THE DESIGN OF WALLS CONTAINING BED JOINT REINFORCEMENT TO RESIST LATERAL LOADS

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ABSTRACT

The design of walls to resist wind loading is covered by BS 5628 Part 1. When a wall is large in relation to its thickness or receives little peripheral support or indeed in very exposed areas, it may be difficult to justify the design. In these instances it is possible to improve the resistance to lateral load by the use of reinforcement in the bed joints. However, the design methods available and which have been codified in BS 5628 Part 2 have only limited experimental support and as a result have certain limitations attached to them to ensure a conservative design is produced. This paper describes the available design methods and reports the results of preliminary tests on full size walls containing varying amounts of steel. The results are considered in relation to the design guidance.

1. INTRODUCTION

The use of bed joint reinforcement in brickwork is a well established practice for spanning openings and for restricting cracks caused by ground settlement. Claims are also made for its performance in limiting any long term moisture expansion in clay brickwork or shrinkage in concrete blockwork although these are supported by a limited amount of evidence only.

Since the publication of BS 5628 Part 1[1] in 1978, which includes a rational design method for unreinforced walls subjected to wind load, there has been an increase in the interest in bed joint reinforcement. In the earlier published Code, CP 111[2] there was merely a limitation on their slenderness. It is likely that in those cases where the design could not be justified, but the deficit in resistance was low, bed joint reinforcement has been specified but not designed.

There is no single accepted design method and as a result the draft Code of Practice BS 5628 Part 2[3] has included a number of optional design methods with varying limitations on each in an appendix. Tests are now in progress at BCRA under a research contract from the Building Research Station to try to determine the appropriateness of the various methods.

2. LITERATURE REVIEW

Relatively few tests have been carried out on walls containing bed joint reinforcement of the types most commonly used in the U.K. The two most popular types consist of parallel wires which are cross connected by either perpendicular or diagonal wires. The cross sectional area of each of the main wires is 10mm^2 to 12mm^2, but the majority of tests have been on walls reinforced with bars of greater cross sectional area[4].

The results of a single comparative test by Johnson[5,6] indicated that a single leaf brickwork wall containing reinforcement in every bed joint was 57% stronger than the equivalent unreinforced wall. The load at which the reinforced wall first cracked was similar to that at which the unreinforced wall failed although the reinforced wall deflected further.

The observation with regard to the cracking load is supported by those of Hodgkinson et al[7] although the investigation had a different aim. In this work bed joint reinforcement was used in the top courses of walls that were unsupported along the top edge, the intention being to test the hypothesis that the reinforced section would so stiffen the unrestrained top that the ultimate load would be increased. The results of this work indicated that substantial increases in ultimate load were possible although any increase in cracking load was relatively small.

The conclusions drawn by Van Biervliet and Smits[8] from their tests contradict those indicated above. The results from tests on simply supported panels spanning horizontally showed that the cracking load was greater for reinforced walls than unreinforced walls and increased with the amount of reinforcement provided. The ultimate load and its ratio to the cracking load both increased with the amount of reinforcement. Whether these conclusions are directly relevant to the use of bed joint reinforcement in the U.K. is not quite clear; the bricks used were large, very highly perforated units and although 4mm diameter wires were included in the investigation the conclusions were drawn from a series which included much greater bar sizes also.

3. DEVELOPMENT OF CODE OF PRACTICE DESIGN GUIDE

The draft of BS 5628 Part 2 which was circulated for public comment did not contain any specific guidance on the design of walls containing bed joint reinforcement to resist wind loads. The comments received from consulting engineers were to the effect that such guidance should be included and when asked the methods that were currently being used by them were explained. These three methods were included in an Appendix to the draft code as well as one developed by Johnson from the test results.

The four methods are described below:-

(a) Design as a Horizontally Spanning Beam

In this method the wall is considered to behave in the same way as a horizontally spanning beam, the design would be the same as for a reinforced concrete element. In most walls where bed joint reinforcement is to be used there is likely to be an element of two way spanning and this method is considered to be conservative. A limitation has been placed on the increase in lateral load that can be considered to be supported by the reinforced wall and that is 50% of the resistance of the unreinforced wall.

The design moment of resistance of the section is given by

$$M_d = \frac{A_s f_y z}{\gamma ms}$$

where $$z = d\left(1 - 0.5 \frac{A_s f_y \gamma mm}{bd f_k \gamma ms}\right)$$

where M_d is the design moment of resistance

A_s is the cross sectional area of the reinforcement

b is the width of the section

d is the effective depth

f_k is the characteristic strength of the brickwork

f_y is the characteristic tensile strength of the reinforcement

z is the lever arm

γmm is the partial safety factor for the compressive strength of brickwork

γms is the partial safety factor for the tensile strength of the steel

These formula apply to any reinforced section in bending and a general upper limit to the value of M_d of 0.4 f_k $bd^2/\gamma mm$ has been fixed. However in view of the low proportion of reinforcement this will not be approached in this type of wall.

In general it is important to note that f_k is the characteristic compressive strength of the brickwork that is relevant to the direction of the force which in this case is parallel to the bed joint. However in the majority of cases z will exceed the upper limit of 0.95d that has been fixed and the precise value of f_k will not need to be known.

It is likely that in the majority of cases the wire nearest to the compression face will be disregarded for design purposes, although at a critical section it is likely to be in tension as shown by Johnson[5] and a more detailed approach where a stress appropriate to the assumed strain at its position and to the stress-strain relationship of the reinforcement could be used.

Where cavity walls are designed using this method the design moment of resistance of the two leaves are added together. This approach has proved to be successful for unreinforced cavity walls although the ties must be adequate to transfer the required forces.

(b) Design with Reinforced Section Carrying Extra Load Only

This method is somewhat curious and cannot be rigorously justified and is likely to survive only until the alternative methods have been further developed. It is considered to apply to single leaf walls only and reinforcement is provided at a frequency such that the deficit in the lateral load capacity of the unreinforced wall is considered to be resisted by the reinforced section and the design for this is as for method (a) above.

The method thus combines the resistance of the uncracked unreinforced wall with that of the reinforced section and the latter is considered not to be mobilised until the wall is cracked in tension. There is consequently a contradiction in the assumed behaviour of the wall which cannot be justified. As the method inevitably gives greater design strengths then method (a), the limit on the strength increase that can be relied on in design has been fixed, is lower at 30%.

(c) Design Using a Modified Orthogonal Ratio

Design of unreinforced walls to BS 5628 Part 1 is based on yield line theory and the design moment to be resisted in a wall subjected to a particular wind load is considered to be dependent on the wall shape and its support conditions and also on the ratio of the flexural strengths perpendicular and parallel to the bed joints.

When bed joint reinforcement is introduced the moment of resistance about an axis perpendicular to the bed joints is enhanced and that about an axis parallel to the bed joints is considered to be unaltered. The orthogonal ratio, which for unreinforced walls is defined as the ratio of the flexural strengths in the two directions, is redefined as the ratio of the design bending moments of resistance. The value for the reinforced section is derived as for method (a) above.

Once a revised orthogonal ratio has been defined the wall may be designed in exactly the same way as an unreinforced wall using the provisions of BS 5628 Part 1. The only exception is that recourse may be made to the basic yield line equations as it is possible that the orthogonal ratio is outside the range of those considered in the Code.

(d) Design Based on Cracking Load

This method is the only one that has been developed from the conclusions drawn from the test work although it is true that failures of reinforced walls do exhibit patterns of cracking that are consistent with yield line theory.

As from the limited amount of experimental evidence the cracking load seems to be at least as large as the failure load of the equivalent unreinforced wall this load is used as the basis of the serviceability load for the reinforced wall. The interpretation of the situation with regard to a real wall is that in service the load would be permitted to

be a large proportion of the cracking load. This is in the knowledge that there is a reserve of strength once the wall has cracked.

The load carrying capacity of the unreinforced wall is calculated using BS 5628 Part 1 with the partial safety factors set at unity. This load is then divided by the partial safety factor for strength of brickwork that is appropriate to the serviceability limit state, in this case 1.5. The load thus defined is the service load. It is necessary to check that the wall has an adequate factor of safety against collapse and this is determined using method (b), with no load limitation, to ensure that the wall can resist the design load for the ultimate limit state. This design load is found by multiplying the service load by the appropriate partial safety factor for wind load.

As this method would allow the designer to exploit two thirds of the unfactored resistance of an unreinforced wall it is possible that deflections could be excessive and it may be necessary to check these using elastic plate thoery.

Some general guidance is also given in the draft Code; limiting dimensions are introduced which increase the maximum size of wall panels from those for unreinforced walls by about 10% and a minimum amount of reinforcement is stated below which no enhancement in capacity may be considered.

Although the Code of Practice is considered to be conservative in its approach there is little evidence to support what has been recommended and as a result testing is now being carried out by British Ceramic Research Association under contract to the Building Research Station.

4. TEST PROGRAMME

The test programme, which is now yielding some preliminary results, was developed bearing in mind the following points:-

1. It is likely that bed joint reinforcement would be used to enhance the flexural strength in situations of least support and hence it is these which should, in the main, be tested. Consequently the main programme should concentrate on three sided simply supported panels. Tests on four sided panels should be considered also as the limiting panel dimensions in these cases are greater.

2. The walls tested should be near to the limiting dimensions to investigate whether deflections are excessive. Also it is such walls that are most likely to need their strength enhancing.

3. The compressive strength of the units is not likely to be of importance, consequently flexural strength is the criterion for choice of the masonry. A high water absorption brick should be used. Although the blockwork equivalent in terms of a low flexural strength requirement would be autoclaved aerated concrete it is considered that use of these in the programme

should be restricted to the inner leaf of cavity walls with the exception that a single leaf wall should be tested to ensure that adding the strengths of the two leaves of a cavity wall remains a reasonable procedure.

4. As a means of strength enhancement it is most likely that we should examine the use of grade (iii) mortar (1:1:6 cement:lime: sand).

5. As a means of verifying the design mild steel reinforcement may be used; however, small scale tests on, in particular the bond of stainless steel to mortar must be considered. It is anticipated that stainless steel will be most commonly specified.

6. Probably two levels of reinforcement will be sufficient, one being defined by the maximum vertical spacing, 450mm. The other should be greater, 225mm spacing is reasonable as this would be consistent with the minimum spacing in the inner leaf of a blockwork cavity wall.

7. Comparative tests on similar unreinforced walls are desirable, in particular some of the design methods include their strength as part of the design process.

5. CONSTRUCTION AND TESTING OF TEST SPECIMENS

The walls so far built and tested have all been built from medium strength, extruded, three-hole perforated brick. The flexural strengths in the two principle directions were determined according to Appendix A3 of BS 5628 Part 1 and the results together with other main brick properties are given in Table 1. The walls were all built off a bituminous damp-proof course using a 1:1:6 mortar. The reinforcement used consisted of two parallel galvanised steel wires connected at intervals with 2.5mm diameter cross wires. The specification for the reinforcement is given in Table 2.

The walls were built within frames made from steel channels to which reaction boards could be fixed so that the wall could be loaded using air bags located between the wall and the reaction board. The method of test has been described in detail by West et al[9].

6. PRELIMINARY RESULTS AND CONCLUSIONS

The results from the first five walls tested in the programme are given in Table 3 together with predicted failure loads based on design methods (a), (b) and (c). Comparisons with method (d) are more difficult as it is a design based on the service load. No partial safety factors have been introduced in the calculation of the predicted strengths.

The results from the three storey-height walls (2.7m) indicate that no real improvement was achieved by providing the reinforcement. Although the cracking load of the walls were similar there was no improvement in the failure load. It may be that for this format of wall, that is whose height is somewhat less than its length, greater amounts of reinforcement would be necessary to have a significant effect. Further work in this area will be necessary. For the taller wall a useful 29% increase in ultimate load was achieved by using the maximum reinforcement spacing, ie 450mm, although the load at first crack was slightly reduced.

Of the design methods examined method(a) is clearly very conservative although this may prove to be less so for taller, shorter walls.

In the case of the storey height walls, method (b) is the most accurate, however this is largely because the predicted strength of the unreinforced wall was low. If the enhancements due to the reinforcement were applied to an accurate estimate of the failure load of the unreinforced wall the strengths of the reinforced walls would be over-estimated. The prediction for the most heavily reinforced wall is the most accurate but in a real design the enhancement would be limited by the 30% upper limit to 1.94 kN/m^2.

Method (c) is clearly less conservative than method (a) although it still provides a very conservative estimate of the wall strength.

At this stage the preliminary results are not very helpful in assessing the various design methods. However, the work is continuing and it is hoped to provide a better assessment in the near future.

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TABLE 1
Properties of Bricks and Brickwork

Bricks - Three hole perforated			
Crushing Strength 26.4 N/mm^2 Water Absorption 16.8 % Initial Rate of Suction 2.9 $kg/m^2/min$			
Brickwork Flexural Strength (1:1:6 mortar)			
Wallette No.	Flexural Strength N/mm^2	Wallette No.	Flexural Strength N/mm^2
Failure Perpendicular to Bed Joint		Failure Parallel to Bed Joint	
1	1.78	1	0.59
2	1.96	2	0.60
3	1.42	3	0.53
4	1.65	4	0.45
5	1.56	5	0.48
Mean	1.67	Mean	0.53

TABLE 2
Specification of Reinforcement

Reference No.	Spacing of Wires (mm)	Area of Wires (mm^2)	Minimum Tensile Strength of Wires (N/mm^2)
BK 60	55	10.06	570

TABLE 3
Wall Strength Results and Predictions

Wall No	Size (m) L H	Vertical Spacing of Reinforcement (mm)	Mortar Strength (N/mm^2)	Failure Pressure (kN/m^2)	Pressure at First Crack (kN/m^2)	Predicted Failures by Design (a)	(b)	(c)	Strength Increase over control %
1	5.5 x 2.7	None	4.1	2.06	2.06		1.49		N.A.
2	5.5 x 2.7	450	5.0	2.28	2.28	0.3	1.79	1.01	11
3	5.5 x 2.7	225	4.3	2.05	2.0	0.57	2.06	1.22	0
4	5.5 x 4.5	None	4.2	1.2	1.2		1.17		N.A.
5	5.5 x 4.5	450	3.7	1.55	0.8	0.3	1.47	0.53	29

Note: All walls have simple supports at the vertical edges, a free head and a d.p.c. at the base.