Fin Wall Construction in Tall Single-storey Buildings

CURTIN, SHAW, BECK AND BRAY

W. G. CURTIN AND PARTNERS
19 RODNEY STREET
LIVERPOOL L1 9EQ
ENGLAND

SUMMARY
The concept of the fin wall developed from the diaphragm wall to provide another economic alternative to steel and concrete framed buildings and is particularly suited to tall, single-storey, wide-span structures. The paper discusses the development of the design method and provides practical information on both structural and architectural detailing considerations. The discussion is illustrated and a table of properties of fin wall profiles is included. Finally, some photographs of completed projects are included to demonstrate the wide architectural scope which the fin wall offers.

SECTION 1 INTRODUCTION AND GENERAL DESIGN

INTRODUCTION

Fin wall construction (ref.1), which has been shown by some considerable experience to be particularly suited to tall, single-storey, wide-span buildings such as swimming pools, sports halls, churches, workshops and industrial units, is another type of masonry structure that obviates the need for steel or reinforced concrete columns, external cladding and internal lining, and is shown in isometric projection in Fig.1.

The brickwork T section (Fig 2) formed by the fin and outer leaf of the cavity wall provides the main structural member, and the inner leaf is the internal lining. Thus, only one material used by one trade under the direct control of the general contractor is needed to form a durable, maintenance free, attractive and economical wall.

GENERAL DESIGN

STRUCTURAL PRINCIPLES

In the current codes of practice, piers are recognised as a means of increasing the vertical load-carrying capacity of plane walls. The effect of piers is presented as an apparent increase in the effective thickness of the plane wall. This, of course, will give a lower slenderness ratio and thus the wall can be allowed to carry a larger vertical load. In CP 111 (ref.2) no specific guidance was given for the design of walls with piers under lateral load. BS 5628 (ref.3) gives some guidance.

In the concept of the fin wall given in this paper the whole fin plus the wall is used in determining the slenderness ratio although, as with diaphragm walls (ref.4) for tall single-storey buildings, vertical loading is unlikely to be critical. The critical loading case for designing such walls will generally be that of wind loads and for this a T section is considered.

ARCHITECTURAL TREATMENT

A typical simple plan layout for a rectangular building is shown in Fig.1.

Examples of the variations which can be made to the plan are in the sizes and spacing of the fins, the details at the corners and even the basic wall profile can be varied in many different ways. Fig.3 shows some examples. The variations can have structural implications, and the selected profile must be checked to suit the structural needs.

On elevation, the fin can be tapered, bevelled, profiled, etc and some typical shapes are shown in Fig. 4.

ROOF

To obtain greatest economy, the roof of the fin wall building should be used as a horizontal plate to prop and tie the top of the walls, and to transfer the resulting horizontal reactions to the gables or other transverse walls of the building (see Fig. 5), assuming such transverse walls to be spaced within a reasonable span for the roof plate.

In cases where only the ring beam and decking form the plate, it is necessary to ensure that the deck and its fixing are stiff enough and strong enough to control the movement and forces involved. When a concrete ring beam is used, it should be designed to help transfer the wind forces from the tops of the walls on which the wind is acting to the transverse walls of the building.

If no capping beam is used, and the roof dead load is small, the main roof beam often requires to be strapped down and this can be done using rods from the padstone taken down to a suitable level to ensure sufficient dead load to resist uplift (see Fig. 6).

In cases where a concrete capping beam is to be used, it is usually better constructed in precast sections of full bay lengths jointed with a joint detail capable of transferring the forces in this location. The use of precast concrete capping beams avoids the problems relating to supporting shuttering at a high level and preventing grout runs over facing brickwork, particularly where the beam is wider than the cavity wall (see Fig.7).

OPENINGS IN WALLS

Large openings required in the main walls can sometimes create high local loading conditions from wind and vertical loads, particularly around beam bearings. In such locations a beam or lintel is normally used to span over the opening and an adjustment to either the fin spacing or fin cross section can usually be made to carry the increased loads involved.

JOINTS

Movement joints for shrinkage and expansion are required at the appropriate centres related to the type of bricks and mortar being used, the differential temperatures expected, and in accordance with the current recommendations for brickwork in CP 121. The joints can easily be accommodated by a double fin, one on each side of the joint (see Fig. 8).

DAMP PROOF COURSES

In addition to the normal impervious requirements for the horizontal dpc, it is important to select a material which has the necessary resistance to sliding and squeezing out under horizontal and vertical loadings respectively. Should it be considered desirable to transfer flexural tension to the foundation, or should prestressing techniques be employed, consideration should be given to the use of an engineering brick or slate dpc. It should be noted, however, that it is not recommended that the flexural tensile resistance at dpc level be exploited in the case of the propped fin unless a much more detailed analysis of the deflection of the prop is considered (see Section 2, Design bending moments).

TEMPORARY PROPPING

Like most other walls, the fin wall is in a critical state during erection and prior to the roof being constructed and fixed. During this period, therefore, the contractor must take the normal temporary precautions such as propping the walls with the bricklayers' scaffolding or other means to ensure that the walls remain undamaged.

STRUCTURAL DESIGN METHOD

The main calculations involved in the design of fin walls are for the critical conditions of combined dead and wind loading. These take into account the maximum bending flexural stresses.

The flexural compressive stresses involved when combined dead, superimposed and wind loading are applied can be critical, particularly when the fin is bending about its weaker axis and the stresses at the extreme end of the fin are considered. The choice of brick and the mortar must, therefore, take into account the tensile and compressive strength required, and the durability needed for the individual building. The walls are assumed to act as 'propped' cantilevers, with the roof acting as the prop and transferring the propping forces to the transverse walls (see Fig. 5) and 'fixed' at the base by virtue of their self-weight. The plate action of the roof will allow some small movement at the prop location, and the stiffness of the wall will vary due to the effects of the gravitational loads and the loss of flexural tensile resistance at dpc level.

Within the height of the wall, there are two locations of critical bending moments, these occur at dpc level, location A, and part way between dpc and roof level at location B (see Fig.9). Due to the unsymmetrical shape of the fin, it is important to consider both directions of wind loading in order to determine the critical stress.

The calculations are carried out on a trial and error basis by adopting a trial section and then checking the stress conditions. For detailed discussion see Section 2.

EXPERIENCE AND PERFORMANCE OF FIN WALLS

A considerable number of fin wall buildings have been completed and more are under construction or in the design stage. The buildings already completed are on the whole, situated on exposed sites in the North West of England.

Those constructed have already survived:

(a) the worst gales on record in January 1976
(b) the hottest summer on record
(c) the worst drought
(d) the wettest autumn

These, and the more recent examples, have also survived one of the most severe winters this century.

The buildings have all performed successfully and no problems have developed as a result of the method of construction. In particular they have, both internally and externally, withstood the hard usage associated with sports halls without requiring maintenance.

FURTHER APPLICATION

In addition to the use of fin walls for new buildings, they have also been found very useful for strengthening existing buildings. In one particular case the rear wall of a grandstand which was showing signs of becoming unstable, was strengthened by bonding into it, at predetermined centres, a series of brick fins designed to resist the excessive loading likely to be applied.

A further application was the use of post-tensioned fins to strengthen a retaining wall to an existing basement, where a change of use resulted in increased lateral loading which made it bulge and crack and become unstable. The post-tensioned brick fins proved easy to construct and economical when compared with alternative forms of construction.

FUTURE PROGRESS

Although the fin wall was developed mainly for use in tall, single-storey wide-span buildings, it has become apparent to the authors that it has a much wider application. For example, the post-tensioned fin wall used as a retaining wall is attractive both economically and visually and has great potential for the future.

The use of fin walls in conjunction with spine walls can result in multi-storey buildings of unrestricted floor areas for office buildings, hospital ward blocks and other building forms which cannot tolerate the restrictions of crosswall or cellular construction.

SECTION 2 DESIGN PRINCIPLES

CRITICAL DESIGN CONDITION

The principles which follow are based on reasonable assumptions, some of which are as yet unsupported by research. However, structures which have been designed in accordance with these theories and assumptions have performed and are performing successfully.

For tall single-storey buildings, the critical design condition is rarely governed by axial compressive stresses but by the wall's resistance to lateral forces from wind pressures. The flexural tensile stresses generally govern the design and it is, therefore, beneficial to either reduce the flexural tensile stresses by reducing the maximum applied bending moment, or by increasing the section modulus and/or increase the compressive stresses.

This can be achieved by:

(a) using the roof as a plate (see Fig 5) to prop the wall, thus reducing the bending moment when compared with a free standing cantilever, and:

(b) using a T section - fin wall;

(c) using post-tensioning to increase the compressive stresses and to decrease section sizes.

The principles of post-tensioned brickwork design is the subject of another paper by the same authors to be presented at this conference. Detailed discussion together with numerous worked examples of fin walls, diaphragm walls and post-tensioned walls, as well as the more basic aspects of loadbearing brickwork, is available in Structural Masonry Designers Manual (ref.5) by the same authors.

INTERACTION BETWEEN LEAVES

As shown in Fig. 10 the fins are bonded to one of the leaves of a cavity wall and considered as a T section combining the bonded leaf with the fin. The other leaf is considered as a secondary member, the cavity ties are assumed to be unable to transmit significant vertical shear forces but capable of transmitting horizontal forces across the cavity width. The type of tie assumed for this condition is the galvanised vertical twist tie, and under most conditions this is adequate. However, the designer should satisfy himself that the ties are suitable for the exposure conditions in which they are employed, and that they can transfer the design forces adequately.

EFFECTIVE SECTION

Because of the unsymmetrical shape of the member, the geometrical properties of the effective sections, when combined bending and direct forces are considered can vary greatly under changes in loading particularly if a 'cracked section' is being analysed. It is, therefore, important when considering the stability moment of resistance to also consider carefully the effective section being stressed and the effects of any cracked portion on the general performance of the wall. The flexural stresses must be kept within those recommended in the Code of Practice but, at dpc level, the majority of damp proof courses must be considered to have no resistance to flexural stress, and at this level a 'cracked section' is often assumed. The moment of resistance at this level becomes the gravitational moment of resistance for the worst loading combination, which is generally that of dead plus wind loading.

DESIGN CONSIDERATIONS

The various loading combinations and their effect on the stress conditions must be considered, therefore, one of the first calculations is that of assessing

the loads:
(1) calculate the positive and negative wind pressure
(2) calculate the dead, imposed and wind loading on the roof and walls.

Having obtained the loading condition, it is important before progressing with the design to make sure that the assumed behaviour of the structure is understood. In the case of the fin wall being used on tall single-storey buildings, it is assumed that the wall acts as a propped cantilever (see Fig. 5 and Fig 11) where the fixed end moment is that due to the vertical loads, and is known as the stability moment of resistance.

UPLIFT
It is most important to take account of roof uplift forces when considering the worst design condition. It is also important to note that the critical section at or near the base of the wall is usually at the location of the dpc where little or no tension is permissible, depending on the chosen membrane.

DETERMINE MAXIMUM CRITICAL STRESSES
It is necessary in the calculations to determine the maximum critical forces, moments and stresses in the wall, which, for a normal propped cantilever, occur at or near the base of the wall and at a point approximately $\frac{3}{8}$H from the top of the wall. However, the propped fin wall will vary from this as explained below.

DIFFERENTIAL STIFFNESS WITHIN HEIGHT OF WALL
For a uniformly distributed load on a propped cantilever of constant stiffness with a rigid prop, the bending moment would be as shown in Fig. 12.

However, for the brick fin wall shown, some deflection will occur at the prop location, and the wall strength will vary within the height of the wall due to the variation at each level in the axial load.

It would, therefore, be merely coincidence if the stability moment at the base was exactly equal to $\frac{pH^2}{8}$ which is the condition for the straightforward propped cantilever.

DESIGN BENDING MOMENTS
As the applied bending moment is increased, the stability moment at the base for the same axial load will not decrease but slight cracking and rotation of the base of the wall will occur and produce increased bending at the upper location. It is, therefore, more realistic in the design to first calculate the stability moment at the base dpc level taking account of the appropriate partial safety factor for loads.

The design load free bending moment can then be superimposed upon the stability moment diagram (see Fig 11). The position and magnitude of the maximum positive bending can then be determined and these stress conditions checked.

CHECK BOTH DIRECTIONS OF BENDING
It is important, when considering the bending moments on the fin, to check for the bending moments in each direction at each level, since the critical stress conditions will not necessarily result from the same direction of applied bending moment.

SPACING OF FINS
The choice of a suitable section must take into account the cavity wall's ability to act suitably with the fin to both transfer wind forces to the overall section and to prevent buckling of the flange of the T section. This involves choosing a suitable spacing for the fin to control both of these conditions and to take into account economic spacing of the roof beams. The spacing of the fin is, therefore, governed by the following conditions:
(a) The cavity wall acting as a continuous horizontal slab subjected to wind load, spanning between the fins.

(b) The cavity wall's ability to support vertical load without buckling. This is governed by the slenderness ratio of the wall, BS 5628, clause 28.
(c) The ability of the cross section to resist the applied loading with the leaf and fin acting together to form a T beam.

The effective flange of the T beam is limited to the least of:
(i) the distance between the centres of the fins
(ii) the breadth of the fin plus twelve times the effective thickness of the bonded leaf
(iii) one-third of the effective span of the fin.

It should be noted that clause 36.4.3 of BS 5628 embraces two of these conditions with reference to piered walls but, since it is felt that the distribution of stress into the flange is also related to the span of the fin (in a similar manner to a reinforced concrete T beam), a span related limit is also necessary.

(d) The vertical shear forces between the fin and the bonded leaf resulting from the applied bending moment on the T section (see Fig. 13).
(e) The economic spacing of the main roof supports.

It should be noted that whilst item (c) restricts the flange length for the design of the fin, the actual distance between the fins can be greater.

Typical fin sizes are 1-2 m deep at spacings of 3 to 5 m and 1½ bricks (327 mm) or 2 bricks (440 mm) wide. Some typical sections and their properties are shown in Table 1. The length and thickness of the fin is governed by the tendency of the outer edge to buckle under compressive bending stress.

The roof plate action and the stresses in the transverse walls which provide the reactions to the plate must also be checked.

REFERENCES

1. Design of Brick Fin Walls in Tall Single-Storey Buildings : Curtin, Shaw, Beck and Bray : BDA : 1980.
2. Structural Recommendations for Loadbearing Walls Code of Practice CP 111 : 1964 : Part 1.
3. Structural Use of Masonry : Part 1 Unreinforced Masonry : Code of Practice BS 5628 : Part 1 : 1978.
4. Brick Diaphragm Walls in Tall Single-Storey Buildings : Curtin, Shaw, Beck and Bray : BDA : 1982.
5. Structural Masonry Designers Manual : Curtin, Shaw, Beck and Bray : Granada Publishing Ltd : 1982.

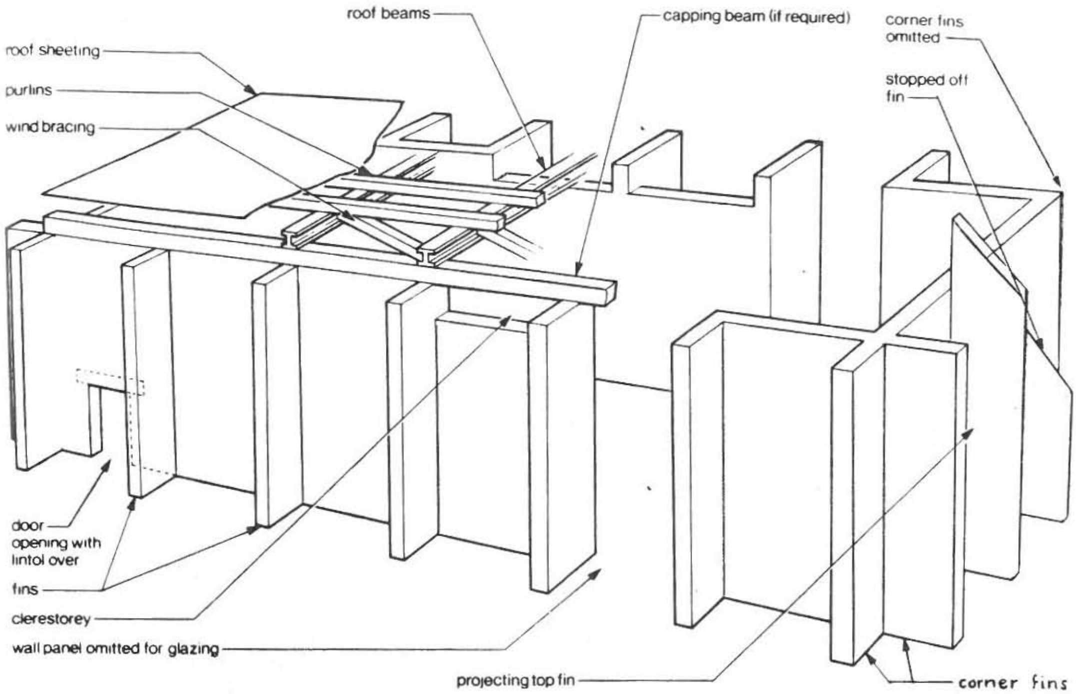

Fig. 1 Typical Fin Wall Building

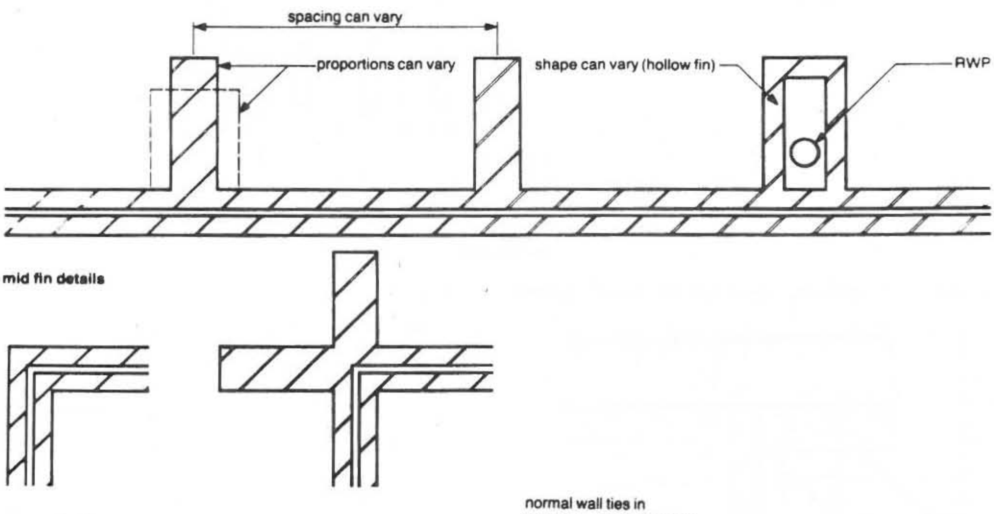

Fig. 3 Variations in Plan Arrangement

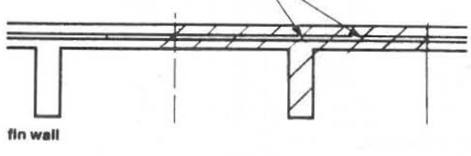

Fig. 2 Effective Section

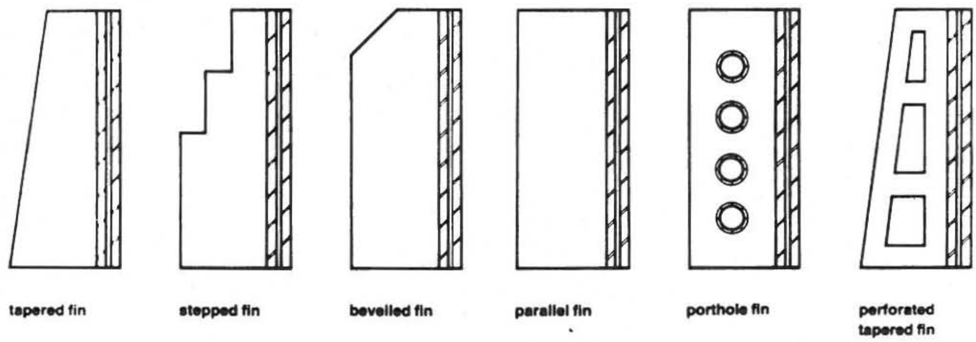

Fig. 4 Variations in Fin Elevation

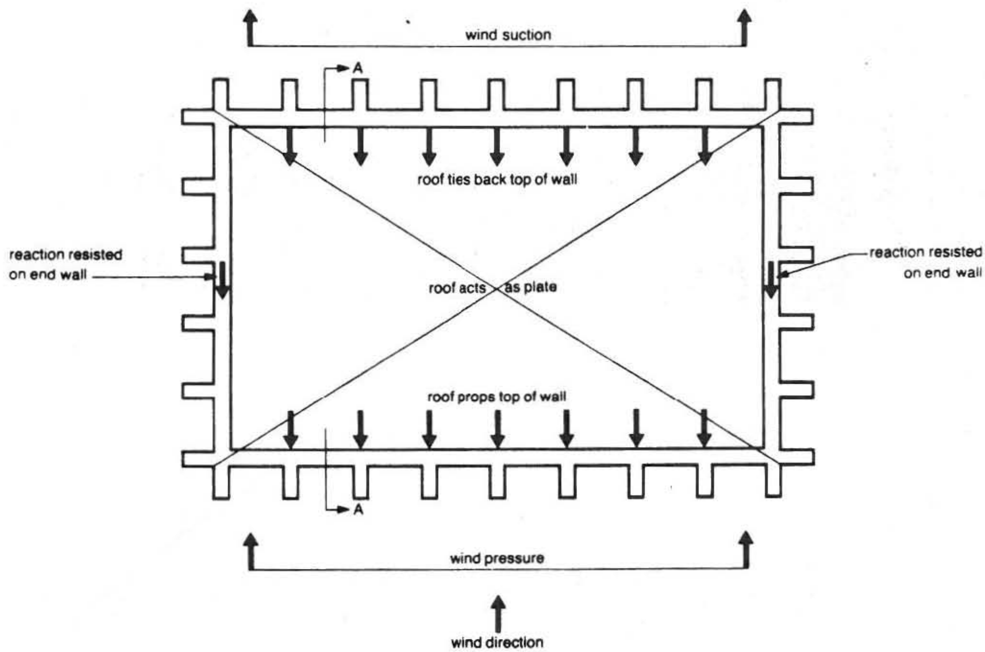

Fig. 5 Propping System at Roof Level

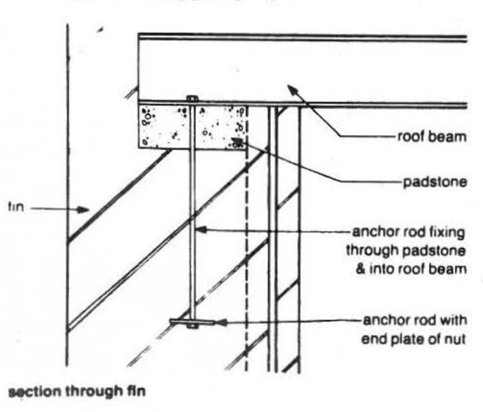

Fig. 6 Roof Beam Strapped Down

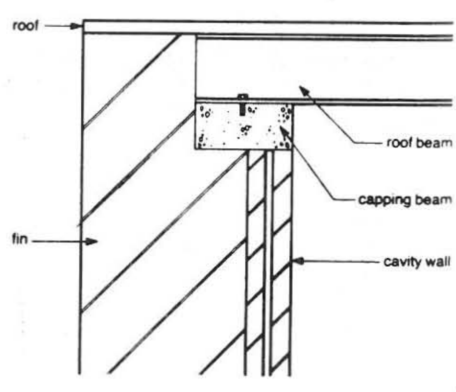

Fig. 7 R.C. Capping Beam

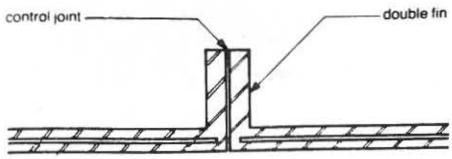

Fig. 8 Double Fin at Joint

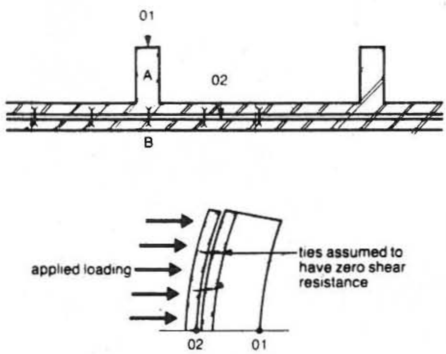

Fig. 10 Deflected Shape of Free Cantilever

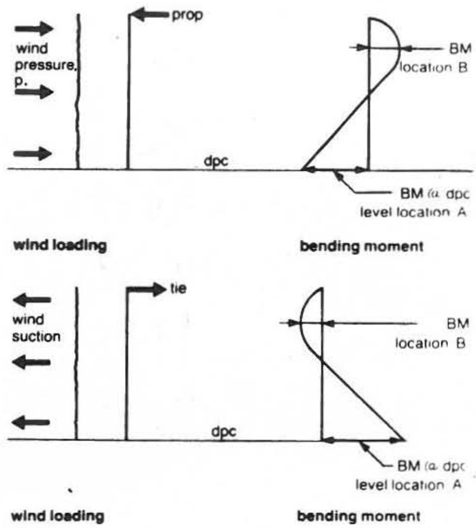

Fig. 9 Locations of Critical Bending Moments.

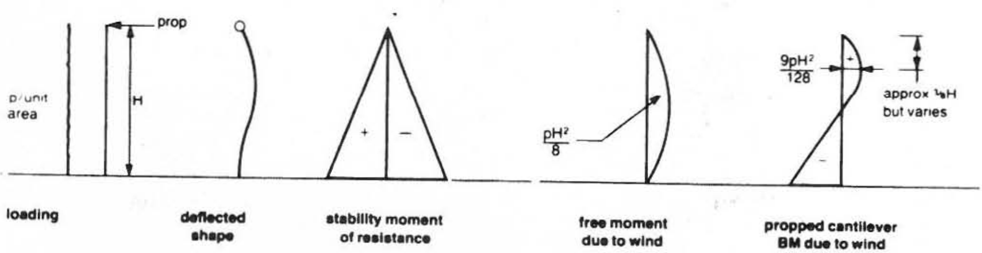

Fig. 11 Assumed Behaviour of Fin Wall in Bending

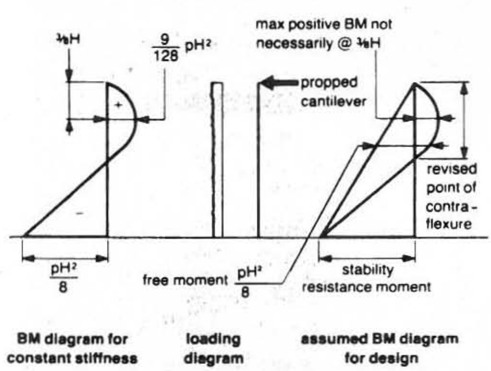

Fig. 12 Bending Moment Diagram

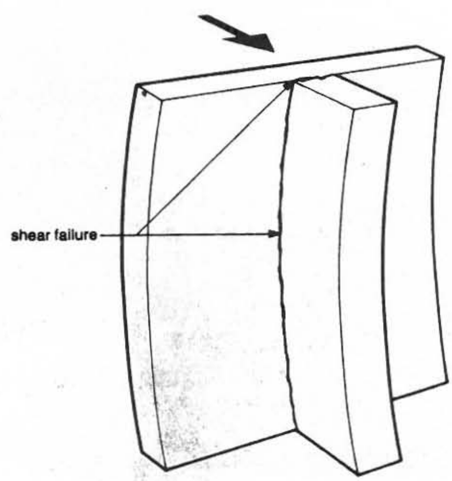

Fig. 13 Possible Shear Failure

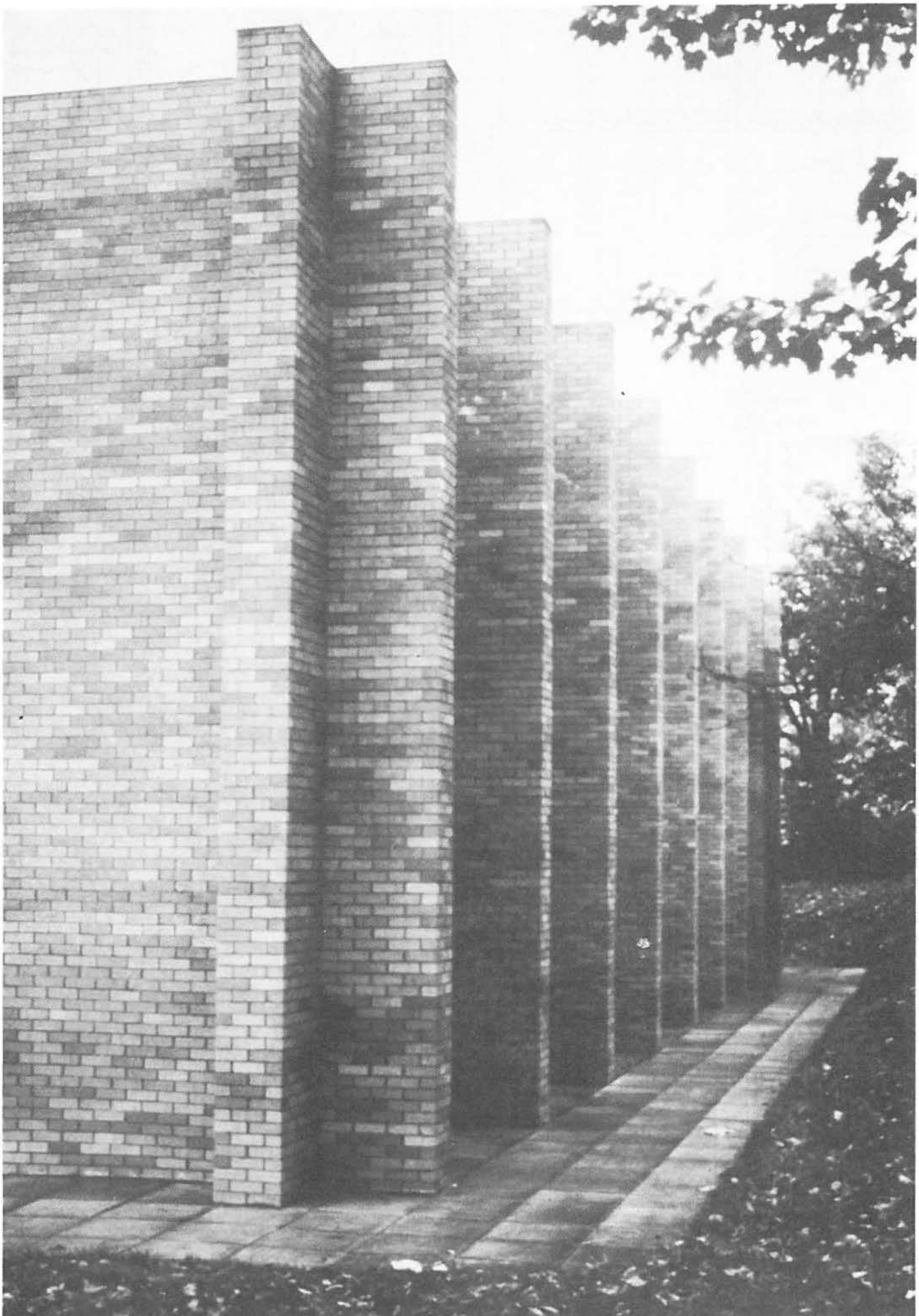

Fig. 14 Typical Fin Wall Building

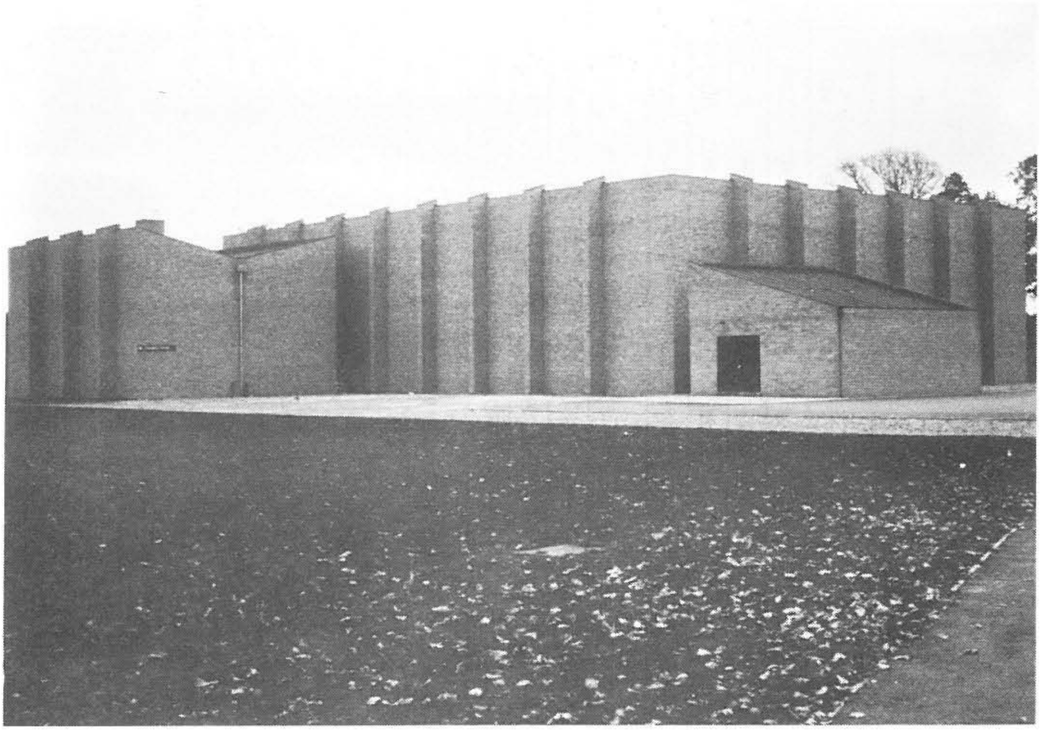

Fig. 15 Typical Fin Wall Building

Fig. 16 Typical Fin Wall Building

Fin reference letter	A	B	C	D	E	F	G	H	J	K	L	M	N	P
Fin size (mm)	665 × 327	665 × 440	788 × 327	788 × 440	890 × 327	890 × 440	1003 × 327	1003 × 440	1115 × 327	1115 × 440	1227 × 327	1227 × 440	1339 × 327	1339 × 440
Effective width of flange (m)	1.971	2.084	1.971	2.084	1.971	2.084	1.971	2.084	1.971	2.084	1.971	2.084	1.971	2.084
Neutral axis Y_1 (m)	0.455	0.435	0.524	0.500	0.589	0.563	0.654	0.626	0.718	0.687	0.780	0.747	0.841	0.807
Neutral axis Y_2 (m)	0.210	0.230	0.254	0.278	0.301	0.327	0.349	0.377	0.397	0.428	0.447	0.480	0.498	0.532
Effective area (m^2)	0.386	0.4611	0.4262	0.5152	0.4595	0.5601	0.4965	0.6098	0.5331	0.6591	0.5697	0.7084	0.6064	0.7577
o.w. of effective area per m height W (kN)	7.720	9.222.	8.458	10.216	9.190	11.202	9.930	12.196	10.662	13.182	11.394	14.168	12.128	15.154
I_{NA} (m^4)	0.01567	0.01939	0.02454	0.0303	0.0359	0.04426	0.05021	0.06187	0.06746	0.08312	0.088	0.10848	0.11208	0.13826
Z_1 (m^3)	0.03441	0.0445	0.04684	0.06059	0.06096	0.07862	0.07677	0.09883	0.09395	0.12099	0.11282	0.14522	0.13327	0.17132
Z_2 (m^3)	0.07462	0.0843	0.09663	0.10898	0.11928	0.13536	0.14387	0.16410	0.16992	0.19421	0.19687	0.226	0.22506	0.26039
Trial section coefficient Ω (kNm/m)	1.6212	2.1210	2.1483	2.840	2.7662	3.6631	3.4656	4.5978	4.2328	5.6419	5.0931	6.8006	6.0397	8.0619

$Z_1 = \frac{I_{NA}}{Y_1}$ $\quad Z_2 = \frac{I_{NA}}{Y_2}$

Trial section coefficient $\Omega = W\,Y_2$

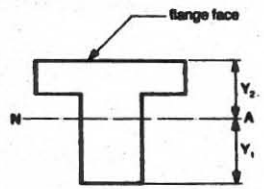

Table 1 Typical Fin Wall Section and Properties