The Future for Prestressed Masonry

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Abstract

The paper reviews some existing uses of prestressed brickwork and tests on it and then considers its properties compared with prestressed concrete and its cost compared with reinforced brickwork. It is concluded that full prestressing gives improved serviceability but must almost always cost more. A brighter future is seen for carefully selected levels of partial prestressing.

1. INTRODUCTION

The second part of the new British masonry code BS5628 (1) - recently issued as a draft for comment - covers not only reinforced but also prestressed masonry, both brickwork and concrete blockwork.

The inclusion of prestressed masonry was a matter for debate. On the one hand it was argued that a code should reflect good current practice but could not do so if effectively there was no current practice. The contrary argument was double-edged, first that there was current practice and secondly that, even if there was not, there would be none if there was no code, because regrettably the thinking of most designers is dominated by codes. The latter argument has prevailed for both reasons and clauses on prestressed masonry have been included, largely based on practice with prestressed concrete. It is thought that BS5628 will be the first masonry code to make specific recommendation on prestressing.

The time now seems ripe for a review of the use that has been made of prestressed masonry and for a debate on its future. What are the advantages? Is it economic? Has it a real future?

Although the new British code covers both brickwork and concrete blockwork most applications of prestressed masonry, in Britain at least*, have been to brickwork and it is prestressed brickwork which is the subject of this paper. In spite of this, much of which follows will also apply to the prestressing of concrete blockwork.

One of the first needs is to cut the mystique out of prestressed brickwork. Prestressing is a well established technique, associated with concrete since the 1930s, tentatively applied to cast iron in the 1840s (3) and, depending on one's definition of the term, to timber for two thousand years or more. One can prestress any material whose properties are such that a useful proportion of the induced stress will be permanent. All one is doing is applying forces where they will be most beneficial.

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* Unbonded cables have been used in New Zealand often to improve the seismic resistance of cavity walls of concrete blockwork (2).

In this paper prestressing is only being reviewed in relation to brick-shaped units. On this basis the Stahlton floor for instance, which is closely allied to the many precast or composite concrete flooring systems, is considered as an example of prestressed ceramic but not of brickwork.

2. PAST TESTS ON PRESTRESSED BRICK AND EXISTING APPLICATIONS

Credit for the earliest prestressed brickwork is probably due to F.J. Samuely who used it in slender blue-brick piers over 10 metres high in 1952 (4). Although Samuely was not one of the major innovators in prestressed concrete he had a rare breadth of understanding of its potential. While others were only prestressing concrete it was just as natural to him to apply this new technique to brick, steel or timber as well. After this pioneer application no thought seems to have been given to prestressing brickwork until the mid 1960s.

In 1966 J.S. Neill described (5) his then recent use - probably quite independent of Samuely's - of prestressed bars to stabilise the 7 metre high brick panel walls of a factory in Darlington, England; the bars run free in the cavity.

Also in 1966 prestressing was applied in a small part of a series of tests for Structural Clay Products Ltd. to prove the feasibility of forming box-beams with concrete slabs and reinforced brick walls (6). The prestress was originally intended as a splint which could be applied to one half of the test rig to enable the tests to go on after a partial failure. However this prestressing proved especially beneficial and will be referred to again in Section 4.5.

A circular water tank in prestressed brickwork of 12 metres diameter and 5 metres high designed by D. Foster for G.H. Downing (7) was completed for the opening of their new works in 1967 and still ranks as one of the largest and most significant applications of prestressing to brickwork.

At the first International Brick Masonry Conference in Austin, Texas (1968) K. Thomas (8) reported on two sets of tests on brickwork beams, a limited one which he carried out by himself, and a more extensive set by J.W. Plowman. These tests were notable in that they used levels of prestress high enough to ensure compressive failure of the masonry and to indicate the relative unimportance of shear strength with prestressed, as compared to reinforced, brickwork.

At about this time, in the S.C.D. System, W.G. Curtin started to apply the principle of the free prestressing bar in the cavity, as used at Darlington, on a wider scale but generally at a lower level of structural performance. He and his colleagues published details of this in 1975 (9). Here he was tackling the problem - completely ignored in much architectural design - of lateral forces on unrestrained cavity brick walls cantilevering up to sill level and supporting continuous glazing above. The height of these walls is generally about one metre (sometimes two metres with clerestory lighting) and the levels of prestress, as reported, are

too low to counteract the theoretical bending tensions in full. Strictly this is either low partial prestressing, or ties with the slack taken out, and no worse for that. The system has been proved by test and used repeatedly.

In 1979, R.E. Bradshaw successfully applied prestressing to cellular (diaphragm) walls cantilevering 2.5 metres vertically and required to retain grain with a 20% surcharge (10). Recently further use has been made of prestressing applied to such walls by Curtin and tests on some of these applications have been carried out at UMIST by Dr. Phipps. It is understood that at least one paper on this work will be presented at the Conference.

Currently a test programme is being carried out by B.J. Sinha at Edinburgh University on prestressed brickwork beams up to 6 metres long. Quite high levels of prestress are being used and, as in the case of Plowman's beam tests reported at the Texas Conference, failure is generally due to bending with, predictably, higher shear resistance than would be possible with reinforced sections. No results have yet been published (11).

DESIGNER RESEARCHER	APPLICATION	DATE	TYPE OF TENDON	METHOD OF STRESSING	TYPE OF PRESTRESS	ORDER OF BRICKWORK STRESS AT CRITICAL SECTION	NOTES
PRESTRESSING BECAUSE OF LOW FLEXURAL TENSILE STRENGTH OF BRICKWORK							
Neill (5)	Wind wall	1966	Threaded bar	Torque Wrench	Vertical axial	0.7 N/mm^2	Bar stress approx 235 N/mm^2
Curtin (9) Adams	Wind walls	late 1960s	Threaded bar	Torque Wrench	Vertical axial	0.05 N/mm^2	Bar stress approx 70 N/mm^2
Bradshaw (10)	Retaining walls	1979	Threaded bar	Torque Wrench	Vert.eccentric	0.2 N/mm^2	Bar stress approx 180 N/mm^2
PRESTRESSING TO RESIST DIRECT TENSION							
Foster (7)	Circular tank	1966-7	7mm wire	Jack	Hoop .... vertical axial	2.0 N/mm^2 .... 1.0 N/mm^2	3.2 N/mm^2, less friction Wires fully stressed
Plowman (6) Sutherland Couzens	Incidental to test	1966	7mm wire	Jack	Vertical axial	1.4 N/mm^2	Wires fully stressed
PRESTRESSING TO DEVELOP FULL FLEXURAL COMPRESSIVE STRENGTH OF BRICKWORK							
Samuely (4)	Slender piers	1952	Macalloy bar	Jack	Vertical axial	1.75 N/mm^2	Bar stress not known
Thomas (8)	Beam tests	1963	7mm wire	Jack	Eccentric	Up to 11 N/mm^2	Tendons stressed to approximately their full capacity
Plowman (8)	Beam tests	1965	7mm wire	Jack	Eccentric	Up to 7.5 N/mm^2	
Sinha (11)	Beam tests	1980-1	Strand	Jack	Eccentric	Up to 4.0 N/mm^2	

TABLE 1: PAST APPLICATIONS OF PRESTRESSING TO BRICKWORK (IN BRITAIN)

Table 1 summarises the methods of tensioning, types of prestress and general stress levels used in these applications, which can be seen to divide into three groups with fairly distinct ranges of stress, depending on the reason for prestressing:

a. Because of the low flexural tensile stress of brickwork

Here there is no question of failure due to lack of

compressive strength, the stress levels in the brickwork generally being less than 0.75 N/mm^2 and even as low as 0.05 N/mm^2.

b. To resist direct tension

Again compressive strength is not the ruling factor, although, as in the case of Foster's tank, hoop stress levels are appreciably higher.

c. To develop the full flexural compressive strength of brickwork

Here the compressive stresses both at transfer and when fully loaded are far from negligible but such as one would derive from the characteristic compressive strength of the brickwork with a reasonable factor of safety.

Admittedly in his pioneer application of around 1951, F.J.Samuely used a maximum compressive stress of only about 1.75 N/mm^2 but his aim was clearly to develop the full flexural strength of the section, the limit being set by what he explained as the then permitted working stress of 16 ton/ft^2 (or 1.72 N/mm^2).

Apart from Samuely's piers all other applications of full strength prestressing which have come to light so far have been confined to the laboratory.

The examples of prestressed brickwork referred to here are not necessarily the only ones - perhaps far from it. It would be useful to know of more, especially from countries other than Britain.

	CONCRETE CP110	MASONRY BS 5628 DRAFT	
TRANSFER CONDITIONS			
Initial jacking force	Generally 70% of characteristic strength of tendons		fci : concrete strength at transfer
Allowable compressive stress			
Mainly triangular distribution	0.5fci	$1.5fk/\gamma mm = 0.6fk$	fcu : characteristic cube strength of concrete
Mainly rectangular distribution	0.4fci	$1.25fk/\gamma mm = 0.5fk$	
Allowable tensile stress	Varies (1N/mm^2 Class 1)	$0.25/\gamma mm = 0.1N/mm^2$	fk : characteristic compressive strength of masonry
SERVICEABILITY LIMIT STATE			γmm : partial factor of safety for compression of masonry (2.5 for highest quality construction)
Allowable compressive stress			
Normal bending	0.33fcu	) $0.6fk/\gamma mm = 0.24fk$	
Statically indeterminate(supports)	0.4 fcu	)	
Direct	0.25fcu	$0.5fk/\gamma mm = 0.2$ fk	
Allowable tensile stress	Nil for Class 1	Nil	Note: γm for concrete included in the factors given
			Steel stress limited by transfer stress
ULTIMATE LIMIT STATE	Criteria generally similar to those for reinforced concrete and reinforced masonry		

TABLE 2: COMPARISON OF STRESS LEVELS & FACTORS OF SAFETY FOR PRESTRESSED CONCRETE & PRESTRESSED MASONRY

3. PROPERTIES OF PRESTRESSED BRICKWORK

3.1 Levels of stress and factors of safety

In Table 2 stress levels and factors of safety recommended in the draft British masonry code are compared with those for prestressed concrete in the current concrete code CP110:1972. It can be seen that if the characteristic strength of masonry (fk) is considered to be equivalent to the characteristic concrete cube strength (fcu) in CP110 but of a lower value*, the various factors used are similar but rather more conservative in the case of masonry. This is understandable in view of the much smaller experience.

3.2 Loss of Prestress

However uncertain we may be over losses of prestress with concrete there are even greater gaps in our knowledge of long-term stress variations with prestressed brickwork. In spite of doubts all evidence points to the losses with brickwork being lower than with concrete. This is a satisfactory starting point.

Relaxation of steel is the same as with prestressed concrete and so largely is friction. Creep under constant load with clay brickwork is certainly less than with concrete and may well be limited to the creep of the mortar in the joints.

Perhaps the biggest difference in prestressing losses between concrete and brickwork lies in the fact that, whereas concrete shrinks with age as it dries out, clay brickwork expands due to the gradual take up of moisture in the years following firing. Overall these movements are of comparable magnitude but of course in opposite directions. Although with concrete, allowances have to be made for shrinkage, regrettably no advantage can be taken of the expansion of clay; not only is this expansion variable and unpredictable but one just cannot wait for it to take place. However, there is an immediate gain in eliminating all drying shrinkage except that in mortar joints and in the background there is the reassuring fact that due to moisture expansion prestressing forces with clay brickwork should increase again after the first losses.

3.3 Corrosion

No records of tendon failures due to corrosion in prestressed brickwork have yet come to light but this does not mean that one can take a cavalier attitude to protection. Existing structures are mostly young and there are very few of them. With prestressed concrete, used on a much wider scale and for longer, it is known that there have been failures of wires or rods in the last few years, mainly at junctions in precast construction in structures at least 15 - 20 years old. Whether there will be many more in the next 20 years must be a matter for conjecture; probably some, but we hope not many. Detailed evidence is seldom readily

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*fk varies from 3.2 N/mm^2 to 24N/mm^2 for the case of brickwork compared with a normal range 20 N/mm^2 to 50 N/mm^2 for concrete.

available but it seems that two or more unfavourable factors are needed to cause trouble. Jointing mortar in precast concrete tends to be porous and if at these joints there is inadequate grouting of the tendons, persistent exposure to moisture and, perhaps worst of all, calcium chloride, trouble is at least likely.

With brickwork, joints are more numerous than in precast concrete, they tend to start by being fairly porous and carbonation follows. Evidence of corrosion of reinforcement and brick ties in all types of masonry is conflicting but for peace of mind the use of austenitic stainless steel for tendons would often be prudent.

3.4 Stainless Steel Prestressing tendons

It is notable that stainless steel bars, especially of small diameter, are available with strengths little, if at all, lower than those of normal threaded prestressing rods (ultimate strength about 1000 N/mm^2.)

It is also notable that the tendon extensions in some actual uses of prestressed brickwork must have been so small that, even with moisture expansion, their full permanence may be in doubt. (About 3 mm for Bradshaw's wall and it seems about 0.5mm on the SCD system).

In exposed positions in particular there is a good case for using the smallest practicable diameter of stainless steel stressed to the highest reasonable level thus combining the certainty of a greater extension with increased resistance to corrosion; 10mm stainless steel bars in Bradshaw's wall, in place of his 18mm bars, could have been stressed (and extended) about three times as much and would have used 1/3 as much steel although admittedly of a more expensive type.

High strength stainless steel rods themselves may well cost anything between five and seven times as much as the normal prestressing bars and equivalent stainless clad steel 2.5 to 3.75 times as much. There will often be no way of setting off all the extra costs against savings in initial protection but the long-term advantages of stainless steel are clear.

4. ECONOMICS AND THE FUTURE OF PRESTRESSED BRICKWORK

4.1 Basis of comparison of costs

Before reviewing the different types of brickwork structure where prestressing might be beneficial, and in particular before making any cost comparisons between prestressed and reinforced brickwork, it is necessary to consider the extent to which such comparisons would be valid. Conditions vary widely but some fundamentals will remain.

First it is convenient to divide the costs both of reinforced

and equivalent prestressed structures into three items :

i) Brickwork material costs.

ii) "Steel-force" supply costs: that is the cost of supplying the steel for the required "characteristic force" (area of steel multiplied by its characteristic strength).

iii) Labour costs, including in the case of prestressing forming ducts, tensioning and grouting or wrapping the tendons, as compared with fixing reinforcement.

The third of these items is almost certain to be greater with prestressing than with reinforcing and thus for an economic balance either the steel force or the brickwork materials, or both, must cost less.

Setting aside stainless steel for the present (where it is needed for prestressing it will equally be needed with reinforcing) the supply costs of appropriate "steel-force" in Britain are of the order shown in Table 3 below.

Material (20 - 40mm) rods	Characteristic strength N/mm	Cost per tonne of materials	Cost of steel supply per kN of force per metre
High yield reinforcement including bending and delivery but not fixing	410-425	Approx £240	£4.5 x 10^{-3}
Prestressing rod including threading ends and delivery (taken as 5m long)	995-1035	£490 - £670	£ 3.8 to 5.0x10^{-3}

TABLE 3 "STEEL-FORCE" SUPPLY COSTS

The figures in this table must be considered only as a rough guide but they do show that per kN of characteristic force the supply cost of high yield reinforcement and prestressing rod are very nearly equal. Thus in comparing steel costs all one needs to do is to consider the amount of the steel-force required either as reinforcement or prestressing tendon.

A further point to bear in mind when comparing prestressed and reinforced brickwork is that, as with all prestressed sections, one must consider the serviceability conditions at working load (no tension and a limited compressive stress) as well as the ultimate condition when the masonry is cracked and the section is acting effectively as reinforced concrete. The serviceability condition can easily be dominant as shown below.

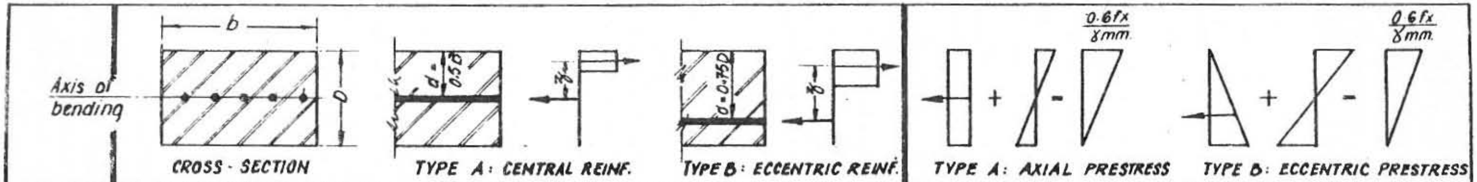
4.2 Cantilever walls

Perhaps the two commonest types of wall where either reinforcement or prestressing would be beneficial are the free-standing cantilever resisting wind (e.g. the boundary wall) and the cantilever wall retaining earth or stored bulk materials. Both have been built with success in reinforced brickwork, but it would be equally logical - perhaps more so - to prestress them; deflections should be less, cracking eliminated and virtually all doubts on shear strength dispelled. Accepting these gains there is still the question of relative cost.

In Table 4 the working-load resistance moment of solid brick walls performing both these functions is compared with either reinforcement or prestressing. This comparison is made primarily on brickwork strength, but the steel-force needed in each case to balance the moment is also shown. Unit length of wall of the same thickness is considered and the same material strength (fk). In the case of walls resisting wind, with complete reversibility of load, the reinforcement is assumed to be central and the prestress axial, while for retaining walls the prestressing tendons are taken at the appropriate kern limit and the reinforcement displaced as in the case of a pocket type wall. The partial factors of safety for load (γf) are taken as 1.2 for wind and 1.6 for retaining walls. Finally, to avoid any uncertainty on the lever arm with reinforced sections, the possible limits of this have been used in comparisons rather than any calculated values.

It can be seen from this table that for each type of wall the serviceability requirements for prestressing lead to a lower working resistance moment for the same thickness and material strength. These differences are not large, but what is more serious is the steel-force for the prestressed case which, expressed as a proportion of the resistance moment, is three to four times as great for the wall resisting wind and about twice as great for retaining walls. Taking these findings with the discussion on relative costs in Section 4 above, one must conclude that prestressed sections are, or should be, appreciably more expensive than equivalent reinforced ones. Altering the partial safety factors and other constants can make only a limited difference. The reasons are deeper.

The comparisons just described are based on solid sections. Cellular (diaphragm) walls are obviously more "efficient" than solid ones under prestress, whether this is applied axially or eccentrically, but here the number of variables precludes the comparison of anything other than individual cases. A few such studies of prestressed cellular walls compared with solid



	REINFORCED		Based on ultimate limit state: As BS 5628 draft	Based on ultimate limit state: Possible mod. to draft 5628	PRESTRESSED		Based on serviceability limit state: As BS 5628 draft
A WALL RESISTING WIND; $\gamma_{mm} = 2.5$, $\gamma_{ms} = 1.15$, $\gamma_f = 1.2$	Central reinf. $(d = D/2)$	Working load resistance moment based on masonry (Mwm)	$\frac{0.375 \times 1.2\, b.D^2 f_k}{4.\gamma_{mm}.\gamma_f} = 0.0375\, b.D^2 f_k$	$\frac{0.3\, b.D^2 f_k}{4.\gamma_{mm}.\gamma_f} = 0.025\, b.D^2 f_k$	Axial prestress	Working load resistance moment based on masonry (Mwm)	$\frac{1}{2} \cdot \frac{0.6 f_k}{\gamma_{mm}} \cdot Z = 0.020\, b.D^2 f_k$
		Steel force $(A_s.f_y)$ needed to match bending moment	$(0.138 \rightarrow 0.109)\, b.D.f_k$	$(0.092 \rightarrow 0.073)\, b.D.f_k$		Steel force $(A_s f_{pb})$ needed (tensioned to $0.7 f_{pb}$ & 25% losses)	$0.229\, b.D.f_k$
B RETAINING WALL; $\gamma_{mm} = 2.5$, $\gamma_{ms} = 1.15$, $\gamma_f = 1.6$	Eccentric reinf. $(d = 0.75D)$	Working load resistance moment based on masonry (Mwm)	$\frac{0.375 \times 1.2 \times 9\, b.D^2 f_k}{16\, \gamma_{mm}.\gamma_f} = 0.0633\, b.D^2 f_k$	$\frac{0.3 \times 9\, b.D^2 f_k}{16\, \gamma_{mm}.\gamma_f} = 0.0422\, b.D f_k$	Eccentric prestress $(e = D/6)$	Working load resistance moment based on masonry (Mwm)	$\frac{0.6 f_k}{\gamma_{mm}} \cdot Z = 0.04\, b.D^2 f_k$
		Steel force $(A_s.f_y)$ needed to match bending moment	$(0.207 \rightarrow 0.164)\, b.D.f_k$	$(0.139 \rightarrow 0.110)\, b.D.f_k$		Steel force $(A_s.f_{pb})$ needed (tensioned to $0.7 f_{pb}$ & 25% losses)	$0.229\, b.D.f_k$
			NOTE: Steel force given for lever arm varying from 0.75d to 0.95d.				

TABLE 4. COMPARISON OF STRUCTURAL PERFORMANCE OF PRESTRESSED & REINFORCED MASONRY

reinforced ones point, at best, to small savings in materials, sometimes the reverse, and probably no saving in cost.

Why prestress such walls? Are the gains in relation to deflection, cracking and shear strength worth the apparent extra cost? Deflections tend only to be a problem where the cantilever is a continuation of some more rigid structure. Shear is of no consequence with walls resisting wind and probably only a problem with cantilever retaining walls because designers are interpreting its action wrongly.

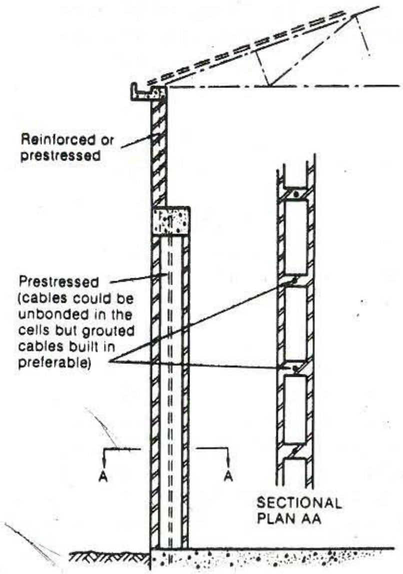


Figure 1: Industrial shed of Prestressed Masonry

In cases such as that in Figure 1 there could be a real case for prestressing to give greater rigidity and with abnormally thin "wind" walls deflection with reinforcement could increase with time due to the gradual breakdown of bond.

All the factors discussed above point to the possible benefits of partial rather than full prestressing. This will be discussed further.

However unpropitious these cost comparisons may look there is still a case for trying out prestressed cellular, counterfort or buttress retaining walls on a real civil engineering scale where the stresses could be much higher than those used, say, by Bradshaw (10). Reports of current work by W.G. Curtin and the results of tests by Dr Phipps on such walls are awaited with interest.

4.3 Tanks

For any wall either of concrete or brickwork which is required to resist direct tension, as in the case of a circular water tank, prestressing has the great advantage of ensuring that there is effectively no extension of the tendons and thus no cracking or opening up of joints when the tank is filled. While this thinking can be applied with success to unlined circular concrete tanks it is only partially applicable to brickwork, the problem being the porosity of the joints as Don Foster pointed out; some lining is needed. In spite of this limitation prestressing is in many ways preferable to reinforcement for circular brick tanks, but will probably cost more.

4.4 Brickwork beams

The problem with brickwork beams is not so much whether they should be reinforced or prestressed but why beams should be made of brickwork at all. Concrete has become well established for

this purpose with almost infinite flexibility of shape and few impediments to reinforcement or prestressing tendons. Brick beams are by their nature full of impediments.

Whatever the structural disadvantages there is likely to be a small but continuing demand for beams in brickwork mainly for architectural reasons. Here prestressing offers a clear advantage over reinforcement in that it can virtually eliminate the crucial problem of shear and thus the puzzle of how to fix shear reinforcement in a brickwork section.

Perhaps the most immediate benefit from current tests on prestressed brick beams at Edinburgh University is that with such experiments one can achieve a true compressive failure in bending under observable conditions. This should help to clarify ideas on how best to simulate in design the real stress and strain behaviour at failure. In this connection there is also a case for reviewing the results of earlier beam tests preferably from the original records and in the light of the current test results. Looking back at K. Thomas's report at Austin (8) one wonders whether in at least one case a failure attributed to shear was really due more to gross overstressing initially.

4.5 Storey-height box beams

One form of brick beam which could have a real future if prestressed, is the storey height box beam with a brick wall as web, and the floor or roof slabs as flanges. In all the tests carried out for the S.C.P. with only reinforcement in the webs very noticeable horizontal cracks occurred, even at or near working load. Further these cracks increased with time. In the one test case where prestressing was provided the unit behaved excellently, as one might predict, in fact as if all the load had been applied to the top and not the bottom flange.

Given even partial prestress, preferably with stainless steel in exposed places, this form of construction could do much to open up the planning freedom with brickwork.

5. CONCLUSIONS

In some ways the writing of this paper has been a sad journey,but there are still rays of light at its end. An initial belief in a new and exciting future for brickwork with traditional prestressing has ended in a conviction that although there are many situations where it would be desirable there are few, in building at least, where it would be justified. Improved shear resistance, smaller deflections and virtually complete elimination of flexural cracks are admirable but only if these are required - or noticed. Fully prestressed sections will generally need a greater steel-force and cost more than equivalent reinforced ones.

The situation with prestressed concrete is perhaps not wholly dissimilar even though prestressing has more to offer in the case of concrete beams and slabs than in walls of any material. There has certainly been a decline in the use of prestressed concrete in building in Britain since the late 1950s and early 1960s. In civil engineering prestressing has held its own much better and has to some extent gained ground but in this field brickwork

itself has lost out; it is thought to be a rather flimsy material only suitable for houses. Given prestressing to make the brickwork more "solid", rather than massive as in the 19th Century and before, perhaps much of the present prejudice against brick as a civil engineering material will vanish. That is the first ray of light.

Even if only used on a limited scale the concept of prestressing all types of masonry should be more widely known as one more technique which engineers can apply with confidence and without administrative impediment. However, instead of insisting on the ideal of no tension under working loads, there should be acceptance of the principle of any level of partial prestressing which the designer may think appropriate.

The concept of partial prestressing for masonry is particularly attractive in the case of tall boundary walls. If one designs the wall for ultimate strength as a reinforced one and fixes the amount of steel accordingly but then tensions some or all of this, the result will be improved performance under the more frequent wind loads, and thus most of the advantage of full prestressing without all the extra costs. This statement may be an over-simplification, but the principle is clear. The idea of partial prestressing is a second ray of light. Perhaps there are others.

On the subject of prestressing, whatever is written in any country's masonry code should give designers as much freedom of action as possible. What is more there should be no requirement, stated or implied, to choose between two separate techniques, one called reinforced masonry where extensive cracking is accepted and the other called prestressed masonry where it is taboo. Much the same thinking could equally be applied to concrete codes.

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