REINFORCED BRICKWORK COLUMNS

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ABSTRACT

The use of reinforced brickwork columns in association with other loadbearing brickwork elements could lead to the elimination of the frame in brick clad structures. Apart from saving the cost of the frame, problems of differential vertical movement are removed and detailing would be simpler. This paper reviews the information available on the performance of reinforced brickwork columns subjected to axial, eccentric and biaxial loads. The results from a preliminary series of tests on storey-height, one and a half bricks square columns are reported. The columns were tested under axial load and the strength enhancement due to the introduction of a variety of types and frequency of placing of horizontal reinforcement in the bed joints is reported. The results are considered in relation to the modes of failure, the strength enhancement and their variability.

INTRODUCTION

Despite the ever improving design guidance and the consequent increase in confidence in the structural design of brickwork there are still many new buildings where brickwork is treated solely as cladding. Various names have been given to the ways brickwork walls may be arranged on plan to provide the necessary resistance to imposed loads, eg cellular, spine-wall, cross wall and many of this type of building are built. However there is little doubt that there are numerous buildings where a steel or concrete frame is specified but had the walls been designed as loadbearing the frame would not be required.

It seems likely that there exists an area where structural brickwork could be more commonly used and this is probably in medium rise buildings, say up to five storeys. The external walls of such buildings could be confidently designed to carry the vertical and horizontal loads, shear walls can be designed to resist horizontal loads which may be directed to them by the action of stiff, in-situ concrete floors that can be supported if necessary by additional walls or columns. There seems also to be potential advantages in fire and sound resistance by using brickwork internally. There will clearly be an advantage in that differential movement between frame and cladding will be eliminated and there will be savings in complex fixing details.

Economic advantages would seem to accrue from savings made on the frame and the foundations and possibly elsewhere. Construction time may be lengthened but there is no reason why internal work cannot commence while the building progresses. In practice there may be delays in the delivering of steel for frames or of pre-cast elements and these delays may be costly.

A variety of views have been expressed for the predominance of frames over loadbearing brickwork, for example, the need to locate walls above one another throughout the structure and the difficulties perceived in designing other than rectangular section members using the Code of Practice[1]. However, with regard to the need for research one which was considered relevant was that brickwork columns tend to be much larger than their equivalent in reinforced concrete. In a design situation the engineer is likely to be restricted in any attempt to reduce the size of a brickwork column. The options of using stronger bricks or mortar are not likely to be open as these would alter the appearance.
Clearly the use of reinforcement needs to be considered and this may be assisted by the publication of BS 5628:Part 2[2] which covers the use of reinforced and prestressed masonry. Nevertheless relatively little research has been carried out into the use of reinforced brickwork columns and a literature review was undertaken[3].

LITERATURE REVIEW

The literature review led to a number of conclusions in relation to the adequacy of the draft Code design guidance, the use of both horizontal and vertical reinforcement and the support for both axial and eccentric loads.

The overall conclusion which may be drawn from the comparisons with the draft Code design method and the available experimental data is that where reinforced brickwork columns are desirable a design method with some experimental justification is available.

The experimental results reviewed indicated that further development in the use of reinforced columns should be selective, for example although large strength increases are likely to be available when using axial reinforcement in low-strength brickwork the detailing may be difficult and similar results may be achieved by using higher strength brickwork. In the case of the high-strength brickwork the use of axial reinforcement in one instance did not increase the axial load capacity greatly.

There is clearly scope for examining the effect of lateral reinforcement only on the performance of columns as this could well be an economical form of construction.

It seems likely that the scope for development of conventional reinforced columns is in situations of eccentric loading where clearly relatively small amounts of reinforcement can have a significant effect.

The available evidence indicates that with some further research and development designs that may be used economically for a range of structures will be available.

COLUMN DESIGN

In the first instance a programme of work was carried out to investigate the performance of storey height columns, reinforced with horizontal stirrups in the bed joints, when subjected to axial load.

As the compressive failure of brickwork is generally considered to be due to the lateral tensile stresses introduced into the bricks by the restrained horizontal expansion of the mortar the restraint provided by the stirrups was considered to be their contribution to any improvement in performance. The columns tested were 327mm square, ie one and a half bricks, and the central hole, half a brick square, was left unfilled. Rectangular stirrups, 6mm diameter, were chosen, the ends were lapped 100mm. The stirrup was thus a standard element of reinforcement and could be readily specified using the appropriate British Standard specification for bar shapes[4]. The cover to the stirrup was 15mm, the minimum recommended in the draft Code of Practice, it was considered that by using this the maximum area of the section would be restrained. A preliminary assessment suggested that the performance during a fire test was likely to be good[5].

As the programme developed other types of reinforcement were considered, eg expanded metal, circular stirrups.

The columns were built off a reinforced concrete section, 100mm thick and 500mm square, a similar slab was used at the head of the column.

TEST PROGRAMME

Each column was 327mm ($1\frac{1}{2}$ bricks) wide, 32 courses high and built in either low or high strength brick and built with $1:\frac{1}{4}:3$ mortar.

In the initial analysis to determine the strength enhancement available with different distributions of reinforcement, a standard stirrup, 300mm square and fabricated from 6mm diameter steel was incorporated in either every 1st, 2nd or 4th course of both low and high strength brickwork columns built in $1:\frac{1}{4}:3$ mortar. Two additional columns with welded rectangular stirrups every fourth course were also constructed in $1:\frac{1}{4}:3$ mortar to assess the importance of the end connection.

With the optimum distribution of reinforcement determined low strength brickwork columns with four different types of reinforcement each placed at the optimum spacing for the stirrups were constructed in $1:\frac{1}{4}:3$ mortar. The types of reinforcement considered were a 50mm square mesh with 15mm cover, an expanded metal with 15mm cover, a hooped stirrup

fabricated from 6mm diameter steel with 25mm cover and a 25mm wide, 3mm thick flat plate square stirrup with 25mm cover. It is of interest to note in relation to the use of plate type reinforcement that these are recommended for the high compression areas of walls being designed to resist siesmic forces[6].

Unreinforced columns were also constructed in each brick type and their axial compressive strengths compared with the characteristic strengths calculated in accordance with BS 5628:Part 1.

Each column was wrapped in polythene after construction and allowed to cure for 28 days before testing. Axial deformations under load were measured by displacement transducers and strains were measured at eleven positions on the surface of the column using a 225mm demec gauge.

RESULTS

Results from the test programme to determine the optimum distribution of reinforcement are presented in Table 1. For both low and high strength brickwork columns useful strength enhancements over unreinforced columns were obtained with rectangular stirrup reinforcement incorporated in every fourth course, and since this distribution of reinforcement was also considered economical and interfered little with the building sequence it was adopted as the reinforcement spacing in the rest of the test programme.

When the stirrups are placed at closer spacings it is difficult for the bricklayer to keep the column in gauge. With reinforcement in every fourth joint any increase in the thickness of the bed joint containing the reinforcement can be compensated for in the succeeding three bed joints. The failure modes of the columns containing rectangular stirrups differed noticeably from those of the unreinforced columns. Unreinforced columns failed by splitting at the perpend joints over the full height of the column to form four distinct 'walls', the column completely disintegrating at ultimate load (see Figure 1). Reinforced columns failed by spalling of the brickwork outside the stirrups and generally had a degree of structural integrity remaining at failure (see Figure 2). Columns containing the welded rectangular stirrups failed by spalling at much lower compressive strengths than the columns containing standard rectangular stirrups.

The results of the test programme to assess the strength enhancements available with different types of bed joint reinforcement are listed in Table 2. A strength enhancement of almost 35% was achieved with a column containing hooped stirrup reinforcement and those columns containing expanded metal and 50mm square mesh reinforcement also had much higher strengths than the unreinforced column. Failure modes of the columns containing mesh and expanded metal differed markedly from those of unreinforced columns and of those columns containing stirrup reinforcement. Numerous vertical cracks appeared across the width of columns

containing expanded metal and 25mm mesh reinforcement (see Figure 3) whilst the column containing hooped stirrup reinforcement failed, by spalling of the brickwork outside the stirrups leaving a clearly defined circular 'core' of brickwork. It was subsequently observed that one of the hooped stirrups at the major failure area of the column had failed in tension and that some of the expanded metal reinforcement had been torn apart at its perimeter.

The effect of the reinforcement in the low strength brickwork appears to have reduced the initial stiffness of the column and the reverse is true in the case of the high strength brickwork. This is an area where further investigation is warranted.

Characteristic compressive strength of unreinforced columns calculated in accordance with BS 5628:Part 1 are given in the headings of the relevant results table.

The column entitled Eccentricity in the table is the ratio determined from the measured strains at the extremes of the column. Although the load was in all cases intended to be axial some eccentricity could have been introduced. It is of course accepted that these estimates also include any effects due to non-homogeneity of the brickwork.

DISCUSSION AND CONCLUSIONS

In the first instance it was considered that the use of stirrups would be most advantageous when using low strength bricks, the reason being that, for the range of buildings that the work was aimed, if high strength bricks were used these were more likely to be adequate without reinforcement.

However, when it became clear that the mode of failure for the reinforced columns was by spalling it was considered that several actions could have been taken. The cover to stirrup could have been increased to give it a greater section to resist spalling, the higher strength lower water absorption brickwork could have been used to increase the tensile strength of the brickwork or if the spalling was associated with the stirrups opening up they could be welded. The fact that in the case of the low strength bricks the use of stirrups in every course caused a loss in strength encouraged the belief that opening of the stirrups was occurring and so some columns with welded stirrups were used. However this proved in both high and low strength bricks to be ineffective in improving the compressive strength. The investigation using high strength bricks indicated that the percentage strength increases obtained were not greatly improved. It was considered that increasing the cover, whilst possibly being effective also reduced the size of the central core and consequently could be counter productive. This has not yet been pursued, however the circular stirrup did have 25mm cover and gave the greatest strength enhancement.

The results of the preliminary investigation into the use of stirrups seems to show that at a practical spacing which gives little problems to the bricklayer a strength increase of 20% is available. This conclusion must be considered with some caution as the results are all from single tests and there is no definitive information on the variability of the results.

The other types of reinforcement were used for various reasons. Expanded metal is recommended to provide an increase in compressive strength and so this was included, the preliminary conclusion is that this is effective. The fact that the mesh tore suggests that a stronger mesh could be more effective. Expanded metal is now being produced from stainless steel and this may mean that, if the preliminary conclusion is confirmed, a useful means of reinforcing elements where resistance to corrosion is an important consideration.

The 50mm mesh resembled reinforcement used by other researchers[7] whose work was reviewed. However in the full size column the strength enhancement at 18.7% was lower than their work, which was on smaller specimens, suggested.

The use of the flat plate was an attempt to increase the surface area/volume of the reinforcement in a practical way as this was considered by Armstrong and Hendry[8] to be an important parameter. This test gave one of the poorest results and the idea was not pursued.

Overall it must be considered that some interesting preliminary conclusions may be drawn and some further research is required. It seems that the use of stirrups may give a useful strength increase when placed at a practical spacing. The use of hoops and expanded metal seem promising. The way that the mode of failure is affected is interesting and the removal of the fear of sudden collapse and the fact that the column has some remaining strength after failure may be pointers to the fact that the use of such reinforcement may enable lower safety factors to be used in otherwise unreinforced brickwork.

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TABLE 1

Results of low strength brickwork column tests, brick strength 24.4 Nmm^{-2}, mortar type $1:\frac{1}{4}:3$, BS 5628 characteristic strength f_k 8.5 Nmm^{-2}

Reinforcement at each course	Failure Load (kN)	Eccentricity Ratio ($\frac{e}{d}$)	Average Stress at Failure (N/mm^2)	Average Strain at Failure (μ strain)	Initial Modulus of Elasticity (E) (N/mm^2)	($\frac{E}{f}$)	Percentage Strength Increase (%)	Failure Mode
None	797	0.07	8.64	1140	9192	1063	-	vertical perp cracks
4th	1046	0.01	11.34	1990	7398	652	31.2	spalling of brickwork outside stirrups
2nd	946	0.02	10.26	1450	8548	833	18.7	"
Every	996	0.02	10.80	1515	8817	816	25.0	"
4th Welded	787	0.05	8.50	1204	6825	803	-1.2	"

Results of high strength brickwork column tests, brick strength 81.2 Nmm^{-2}, mortar type $1:\frac{1}{4}:3$, BS 5628 characteristic strength f_k 22.1 Nmm^{-2}

Reinforcement at each course	Failure Load (kN)	Eccentricity Ratio ($\frac{e}{d}$)	Average Stress at Failure (N/mm^2)	Average Strain at Failure (μ strain)	Initial Modulus of Elasticity (E) (N/mm^2)	($\frac{E}{f}$)	Percentage Strength Increase (%)	Failure Mode
None	2391	0.02	25.8	1732	21500	833	-	explosive
Every	2092	0.04	22.6	1763	45744	1457	-12.5	spalling of brickwork outside stirrups
2nd	2902	0.05	31.4	1961	31159	1379	21.4	"
4th	2870	0.02	31.0	1664	32119	1036	20.0	"
4th Welded	2391	0.07	25.8	1343	22417	869	0	"

TABLE 2

Results of low strength brickwork columns, brick strength 24.4 Nmm^{-2}, mortar type 1:¼:3, BS 5628 characteristic strength f_k 8.5 Nmm^{-2}

Reinforcement at each course	Failure Load (kN)	Eccentricity Ratio $(\frac{e}{d})$	Average Stress at Failure (N/mm^2)	Average Strain at Failure (μ strain)	Initial Modulus of Elasticity (E) (N/mm^2)	$(\frac{E}{f})$	Percentage Strength Increase	Failure Mode
Expanded Metal, every 4th course	1046	0.08	11.34	1599	7594	670	31.2	Vertical cracks across width, splitting of expanded metal at perimeter
50mm Mesh every 4th course	946	0.02	10.26	1554	7352	717	18.7	Vertical cracks across width, spalling
Flat plate, 25mm cover, every 4th course	697	0.14	7.56	1086	6680	883	-12.5	Spalling of brickwork outside stirrups
Hooped stirrup, 25mm cover, every 4th course	1075	0.02	11.66	2039	6656	571	34.9	Spalling of brickwork outside stirrups, failure of stirrups

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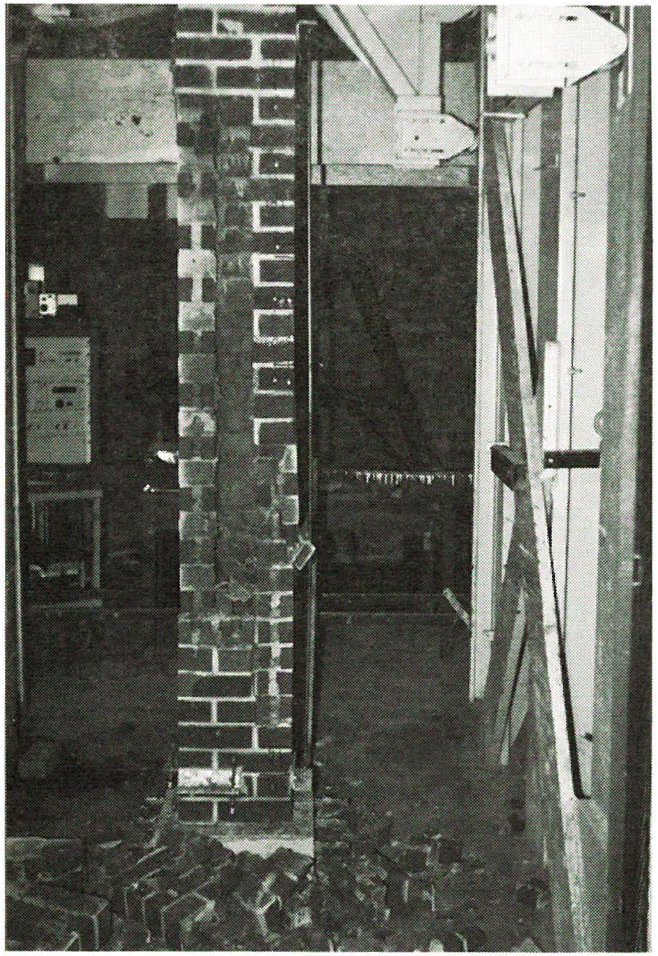

FIGURE 1

Typical Failure of Unreinforced Column

FIGURE 2

Spalling Outside Rectangular Stirrups, Every Course

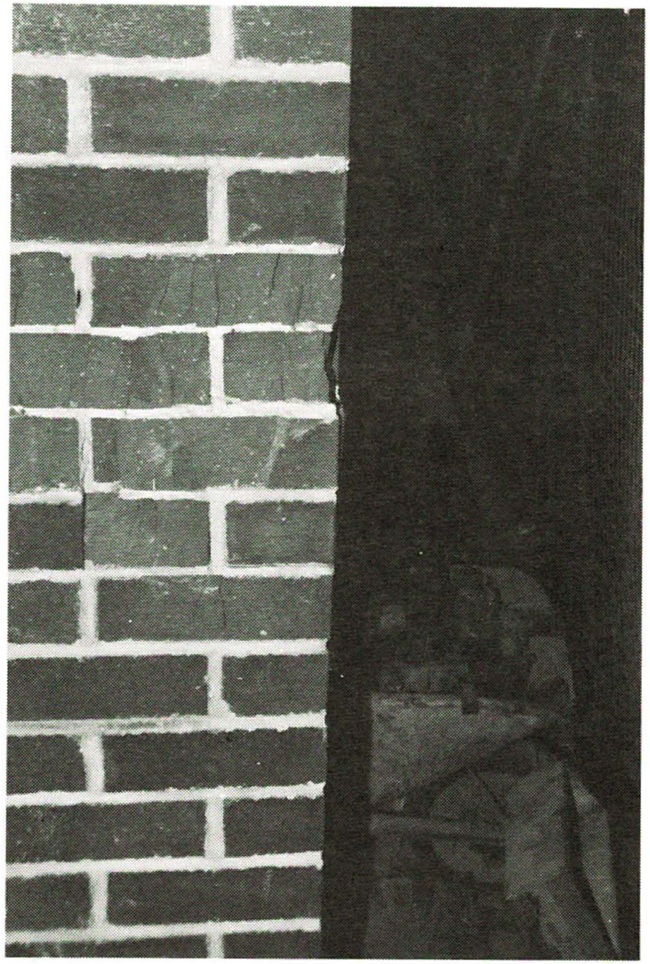

FIGURE 3

Localised Failure in Column containing Expanded Metal