A REINFORCED BRICKWORK RETAINING WALL

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This paper considers the ultimate load design and construction of a 4m high reinforced brickwork retaining wall.

The brickwork wall, built on a reinforced concrete base, is held to the base by reinforced concrete pockets incorporated in the tension side of the wall. The thickness of the wall is 440mm at the base reducing in two steps to 215mm at the top.

The long term lateral deflection of the finished wall is being measured.

UN MUR DE SOUTENEMENT EN MACONNERIE ARMÉE

Ce document traite au calcul de la charge de rupture et à la construction d'un mur de soutènement de 4 m de haut en maçonnerie armée.

Le mur en maçonnerie, construit sur une fondation en béton armé, est fixé à celle-ci par des ancrages en béton armé incorporés dans le côté tendu du mur. L'épaisseur du mur est de 440 mm à la base, se réduisant en deux gradins jusqu'à 215 mm au sommet.

On mesure la fente latérale à long terme du mur terminé.
INTRODUCTION

A 4m high pocket reinforced brickwork retaining wall has been designed by Structural Clay Products Limited for one of its member companies. Very few, if any, such walls have been built in Britain but they have been used in the United States. It is hoped this example will help to encourage further use of reinforced brickwork in Britain. (Figs. 1, 2 & 3).

The long term deflection of the present wall is being measured and some of the results are given.

POCKET WALLS

The design of the wall described herein was based on American practice. Pocket walls can be considered to be equivalent to reinforced concrete T beams where the flange of the beam is replaced by brickwork. The space between the concrete webs is filled in with brickwork resulting in a uniform wall thickness. This allows the concrete web or pocket to be easily cast, increases the shear strength at the concrete-brickwork interface and increases the strength of the brickwork panel spanning between the pockets.

The concrete webs or pockets have usually been spaced at 1.22 m intervals but in the present design they vary from 1.375 m and 1.575 m in the central section of the wall to 2 m in the sloping portion. The spacing is dependent on:

1) the ability of the brickwork to resist the lateral load and transfer it to the reinforced concrete pockets without needing any reinforcement apart from some nominal steel. The brickwork will derive much of its lateral strength by arching between the concrete pockets.

2) the magnitude of the anchorage stresses in the bars holding the wall to the reinforced concrete base.

3) the amount of steel that can reasonably be accommodated in the pocket, although the width can be varied. The present wall was designed to have pockets with a clear width of 235 mm but with indentations every other course to give a good key between the concrete and the brickwork.

It has been standard practice to insert nominal horizontal steel in the brickwork mortar joints as a precaution against cracking due to temperature and shrinkage. While this is necessary for concrete it is not considered necessary for brickwork - any excessive movement due to temperature or moisture expansion should be taken up by movement joints. Nevertheless in the present wall nominal steel was inserted towards the back of the 215 mm thick section only but as a trial left out altogether over one of the 1.38 m spans. This span has shown no signs of trouble.

MATERIAL

Bricks

A 215 x 102.5 x 65 mm wirecut, perforated brick was used. The bricks were of Special Quality which implies frost resistance and low salt content. The average compressive strength was 64 MPa.

Cement

A sulphate resisting Portland cement was used for both mortar and concrete.

Mortar

1:1:3 cement:lime:sand mix by volume.

Concrete

Concrete characteristic strengths of 25 MPa were specified for both base and wall pockets.

Reinforcement

Hot rolled high yield steel was used with the exception of the starter bars which were high yield square twisted.

FORCES ACTING ON RETAINING WALL

Lateral pressure on wall

An estimate of the lateral load applied to the retaining wall was based on Rankine's method.

The embankment to be retained consisted of tipped material containing clay, shale and sand. To ensure a self draining and more stable backfill, the soil behind the wall was replaced by hardcore consisting mainly of reject bricks. The angle of internal friction was assumed to be 35° giving a coefficient of active pressure of 0.27. The backfill was horizontal but a 500 kg/m² superimposed load was assumed which included the weight of a conveyor system.

Foundations

Two conditions were checked - sliding and soil pressure.

Terzaghi & Peck recommend a minimum factor of safety against sliding of 1.5. For a wall resting on silt or clay they also recommend the footing is cast on to a well compacted layer of sand and gravel. In this case a 500 mm layer of hardcore was used. The coefficient of friction between this layer and the soil is assumed to be 0.35. Only this friction was taken into account in resisting sliding. Passive resistance exerted by the soil in front of the wall and on the key beneath the base will increase the safety factor but was not considered to be very reliable.

The allowable soil pressure was assumed to be 80 kPa. As settlement of the infill material on which the wall was placed was possible, care was taken to ensure that the resultant of the forces acting on the wall was near the centre of the base.

DESIGN OF BRICKWORK

The wall was designed as a cantilever using ultimate load theory based on the limit state principles presented in CP 110 (4).

Partial safety factors

A partial safety factor of 2 was applied to the load for the design of the reinforced brickwork compared to 1.6 for the reinforced concrete base. A higher value was taken for the brickwork because the contractor did not have any experience with reinforced brickwork nor would there be much supervision.

The partial safety factor adopted for material stresses was yms = 1.15 for steel and ymm = 1.5 for both concrete and brickwork. The factor for brickwork may be better at 2 or more but has little influence on
the present design.

**Flexural design of wall**

The ultimate load design for the reinforced brickwork used the Whitney uniform compressive stress block.

\[
\text{Mu} = f_{y}A_{s}z \leq 0.32 \frac{f_{mk}}{\gamma_{ms}} \frac{bd^{2}}{2}
\]

where

\[
z = d(1-0.59) \frac{f_{y}A_{s}}{f_{mk}bd} \frac{\gamma_{ms}}{\gamma_{ym}}
\]

**Notation:**

- \(A_{s}\) area of tensile steel
- \(b\) width of section
- \(d\) effective depth
- \(f_{mk}\) characteristic compressive strength of masonry
- \(f_{y}\) characteristic yield strength of steel
- \(z\) lever arm
- \(\gamma_{ms}, \gamma_{ym}\) partial safety factors for materials

Reinforcement in wall pockets

At the base, the wall thickness is 440 mm giving an effective depth of approximately 375 mm (50 mm concrete cover to steel).

Taking a brickwork characteristic strength of 10 MPa (from the draft brickwork code [5]), a 1.5m width of wall, resisting a design moment of 180 kNm, requires the following percentage of steel:

\[
\frac{A_{s}}{bd} = 0.21\%
\]

or \(A_{s} = 1200 \text{ mm}^2 / 1.5\)

Three x 25 mm square twisted bars were provided (1470 mm²).

For other levels of the wall the required steel area was found graphically. On the same graph of moment vs. height of wall, curves can be drawn giving the required steel area for a given thickness and height of wall.

**Bond and anchorage**

Bond and anchorage calculations were based on stresses obtained from CP 110.

**Shear**

A characteristic shear stress of 0.4 MPa was assumed. This value is expected to be conservative for cantilever walls with the bricks laid flat in the usual manner.[6] The design shear stress becomes 0.27 MPa if a partial safety factor of 1.5 is used. The calculated shear stress based on effective depth was 0.2 MPa at the bottom of the wall.

The shear stresses at the interfaces of the concrete pockets and the brickwork were below 0.1 MPa.

**CONSTRUCTION**

**Reinforced concrete base**

Before casting the base a layer of concrete blinding was placed on to a 0.5 m thick layer of well compacted hardcore. Wooden shuttering was used for the sides of the base. The use of a safety factor of 2 for loads was justified because the starter bars were inadvertently placed 60 mm too far forward.

**Wall**

Wall construction commenced two days after the base was cast. The initial line of the wall was defined by the raised section of the base while guide posts at the ends of the wall and where the wall began to decrease in height ensured that the face of the wall was plumb and coursing correct. English bond - alternate courses of headers and stretchers - was used. The positions of the concrete pockets were determined by the starter bars but there was a tendency for the pockets to 'wander' when wall height passed the top of the starter bars. Apart from the starter bars, the reinforcement in the pockets was inserted after the wall was finished. Boards were placed across the pockets and the concrete was cast and vibrated in three lifts, corresponding to the different wall thicknesses. The back of the wall was then painted with two coats of bitumen.

**Backfill**

The major portion of the backfill was hardcore spread in layers. The top of the fill was covered with earth. A single layer of bricks was placed next to the wall to protect the bitumen.

**Workmanship**

Two of the three bricklayers were self-employed and time to them was more important than quality. Bat­ching boxes were recommended but not used. Instead the mortar mix was based on one bag of cement, equivalent to 7 shovels, to 21 shovels of a lime-sand mix.

Therefore it is not surprising that only half the mortar achieved the specified cube strength of 11 MPa at 28 days, the lowest being 6 MPa.

Much more money should be spent in Britain into ways of improving workmanship and contractors specialising in structural brickwork with bricklayers on their permanent staff should be encouraged.
WALL DEFLECTION

The lateral deflection of the wall is being monitored using a theodolite placed on a specially prepared concrete base situated 15 m away from the side of the wall. The line of sight of the theodolite passes approximately 200 mm in front of the wall on to the apex of the roof of a distant house. A steel rule placed at right angles to the wall measured the distance of the wall from the line of sight.

The overall deflection of the wall measured at three levels along the length of the wall is shown in Fig. 4. It shows the deflection 20 and 517 days after filling. Note that the central section which is more heavily loaded deflects most.

Figure 5 shows the deflection over the height of the wall 1.37 m away from the centre pocket. There is a slight reverse curvature, not a typical cantilever curve as may be expected. A likely cause is restraint by the more lightly loaded sections of the wall. The curves also show there is some sliding movement of approximately 8 mm over 517 days but this could also be due to movement of the theodolite base.

Figure 6 shows a plot of wall deflections versus time. The difference between the bottom and top level deflections gives an indication of wall angular movement due to wall deformation and tilting. The graph shows the angular movement has almost stopped after 517 days. On the other hand the overall movement as shown by the top level deflection is still increasing although at a decreasing rate. At 517 days the top deflection was about 24 mm of which approximately 8 mm is sliding movement.

REFERENCES


2. BRICK & TILE SERVICE INC. RBM retaining walls. Greensboro, N.C. U.S.A.


Fig. 1 Completed wall
Figure 3 Constructing the wall pockets

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Figure 3 PLAN & ELEVATION

1500 kg/m³
φ = 35°

Hardcore fill

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215
325
440

1860
1150

5000
4000

Y16
Y16
Y16
Y25

Y16
Y16
Y25

3630

1000
3000
800
Figure 4  OVERALL DEFLECTION

Figure 5  DEFLECTION OVER HEIGHT OF WALL

Figure 6  DEFLECTION VERSUS TIME