using "Terram" geotextile at the University of Leeds (14,15) and "Tensar" geogrid at the University of New Brunswick, Canada (16,17), confirmed that the effective strength of small earth retaining walls could be substantially increased with the addition of soil reinforcement with a very small increase in cost. This technique seems to be particularly suitable for repairing and strengthening existing masonry earth re-

taining walls; as far as the author is aware, it is rarely used for new construction in the United Kingdom.

NEW BRICKWORK ARCH BRIDGES

The improvements in ground investigation techniques and the design and construction of foundations referred to earlier, coupled with the development of lightweight, easy-to-install falsework suitable for centering, may make the brickwork arch an economically viable form of new construction for small span bridges. Furthermore, experience in the United Kingdom has shown that the maintenance costs for masonry arch bridges can be on the order of 30 percent less than those for other forms of bridge construction (18). The aesthetic appeal of the unreinforced brick or stone masonry arch and the anticipated savings in whole-life costs have prompted many bridge owners in the United Kingdom, such as the Department of Transport, the Scottish Office (19), and some local regional Highway Authorities (18,20), to recommend the use of the masonry arch form of construction for new short span bridges. One of these, Kimbolton Butts Bridge, is described below.

Judging from the above, many engineers recognize the potential advantages of brick and stone masonry arch bridges. However, few bridges of this type are likely to be built until a lower cost, more rapid method of arch construction is developed; such a technique, which involves the use of prefabricated brickwork arch rings, is currently at the very early stages of development at the University of Bradford (21). In addition, the critical review has identified the need to adopt forms of construction that can overcome the aforementioned problems with the spandrel walls, wingwalls, and parapets of arch bridges. Reinforced or prestressed brickwork can be used for such structural elements and others subjected to large magnitude lateral loading, such as bridge piers, abutments, and earth retaining walls; these are considered in more detail below.

REINFORCED BRICKWORK

As noted previously, a major limitation of plain brickwork is its low flexural tensile strength. However, as with other low tensile strength materials such as concrete, the flexural strength of brickwork can be increased considerably with steel reinforcement. This concept is not new; indeed, Brunel is reported to have used a form of reinforced brickwork for the construction of the Wapping to Rotherhithe Thames tunnel caissons in London in 1825 (22). In a design guide published in the United States in 1953 (23), the use of reinforced brickwork is cited for several types of structure, including

earth retaining walls, bridges, and culverts built in India and Japan during the period 1919–1930. A highway bridge, built in Ohio in 1934 with reinforced brickwork parapets, abutments, and piers, is also described. More recently, the use of reinforced brickwork for the construction of earth retaining walls (24,25) has been reported.

Cost studies by independent quantity surveyors (26, 27,28) have shown that, in the case of retaining walls, reinforced brickwork construction may be a cheaper alternative to brick clad reinforced concrete. Similar economies may also be possible for other structures where an exposed brickwork finish is required. Although some small earth retaining walls were built in London in the 1960s and in Dartford, Kent in the mid-1970s (29), there has been comparatively little use of reinforced brickwork construction in the United Kingdom. There is, however, considerable knowledge of the behavior of reinforced brickwork earth retaining walls. Research was conducted at the Building Research Establishment (30), at Edinburgh University (31,32), and at the British Ceramic Research Association (33,34) during the 1970s and early 1980s. More recently Redland Brick Limited and the Brick Development Association have sponsored a program of full-scale testing at British Ceramic Research Limited (35). As well as funding research, various U.K. brick manufacturers have built trial walls, notably George Armitage and Sons (now Marshalls Clay Products) (36) and Butterley Brick Limited, who investigated the feasibility of using prefabricated retaining wall panels (37). As a result of this research and development, two main forms of reinforced brickwork have emerged for the construction of laterally loaded walls, namely, the reinforced grouted cavity wall and the reinforced pocket-type wall; more recently the reinforced cellular or diaphragm wall has been suggested as an additional form of reinforced brickwork construction (38).

The most likely uses of reinforced brickwork are for laterally loaded structures such as noise barriers, earth retaining walls, wingwalls, small bridge abutments, and bridge parapets. A more detailed review of reinforced brickwork for highway structures, including a comparison of the different forms of construction and case study details, is given in the references (39); reinforced grouted cavity and reinforced pocket-type walling were also used for the case study bridges described in this paper.

PRESTRESSED BRICKWORK

It is likely that prestressed brickwork will be more economical than reinforced brickwork for the construction of most bridge piers, abutments, and tall earth

retaining walls. The development of prestressed brickwork is still at a relatively early stage; most uses have been in building construction where vertical walls must resist a large horizontal thrust from a sloping roof or surge effects from crane girders. Prestressing has also been used to improve the resistance of brickwork walls to the effects of settlement and seismic activity. As far as highway structures are concerned, laboratory-based full-scale tests of prestressed brickwork retaining walls (40,41) and a bridge abutment (42,43) have been reported. Design guidance is given in part 2 of BS 5628 (44) and elsewhere (45,46,47). The aforementioned tests have shown that the design shear strength recommendations of BS 5628: part 2 are conservative when applied to sections suitable for highway structures; a new design method proposed for revision of BS 5628: part 2 and the proposed Eurocode for masonry, EC6, based on recent research (48), should lead to greater economy.

The main aim of prestressing brickwork is to produce sufficient vertical compressive stress to counteract any tensile stresses that would otherwise have been caused by lateral loading. Even when subjected to design ultimate loads, the maximum compressive stress in the brickwork due to combined prestress and flexural compression is unlikely to be greater than 6 or 7 MPa, hence the brickwork stresses are relatively low.

As bridge piers and abutments are subject to a vertical compressive force from the bridge deck that they support and to reversible horizontal forces caused by traction, skidding, wind, and temperature changes, the most appropriate form of brickwork construction is likely to be symmetrical, such as the cellular or diaphragm wall.

In many respects the prestressed brickwork diaphragm wall is the modern equivalent of the cellular masonry piers and abutments built well over 100 years ago; both forms of construction are hollow or cellular and in both cases the masonry is always in a state of vertical compression. Details of a typical abutment are given in Case Study 1, below.

CASE STUDY 1: FOXCOVERT ROAD BRIDGE

This bridge carries the Glington-Northborough bypass over a minor road that links the villages of Glington and Werrington to the north of Peterborough, England. It was designed by the engineers of the Transportation Department of Cambridgeshire County Council, who required all structures on the scheme to have an exposed brickwork finish to ensure visual harmony with existing and proposed brick-clad housing near the site. The 7.2-km-long scheme was opened to traffic in 1989.

The designers chose structural brickwork for the abutments and wingwalls rather than brick-clad rein-

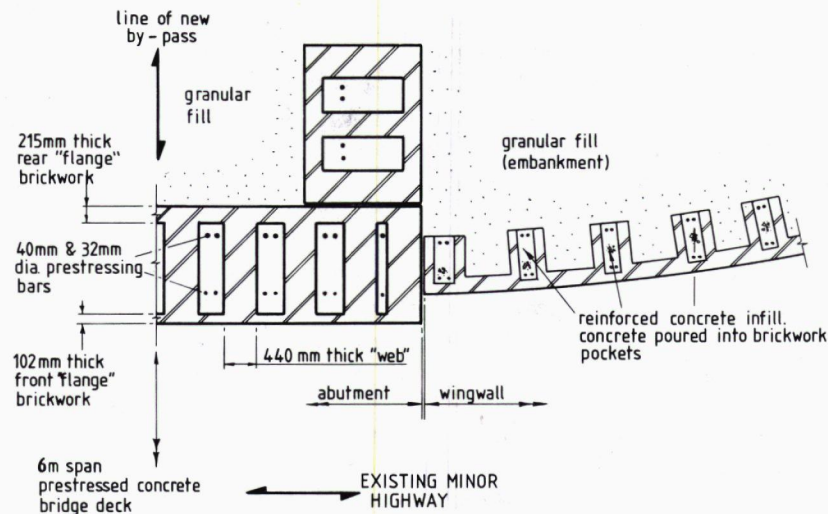


FIGURE 2 Foxcovert Road Bridge: horizontal section through end support showing prestressed brickwork diaphragm wall abutment and reinforced pocket-type wingwall.

forced concrete because of the lower anticipated long-term maintenance costs. The 6m span square bridge deck, consisting of precast prestressed concrete inverted T-beams with in situ concrete infill, is supported on prestressed brickwork diaphragm wall abutments. The wingwalls are of reinforced brickwork pocket-type construction.

The exposed brickwork consists of FL quality clay bricks, with a minimum compressive strength of 56 MPa and a maximum water absorption of 10 percent, laid in 1:1/4:3 cement:lime:sand mortar containing an SBR additive. Class B engineering bricks were used for the buried faces of the abutments and wingwalls. Details of the prestressed brickwork abutment and the curves reinforced pocket-type wingwall are given in Figures 2 and 3.

Prestressed Brickwork Abutments

The abutments are 1.565 m thick and measure approximately 6.5 m high from the top of carriageway down to the top of the reinforced concrete (r.c.) foundation. The front and rear flanges of the diaphragm wall are 102.5 mm (one-half brick) and 215 mm (one brick) thick, respectively, and are connected by 440-mm (two-brick) thick webs spaced at 787-mm centers.

Corrosion protected 40- and 32-mm-diameter high tensile steel Macalloy bars, initially stressed to 70 percent of their characteristic load using hydraulic jacks, provide the prestress. The lower and upper end anchorages were provided by the r.c. foundation and the r.c. bearing shelf. After prestressing, the annular spaces

between the tendons and the ducts cast into the r.c. anchorages were filled with a cementitious grout. A 20 percent loss of prestress was assumed in design to take account of the effects of stress relaxation, temperature change, and creep.

Corrosion protection of the Macalloy bars consisted of hot dip galvanizing followed by a covering of grease and two layers of waterproof tape. Small plastic tubes were also built into the exposed faces of the brickwork to permit inspection of the bars and the voids or cells of the diaphragm walls using a borescope. Unfortunately, out of the 184 bars used on the scheme, 9 failed between 2 and 3 days after stressing as a result of hydrogen embrittlement caused during galvanizing; for-



FIGURE 3 Foxcovert Road Bridge under construction.

tunately it was possible to replace the defective bars. In future, the use of lowly stressed, ungalvanized bars with waterproof coatings or stainless steel bars is recommended.

An 18-m span rail bridge with prestressed diaphragm wall abutments (49) was also part of the Glington-Northborough bypass scheme; outline design calculations for these abutments have been published by the Brick Development Association (50).

Reinforced Brickwork Wingwalls

These are curved in plan and vary in height from about 5.5 m adjacent to the abutments to about 0.9 m on the foot of the bypass embankment. They are of counterfort reinforced brickwork pocket-type construction with 215-mm-thick front face brickwork and 787-mm-deep pockets spaced at 1125-mm centers.

CASE STUDY 2: KIMBOLTON BUTTS BRIDGE

Cambridgeshire County Council also designed Kimbolton Butts Bridge, which is thought to be the first new brick arch bridge built in the United Kingdom for almost 100 years. The bridge carries the B660 highway over the River Kym in Huntingdon, near Cambridge, and was opened to traffic on December 16, 1992; details of the bridge are shown in Figure 4. The original structure, which was not strong enough to carry modern highway loading, was of composite steel beam/concrete deck construction. At the early stages of the design of the replacement bridge, a conventional structure with

a precast prestressed concrete beam deck was compared with the design eventually adopted; each bridge was estimated to cost approximately £100,000 (18). The arch bridge was selected because it was judged to have the greatest aesthetic appeal for its rural location, it was much preferred by the representatives of the local Parish Council, and the anticipated maintenance costs were less than that for the concrete alternative.

The design of the arch ring was based on the Department of Transport's guidelines for the strength assessment of masonry arches (4). The problem of spreading spandrels and wingwalls and the need to contain the damaged masonry resulting from vehicle collision with the parapets were addressed by using prestressed brickwork diaphragm walls for the wingwalls and reinforced grouted cavity brickwork parapets. The comparatively small spandrel walls were of mass brickwork construction. Although the vertical settlement of the abutments was estimated to be on the order of 15 mm, because a masonry arch is known to be capable of accommodating small movements, spread footings rather than piled foundations were judged to be adequate. Clay bricks and mortar with a similar specification to those in the Foxcovert Road Bridge were used for this project.

The arch ring was built on centering consisting of plywood sheet decking nailed onto timber members, which were fastened to curved, rolled steel universal column sections spanning across the river between the reinforced concrete foundations of the bridge. The top surface of the arch and the inner faces of the wingwalls and spandrel walls were waterproofed with a spray applied, two-coat acrylic membrane. It is interesting to note that, to date, the Cambridgeshire engineers have

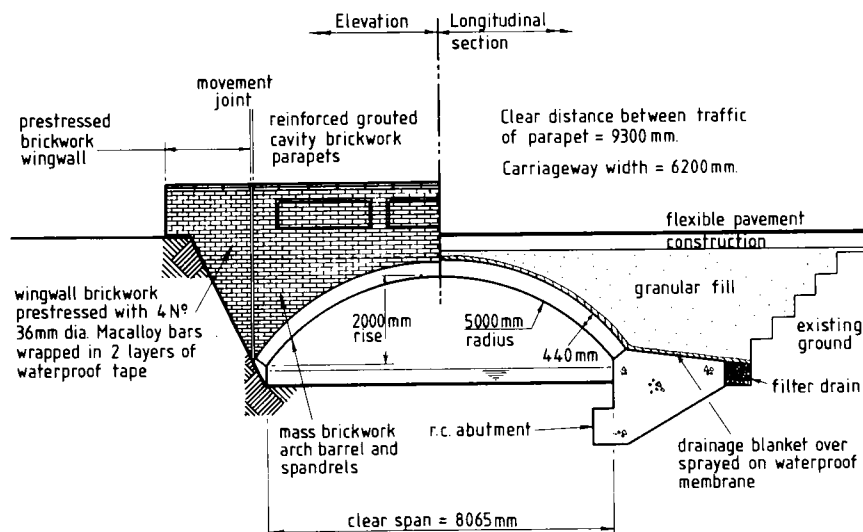


FIGURE 4 Kimbolton Butts Bridge: general details.

not experienced any difficulty in finding bricklayers with skills adequate to cope with the construction of arches, reinforced brickwork, or prestressed brickwork.

CONCLUDING REMARKS

Judging from the excellent long-term performance of many of the existing brickwork structures that were built well over 100 years ago in the United Kingdom, clay brickwork has proved that it can withstand the severe exposure conditions experienced by most highway structures. Following over 30 years of research, a number of cost-effective, structurally efficient forms of plain, reinforced, and prestressed brickwork have been developed. Recently, these forms of construction have been successfully used for new highway structures such as short span arch bridges, earth retaining walls, bridge abutments, wingwalls, and parapets. These projects have demonstrated that structural brickwork is worthy of serious consideration as a viable structural medium for new highway works.

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