JAMES COOK CYCLONE STRUCTURAL TESTING STATION

CYCLONE TESTING STATION

RECOMMENDATIONS FOR THE TESTING OF ROOFS and WALLS TO RESIST HIGH WIND FORCES

TECHNICAL REPORT NO. 5

June 1980

CYCLONE TESTING STATION

RECOMMENDATIONS FOR THE TESTING OF ROOFS AND WALLS TO RESIST HIGH WIND FORCES

G.F. Reardon

TECHNICAL REPORT No. 5

ISBN No. 0-85874-058-3

Department of Civil & Systems Engineering
James Cook University of North Queensland
Townsville, Queensland. 4811

Wholly set up and printed within the University.

RECOMMENDATIONS FOR THE TESTING OF ROOFS AND WALLS TO RESIST HIGH WIND FORCES

G.F. Reardon

PREAMBLE

The recommendations contained herein for the testing of roof and wall assemblies are based on the best information currently available. The test methods recommended are those most commonly used and as such represent the current state of the art. However from time to time other test methods may be developed that may provide the same results as the methods described herein, or that can provide a more realistic representation of the wind gust conditions that occur during a cyclone. It is not the intent of this document to preclude the use of such methods provided that they can be shown to be satisfactory.

The recommended pressures have been calculated using the wind velocities, terrain category factors and pressure coefficients specified in AS1170 Part 2 - 1975 "SAA Loading Code Part 2 - Wind Forces". Amendments introduced in future editions of that Code may make obsolete some of the tabulated values included herein. However as derivations of the pressures have been included, alterations to the tables can readily be made.

1. INTRODUCTION

In July 1977 a successful workshop was held at the Experimental Building Station of the Department of Construction. At this workshop consensus was reached on loads to be applied during testing and procedures to be adopted when testing and evaluating the performance of products to be used in cyclone prone areas. The workshop was attended by representatives of industry, professional consultants, universities, government research organizations as well as local, State and Commonwealth governments, thus a very broad spectrum of interested parties contributed to the recommendations of the workshop. The final recommendations were published as EBS Technical Record 440, "Guidelines for the Testing and Evaluation of Products for Cyclone-Prone Areas".

After conducting tests according to the recommendations of the Guidelines, a number of industry researchers found that they required more comprehensive details in some areas. These related especially to test assemblies and test procedures. It is therefore the intent of this document to amplify the sections in TR440 which deal with the testing of roof claddings (Section 3) and the testing of wall systems (Section 4) by providing full details of test specimens, apparatus and procedures. It is anticipated that this document will form the basis for an industry standard in the testing of roof claddings and wall systems.

Of necessity this document has been written so that it can be used independently of TR440 although complementary to it, thus it does duplicate some of the recommendations contained therein.

The recommendation contained herein relate expressly to the determination of the capacity of products to resist high wind forces. They do not relate to forces resulting from dead loads or from live loads. Thus there should be no conflict between these recommendations and those contained in any existing Australian Standard.

2. SELECTION OR FABRICATION OF TEST ASSEMBLIES

2.1 Representative of Practice

With the exception of prefabricated wall panels, it is unlikely that any assembly to be tested according to these recommendations will be the product of an assembly line. However for the sake of that exception it is recommended that any such product to be tested should be chosen at random from a group of similar products thus making it representative of the production line. The test specimen should not be fabricated specificially for test purposes as there is a tendancy in such cases to make a product better than the average.

As most low rise buildings almost entirely are assembled on site, assemblies must be specificially fabricated for test purposes. Due care must be taken to ensure that the test assembly is truly representative of the final approved product assembled on site, with respect to both materials and workmanship. Also, care must be taken to test the assembly likely to experience the most severe stresses, for example it is of little value to conduct a series of tests of roof sheeting attached to torsionally stable purlins if it is common practice to attach the sheeting to a torsionally unstable section which may produce a more severe stress on the product and its attachments. When testing an assembly, the immediate supporting structure (purlins in the previous example) should have a stiffness similar to that which it would have in practice. That is, the stiffness of the test assembly with its free end conditions should not be less than that of the roof assembly used in practice; otherwise this excessive flexibility may adversely affect the test results.

2.2 Size of Assemblies

2.2.1 General

The assemblies to be tested normally will be full scale portions of roof framing or wall framing. Tests on scale models should only be adopted where it has been shown that the results of such tests reflect the behaviour of full scale assemblies.

2.2.2 Wall Assemblies

With regard to the fabrication of full scale walls for test, their height should be similar to that used in practice, usually 2400 mm or 2700 mm. The length of wall will usually depend upon its bracing medium. If a diagonal brace is used, it should be located so that its angle to the horizontal is between 30° and 45°. Thus the length of wall would be approximately three metres. Another parameter which may influence the length of the wall is the spacing of anchor rods (cyclone bolts) if they are incorporated.

The length of a wall with sheet cladding will usually be a multiple of the standard width of the sheeting. Again this may be influenced by the spacing of anchor rods. For this type of wall, if diagonal bracing is not included, a length of 1800 mm is recommended to be used as a standard length for test purposes. This length is compatible with sheet cladding widths of 300, 450 and 600 mm as well as the traditional maximum spacing of anchor rods of 1800 mm. It can then be used as a basis of comparison for different types of bracing medium.

It is recommended that test walls of masonry construction also be standardized at 1800 mm long.

Consideration must also be given to the method by which lateral stability will be provided during test, and whether any additional features to achieve this need be incorporated during the construction. This particularly applies to masonry construction which is more difficult to attach temporary bracing to than is framed construction.

2.2.3 Roof assemblies

Three distinct types of roof cladding are used for low rise construction in Australia.

(a) lightweight sheeting that spans three or more purlins/battens
(b) concrete or terra cotta roof tiles that span between two battens
(c) lightweight metal "roof tiles" that span between two battens

For the purpose of this document the latter two types will be grouped together as "tiles" because they both span only two battens.

2.2.3.1 Sheet roofs

The width of a section of sheet roofing to be tested should be at least one full sheet width or 500 mm minimum. Where the width is one sheet only, extra strips or roofing, not more than one quarter of a sheet wide, may be used to simulate continuity in the lateral direction. If such strips are used they must be considered as being part of the area of the roof to be loaded. If there is any evidence of an uneven distribution of load per fastener because of the strips, they should be removed.

Care should be taken when fabricating the test assemblies to ensure that the fasteners securing the roof sheeting to the battens are not unrealistically tight. Overtightening the fasteners can improve the performance of roof sheeting during test. It is therefore recommended that each fastener is tightened until the sealing washer just starts to compress.

The length of roofing to be tested will depend upon the type of apparatus used to apply the load. Three continuous spans of roof sheeting uniformly loaded in each span would be the minimum number of spans necessary for continuous conditions. The bending moments in the centre span and at the purlins of such an arrangement would reasonably represent those of a real roof. The deflection, however, would be more than twice that of a real roof which typically has at least four to six spans in a length of roof sheet. The size of such a test rig and the problems associated with cycling such a load would be rather complex and for this reason other methods are usually used to simulate the conditions of a real roof.

If equipment is available to apply and cycle a uniformly distributed load, the test specimen should have a length of at least once the recommended purlin spacing, but prefereably twice the spacing. Allowance should be made at each end of the specimen for the sheeting to be continued past the support point by about 30% of the span, to allow simulation of longitudinal continuity of the sheet.

If the test rig is designed to apply a midspan load across the width of the sheet and model the stresses or deformations of the sheeting, the purlin spacing must be altered. It is recommended that fastener load and bending moment at the purlin be modelled exactly (see Section 3.3).

If the exact number of spans in the real roof is unknown, a reasonable simulation of a continuous roof system can be provided by making the test span approximately 70% of the real span. Thus the length of sheeting needed for this test is approximately 1.3S times the real span being tested.

2.2.3.2 Tile roofs

As there is no structural continuity between heavy tiles on a roof, there is no need to model boundary conditions, thus the size of roof to be tested should relate to a discrete number of tiles. A typical size of roof section would constitute four rows of tiles having five tiles per row, giving a width of approximatley 1500 mm.

A roof section for testing metal tiles should be approximately the same size as one for heavy tiles. As most metal tiles have a length parallel to the battens of four or five times that of a heavy tile, the test section could consist of four rows of such tiles. Actual overall dimensions would depend on the specified spacing of battens and on the size of tiles.

2.3 Summary

The test assemblies should be truly representative of approved practice and should include details likely to occur in approved practice that may affect the performance of the product.

Full scale walls should be 2400 or 2700 mm high and 1800 to 3000 mm long depending upon the bracing medium.

Sheet roof assemblies should be at least one full sheet or 500 mm wide and be sufficiently long to reproduce the exact load per fastener and bending moment or deflection as anticipated in practice. Allowance should be made in the length to simulate continuity of roof sheeting.

Tiled roof assemblies should consist of four rows of tiles with approximately 1500 mm of tiles per row.

3 TEST APPARATUS

3.1 General

Traditionally, apparatus used for testing structural assemblies has been fabricated in a piecemeal fashion, making the best use of available equipment. Thus the result may be the most economic piece of apparatus to do the job, but by no means the most efficient. Whilst the ingenuity behind such an approach is commendable it can lead to difficulties when comparing the results of tests from two different equally ingenious sets of test apparatus. The obvious solution is to recommend apparatus that will most nearly duplicate the forces likely to occur on the structure in question during a cyclone. However, because relatively large areas such as walls and roofs are involved it is not practicable to test a whole assembly. Part of the problem therefore is associated with being able to test only a relatively small element of the structure and thus, in the case of roof sheeting, having to simulate boundary conditions for moment and rotation. Another part of the problem, again related to roof sheeting, is associated with the provision of a uniform load that can easily be cycled.

Acknowledging the difficulties mentioned above, the following recommendations are made as being a reasonable solution to the problem. They do not mean to exclude any other suitable test apparatus.

3.2 Wall Racking Tests

The apparatus need to conduct racking tests on walls is relatively simple, although it needs to be able to resist large forces and bending moments. When designing the apparatus, provision should be made for a double acting hydraulic cylinder or jack of 40 to 50 kN capacity operating at top plate level, that is 2400 or 2700 mm high. The jack may be activated by a motor driven or hand operated hydraulic pump. A typical frame for conducting wall racking tests is shown in Figure 3.2. If required, such a frame would be capable of providing uplift forces at the same time as the racking forces. An advantage of such a frame is that is provides a contained system for the applied forces and their reactions. If a structural reaction floor is available the full frame is not necessary, as reaction forces can be transmitted through the floor.

Apart from the main structural frame a number of other details are necessary to ensure a proper test. At the top plate level provision must be made to restrain the wall against buckling sideways. This can be achieved either by a series of ceiling battens spaced at the appropriate centres, by sets of rollers located each side of the top plate or by slightly larger members say 100 x 50 mm at 900 mm spacing. the latter method is preferred as the members can be pinned to the top plate and to another support system at top plate level. The pin fixing is to ensure that no load can be shed from the test wall to the support system. If ceiling battens are used as the stabilizing medium, care must be taken to ensure that there is no load shedding to the support system.

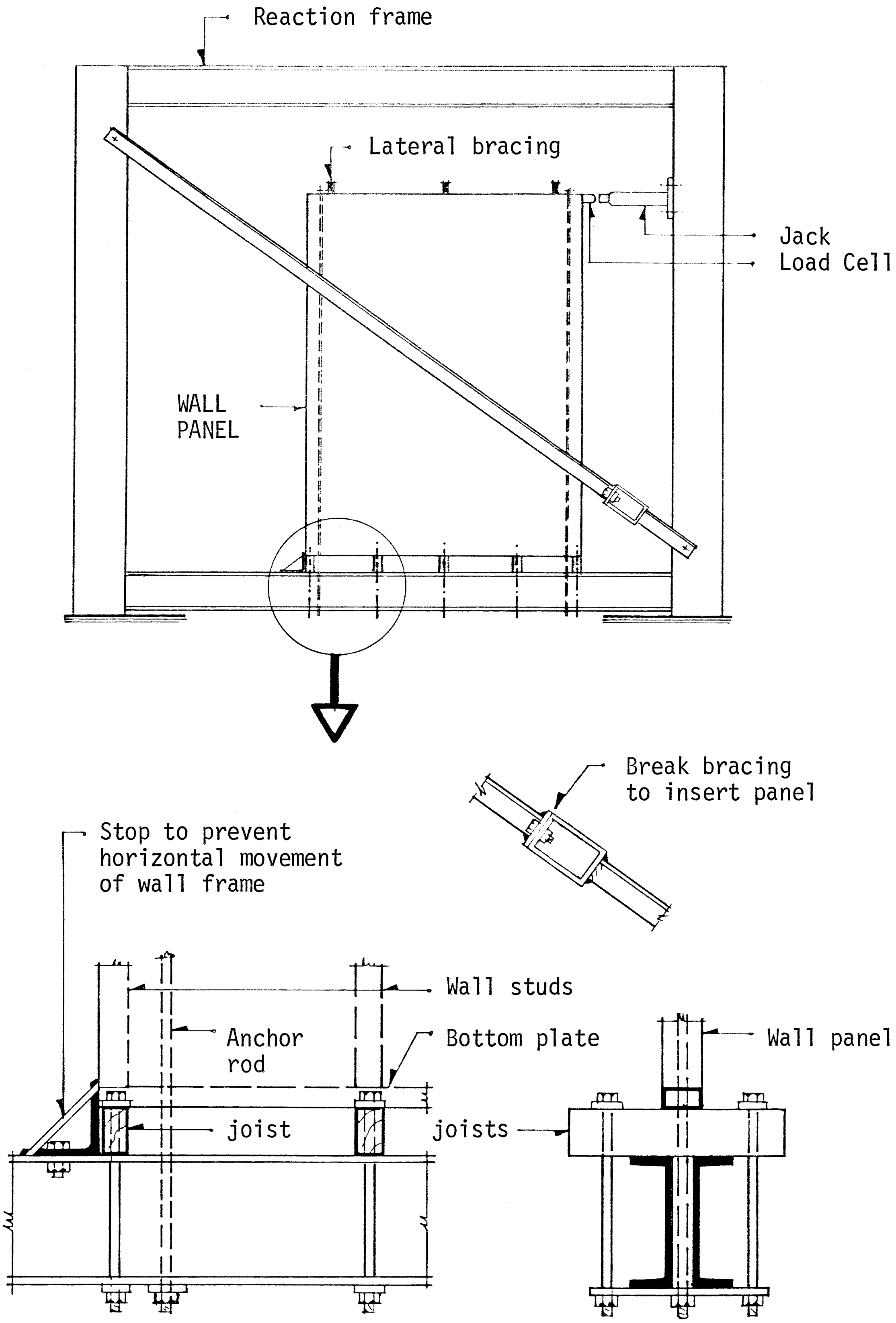


Figure 3.2 Frame for Wall Testing

Short lengths of floor joists should be secured to the bottom plate in the same manner as would be used in practice. These joists should then be securely attached to the bottom member of the structural frame. If anchor rods (cyclone bolts) are used in the wall, they should be taken through to below the bottom member of the frame. The bottom plate should be prevented from sliding horizontally by a stop attached to the bottom member of the frame.

If the test wall is of masonry construction, it should be built on a reinforced concrete beam and anchored to that beam as it would be to its foundations. The beam should then be securely attached to the structural frame for testing. Provision should be made in the test apparatus to be able to apply the racking force in both directions. The easiest way of achieving this is by using a double acting hydraulic cylinder and attaching it to the top plate or bond beam. However allowance must be made for vertical displacement of the wall at this position.

If the test is to include uplift forces as well as racking forces, they should be applied through short lengths of rafter attached to the top plate or bond beam in a similar manner to that used in practice. Uplift forces should not be applied to the members stabilizing the top chord against lateral movement, as this would probably cause a shedding of both uplift and racking forces onto the support structure.

3.3 Roof Sheeting Tests

There are currently two different methods being used to test roof sheeting. One involves the use of air bags to uniformly load two continous spans of sheeting. Cyclic loading can be achieved by raising and lowering a platform to activate the pressure in the bags. The other method uses a midspan load across the full width of the sheet. This load is usually applied by means of a central test purlin that is independent of the support frame and to which the sheeting is fastened. In order to produce some parameters concordant with those expected from a uniform load, the single span in this test is reduced to approximately 70% of the real span.

There are advantages and disadvantages to both methods, the air bag method has the apparent advantage of applying a uniform load, but there may be some doubt as to the degree of uniformity if the roof membrane is too flexible. In the midspan method a known force is easily applied, but the moving purlin can introduce secondary stresses if the real condition is not accurately modelled. Both methods are open to question with regard to boundary conditions because of discontinuity at the edges and lack of complete continuity in the longitudinal direction.

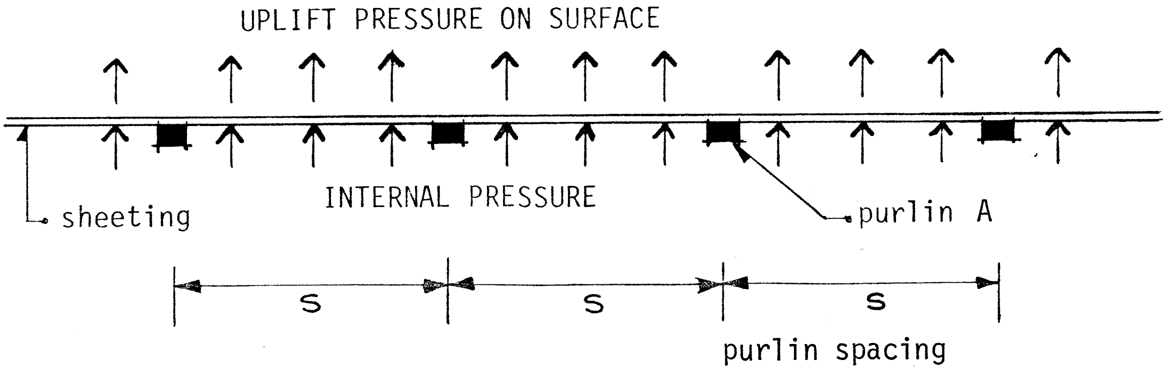
To the best of the writer's knowledge there is no evidence to prove one method superior to the other, so no recommendation will be made as to which method should be used. However because it is believed that the cost advantage is with the midspan load method, the remainder of this document will refer to that method, but in most instances the recommendations would apply equally well to the air bag method.

As has been previously mentioned, compensation must be made for the fact that a midspan load rather than a uniform load is applied to the roofing. This can be achieved by either changing the magnitude of the load or by changing the magnitude of the load or by chaning the span.

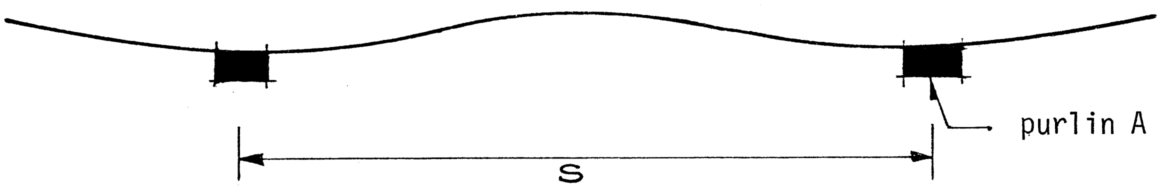
As the critical aspect of the test is the performance of sheeting at the fasteners, the load per fastener should be modelled exactly, therefore the test span must be different from the span used in practice. The two parameters to be considered in determining the span of the sheeting are strength and stiffness, but they cannot both be satisfied using the one span. When testing to resist cyclone wind forces strength, in the form of bending moment should be modelled exactly. Appendix 1 gives guidance for the modelling factor to be applied to the real span.

Figure 3.3.1 illustrates graphically the concept of the modelling technique and Figure 3.3.2 shows typical apparatus used for the rest.

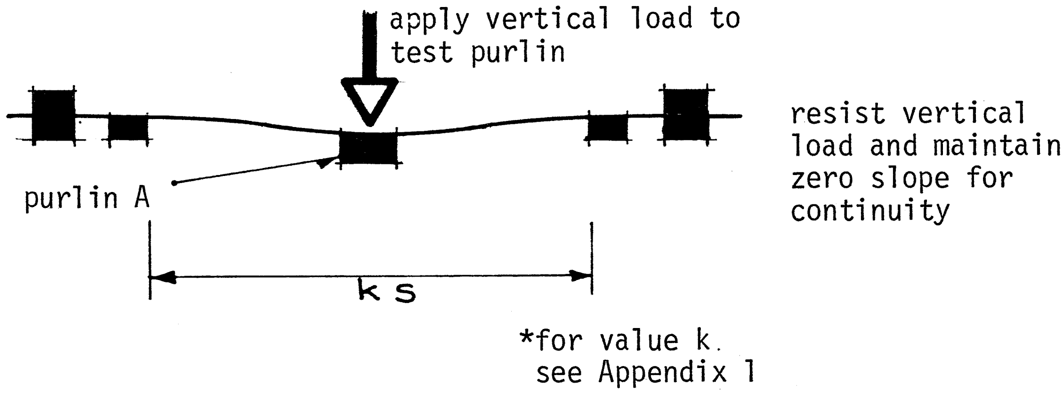
A jack is used to load the unsupported test purlin, to which is fastened the roof sheeting at its midspan. Care must be taken to ensure that the load applied by the jack is distributed evenly between the fasteners in the test purlin. The usual cause of uneven distribution of load is excessive deflection of the test purlin over its length. Such deflection



(a) Wind forces on roof sheeting



(b) Deformed shape (exaggerated)



(c) Laboratory model

Figure 3.3.1 Concept of Modelling

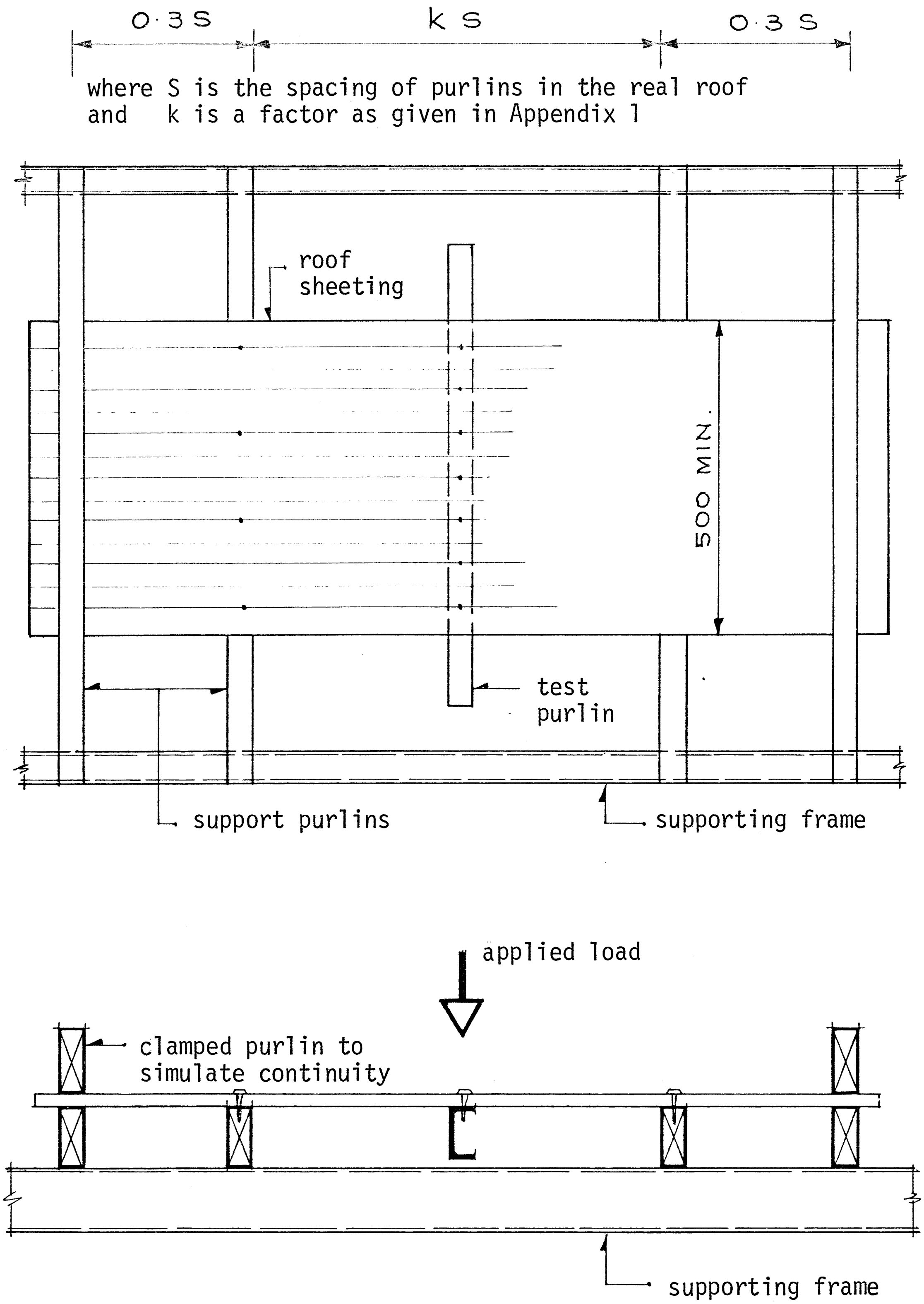


Figure 3.3.2 Apparatus Used when Modelling Roof Spans

can be limited by either using a larger purlin than normal or by applying the load to the purlin at positions other than the ends. This usually necessitates the jack being located underneath the roof sheeting where access to the entire length of the purlin is readily available.

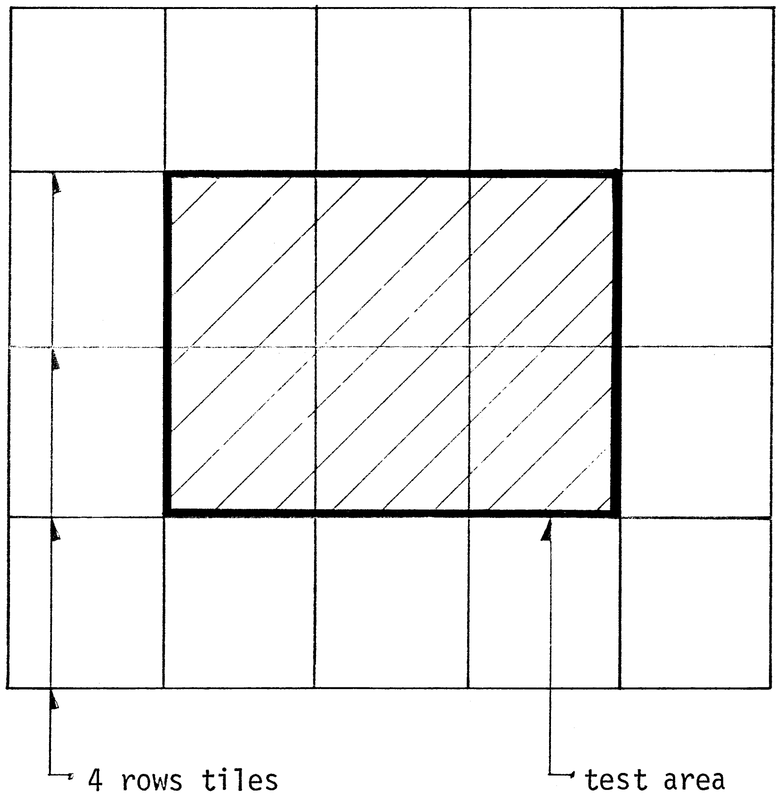
If there is any likelihood of the roof sheeting being supported in practice by purlins of torsionally unstable section, such a section should be used as the test purlin. In this way, any additional stresses in the roofing caused by twisting of the purlin will be allowed for during test. However the test purlin must not be allowed unrestrained notation as this would cause stresses greater than are likely to occur in practice. Ideally, this restraint should be applied to the bottom flange of the purlin allowing the top flange to rotate as it flexes.

The maximum cycle rate should be taken as three hertz, to avoid any local build-up of heat during the test. The actual cycle rate is usually dependent upon the capacity of the testing equipment, as well as the magnitude of the deflection of the roof sheeting. Because more than 10 000 cycles of loading are recommended, it is desirable to test at a rate as near to three hertz as practicable but slower rates are permissible. The duration of test at three hertz is approximately one hour.

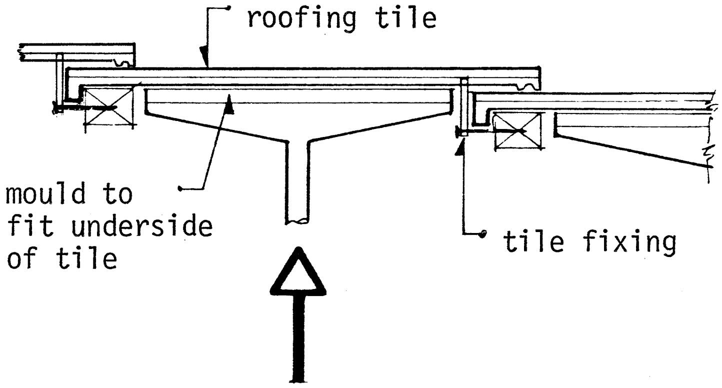
In recommending the equivalent test span to be used, kS, the value of k has been based on encastre conditions for the sheeting in the longitudinal direction. Whilst it may not be possible to guarantee zero slope of the roofing at the supports, the clamping arrangement shown in Figure 3.3.2 is used to approximate encastre conditions. The short spans of 0.3S shown in that Figure are recommended, but are not critical as is the value of k. If required the short spans may be altered for practical reasons but it is still necessary to provide zero slope at the supports when the sheeting is loaded. Better results will be obtained by using a wide clamping device rather than a narrow one.

3.4 Roof Tiles Tests

Because roof tiles are relatively small discrete elements the apparatus used to test them must be capable of applying load to each tile individually. As with other types of roof cladding, the test is really to determine the efficiency of the fastening medium attaching the cladding to the battens. Therefore as the performance of each tile and fastening medium may vary,



(a) Recommended area of model roof



(b) Typical method for applying load to each tile in the test area

Figure 3.4 Details of Tile Testing

the applied load to each tile must be capable of being monitored and adjusted individually.

When testing tiles it is usual to load a central group of four or six tiles in a group of sixteen or twenty. As described in Section 2.2.3.2 the usual pattern is to provide a small area of roof five tiles long and four courses wide. Therefore the perimeter of unloaded tiles lend some support to the central loaded group. For metal tiles the length of test roof should be approximately 1500 mm. This dimension will depend upon the length of the tiles, but it should not be less than 1200 mm.

Figure 3.4 shows a typical apparatus for testing tiles.

As the test load is applied directly to the underside of the tile, care must be taken not to cause unnecessary stress concentration by loading the protruding points only. Some form of a cushion or mould should be used to spread the load evenly over the surface. Provision must also be made to prevent the mould from bearing on the fastening device. Each mould and loading head must load the tile in such a way that rotation is not prevented.

The cyclic loading pattern can be achieved by raising and lowering a platform on which the jacks or calibrated springs are supported.

4. LOADING CRITERIA

4.1 General

The design pressures and loading regimes contained in this section relate to the effects of tropical cyclone winds. For wind gusts associated with other weather phenomena, the design pressures should be calculated separately based on recommendations of AS1170 Part 2, SAA Wind Loading Code. It is unlikely that the cyclic loading tests would be needed in such circumstances but the recommended minimum ratios between test load and nominated design load as given in Table 4.4(b) should still apply.

These recommendations for loading criteria are in general agreement with those contained in TR440. The design for strength in tropical cyclone areas is based on the following specifications of AS1170 Part 2 - 1975, SAA Wind Loading Code

For strength

wind speed, 50 year return period	: 55 m/s
cyclone factor	: 1.15
height above ground	: 6 m
internal pressure coefficients	: + 0.8 or -0.6

Maximum internal pressure coefficients are recommended as it is considered that a major opening may develop in a wall due to glass breakage or damage from flying debris.

For serviceability lower design loads may be used. They are based on wind velocity for a 25 year return period, the cyclone factor is not applied, and internal pressure coefficients are used which may be considered applicable to a closed building containing minor openings in the walls.

For serviceability

wind speed	: 50 m/s
cyclone factor	: not applicable
height above ground	: 6 m
internal pressure coefficients	: + 0.2 or -0.3

4.2 Loads for Strength Design

The following pressures are recommended to be used in the design for strength of a low rise building.

TABLE 4.2 (a)

DESIGN PRESSURE (kPa) ACTING NORMAL TO WALLS

FOR STRENGTH CALCULATIONS

Terrain Category	Dynamic Pressure q_z (kPa)	Design Pressure (kPa)	
		Wall structure and general cladding (C_p = 1.4)	Wall cladding at corners (C_p = 1.7)
3	1.05	1.5	1.8
2½	1.54	2.2	2.6
2	2.12	3.0	3.6
1	2.55	3.6	4.3

To determine the design pressure for the external cladding of a wall clad internally, use 40% of tabulated values for general cladding and 50% for cladding at corners.

TABLE 4.2 (b)

DESIGN UPLIFT PRESSURES (kPa) ON ROOFS

FOR STRENGTH CALCULATIONS

Terrain Category	Dynamic Pressure q_z (kPa)	Design Pressure (kPa)		
		Structure and general cladding	Cladding and Battens	
		(C_p = 1.7)	at edges (C_p = 2.15)	at corners (C_p = 2.6)
3	1.05	1.8	2.3	2.7
2½	1.54	2.6	3.3	4.0
2	2.12	3.6	4.6	5.5
1	2.55	4.3	5.5	6.6

If a design is required for the overhang of a rafter at the eaves, the loading relating to cladding and battens at edges should be used.

It is common practice to apply an impervious membrane underneath roofing tiles when they are used on roofs having a relatively low pitch. Where this membrane can be shown to be strong enough to resist the internal pressures that normally act on the underside of roof cladding, only the forces acting on the top surface of the tiles need be considered. In this case the design pressures would be considerably less than those given in Table 4.2(b). The recommended pressures are as follows

(a) for general cladding:
53% of the tabulated values for general cladding

(b) for edges:
63% of the tabulated values for edges

(c) for corners:
69% of the tabulated values for corners.

These recommendations are based on C_p values of 0.9, 1.35 and 1.8 respectively.

4.3 Loads for Serviceability Design

The following pressures are recommended to be used when checking the stiffness of members and cladding.

TABLE 4.3 (a)
DESIGN PRESSURE (kPa) ACTING NORMAL TO WALLS
FOR SERVICEABILITY CALCULATIONS

Terrain Category	Dynamic Pressure q_z (kPa)	Design Pressure (kPa) Wall Structure and Cladding (C_p = 1.1)
3	0.65	0.7
2½	0.96	1.1
2	1.33	1.5
1	1.59	1.7

TABLE 4.3 (b)

DESIGN UPLIFT PRESSURE (kPa) ON ROOFS

FOR SERVICEABILITY CALCULATIONS

Terrain Category	Dynamic Pressure q_z (kPa)	Design Pressure (kPa)		
		Structure and General Cladding (C_p = 1.1)	Cladding and Battens	
			at edges (C_p = 1.55)	at corners (C_p = 2.0)
3	0.65	0.7	1.0	1.3
2½	0.96	1.1	1.5	1.9
2	1.33	1.5	2.1	2.7
1	1.59	1.7	2.5	3.2

For tiled roofs on which an impermeable membrane is installed beneath the tiles, the following design pressures are recommended for serviceability conditions

(a) for general cladding:
82% of the tabulated values for general cladding

(b) for edges:
87% of the tabulated values for edges

(c) for corners:
90% of the tabulated values for corners

These recommendations are based on C_p values of 0.9, 1.35 and 1.8 respectively.

4.4 Application of Loads for Testing

The term "ultimate load" which is used frequently in this section is defined as the product of an appropriate factor times the design load. The value of this factor, which is dependent upon the type of test and the number of replications tested, is given in Table 4.4 (b). In this context the ultimate load is not the load at which failure occurs.

4.4.1 Wall loads

The design load for strength "D" should be based on the design pressures given in Table 4.2 (a).

If the wall system is to be tested using a repeated loading sequence, the magnitude of loads and the format of cycles should be as given in Table 4.4 (a). For a repeated load test the load at failure must be not less than the product of γ times D, when γ is the appropriate value given in Table 4.4 (b). Where more than one test is conducted the lowest load at failure must be not less than the product of γ and D.

TABLE 4.4 (a)

RECOMMENDED REPEATED LOADING CRITERIA
FOR WALLS

Sequence	Loading range (D = design load for strength)	Number of cycles	Direction of applied load
1A	0 - 0.625D - 0	400	Pushing
2A	0 - 0.75 D - 0	100	"
3A	0 - D - 0	10	"
1B	0 - 0.625D - 0	400	Pulling
2B	0 - 0.75 D - 0	100	"
3B	0 - D - 0	10	"
4	0 - Nominal ultimate load	1	either

Note: The sequence 1A,1B,2A,2B,3A,3B,4 is also acceptable.

TABLE 4.4 (b)

MINIMUM RATIO BETWEEN TEST LOAD AND NOMINATED DESIGN LOAD

Number of Specimens tested	Minimum ratio		
	Static load		Repeated test load to failure γ
	Test to failure α	Serviceability test β	
1	2.6	1.4	2.0
2	2.2	1.2	1.8
5	2.0	1.1	1.6

Note: $\alpha = \frac{\text{Static test load to failure}}{\text{nominated design load}}$

$\beta = \frac{\text{Serviceability test load}}{\text{nominated design load}}$

$\gamma = \frac{\text{Repeated test load to failure}}{\text{nominated design load}}$

It should be noted that there is evidence to show that for timber framed walls the wall strength is unaffected by a previous history of cyclic loading. Thus a static test to failure may be more appropriate.

The minimum test load at failure of a number of static tests must be not less than the product of D times the appropriate value of α from Table 4.4 (b).

If it is inappropriate to load the test wall to failure, a nominal ultimate load equal to D times the pertinent value of α or γ should be applied.

For a serviceability test, the nominated test load is calculated using the appropriate value given in Table 4.3 (a). The serviceability test load is then taken as β times the nominated test load. The serviceability test load should cause a deflection at the top of the wall of no greater than H/300, where H is the height of the wall. For masonry walls this load should not cause cracking. Further specifications for this test are given in Section 5, Test Procedures.

4.4.2 Roofing Loads

The design load for strength "D" should be based on the design pressures given in Table 4.2(b), modified for tiled roofs if appropriate.

Static testing only is not considered to be a satisfactory criterion for roofing and the associated fastener assemblies. The repeated load regime given in Table 4.4 (c) should be used for all tests of roofing and roof fastener assemblies for cyclone areas. The test load at failure should be not less than the nominal ultimate load, that is the product of D times γ, the appropriate value given in Table 4.4 (d). Where more than one test is conducted the lowest load at failure must be not less than the nominal ultimate load.

Serviceability tests for sheet metal roofing subject to wind loading are specified in AS1562-1973 "Design and Installation of Self-Supporting Metal Roofing Without Transverse Laps". This Code specifies that the maximum deflection between adjacent battens of the sheeting and fastening system shall not exceed S/90 during test and the residual deflection 5 minutes after removal of the force shall not exceed S/900. S is defined as the centre-to-centre distance between battens. The Codes for corrugated asbestos cement roofing and for roofing tiles do not specify such tests.

TABLE 4.4 (c)

RECOMMENDED REPEATED LOADING CRITERIA
FOR ROOFING

Sequence	Loading Range (D = Design load for strength)	Number of cycles
1	0 - 0.625D - 0	8000
2	0 - 0.75 D - 0	2000
3	0 - D - 0	200
4	0 - nominal Ultimate load	1

The nominal ultimate loads for static tests on roofing when required for the testing of walls for racking and uplift should be taken as the product of D times α, the appropriate value given in Table 4.4 (b).

5 TEST PROCEDURES

5.1 General

(a) Bracing Media

Plane structures such as walls which are tested in the vertical position need to braced laterally to a strong stiff structure. It is often convenient to brace to the structural members of the laboratory, but if this is not the case a special bracing structure must be erected. Connection of the test structure to this special bracing structure is very important, as there must not be a path by which the applied load may be shed from the test structure. This usually means that any bracing members must be pinned at each end to allow the test structure to deform in the direction of the applied load without restriction, while still providing adequate bracing against lateral movement.

The bracing structure must not be used as a datum from which deflections are measured as it may deflect slightly during the test.

(b) Conducting the Test

Unless a lot of expensive electronic equipment is used, most structures such as walls must be loaded incrementally so that dial gauges or the like can be read. The increments should preferably be either 20% or 25% of design load, so that a sufficient number of points can be gained to plot a curve. Because of this incremental loading it is not practicable to specify a rate of loading, but the load should be applied so that it does not cause any impact loading on the structure.

5.2 Wall Racking

5.2.1 Static Tests

5.2.1.1 Serviceability Test

The serviceability test load is determined as outlined in Section 4.4.1. Deflection measurements should be recorded at the positions shown in Figure 5.2.1, that is for a load applied as shown, horizontal and vertical deflections of the wall should be measured at the positions shown.

The following test procedure is recommended

1. Set the jack in compression mode and set all dial gauges to a convenient reading for the no-load condition

2. Increment load by 20% of the serviceability load and record all deflections

3. Repeat step 2 until the serviceability load is reached

4. Unload jack and record all deflections

5. After an interval of five minutes read deflections again and if they have not returned to their original readings, reset them

6. Set the jack in tension mode and repeat steps 2 to 4.

If the jack used to apply the load is not capable of operating in a tension mode, it should be repositioned at the other end of the wall so that the wall assembly will be racked in the opposite direction.

For very stiff walls such as masonry walls the stiffness criteria of H/300 will not be practical. Therefore inspections must be made after step 3 to determine if any cracking has occurred.

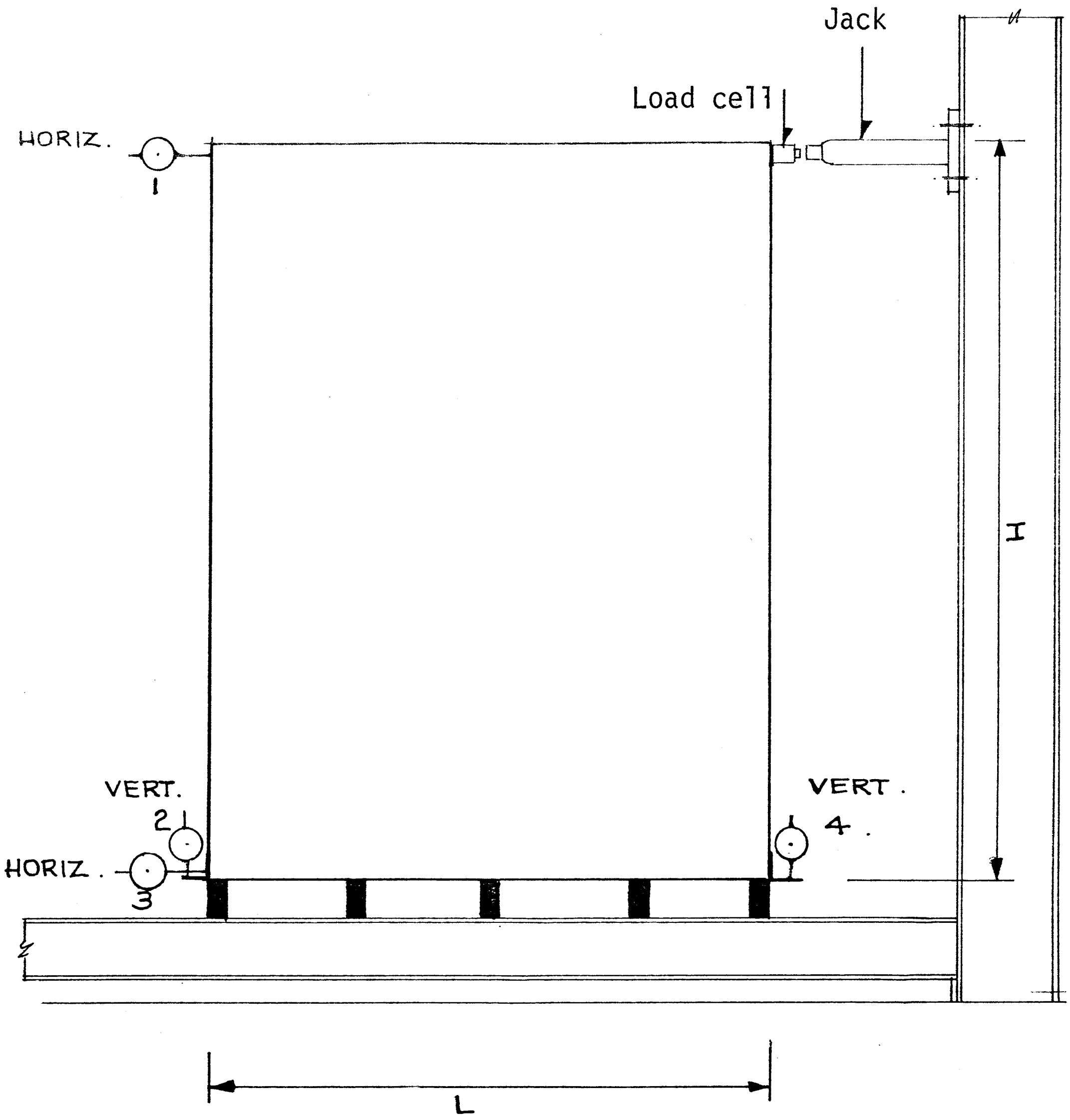


Figure 5.2.1 Positions at which Deflections Should be Measured During Racking Tests on Walls

5.2.1.2 Ultimate Static Load Test

The nominal ultimate load for static testing is determined as outlined in Section 4.4.1. It is not essential during this test to record deflection measurements, although it is good practice to do so as this can lead to a better understanding of the performance of the wall assembly. If deflection readings are to be recorded, they should be measured at the positions specified on Figure 5.2.1.

If no deflection readings are to be taken, the wall should be loaded in a single direction at a rate of approximately 2 kN per minute until the ultimate test load is achieved. This load should then be maintained for one minute before it is removed.

If an estimate of the overall strength of the wall is required, the load should not be removed but should be increased at a uniform rate until failure occurs. During this period the prescribed rate of loading need not be maintained as to do so would become increasingly difficult, as the wall assembly nears failure. The failure load can be defined as the maximum racking load sustained by the wall assembly regardless of the amount of deformation.

If deflection measurements are to be taken, the following test procedure is recommended.

1. Set all dial gauges to a convenient no-load condition

2. Increment the load in a single direction by 12½% of the ultimate test load and record all deflections

3. Repeat step 2 until the ultimate test load is reached

4. Hold the ultimate test load for a period of one minute

5. Remove the load and record all deflections

If an estimate of the overall strength of the wall is required, step 5 should not be taken but the load should be increased gradually in a single direction until, regardless of deformation, it can be increased no further. The maximum load achieved should be considered to be the failing load of the wall assembly.

5.2.2 Repeated Load Test

The loading regime for repeated load tests on wall assemblies is given in Table 4.4(a). The design load for strength "D" should be based on the design pressures given in Table 4.2(a). The nominal ultimate load for repeated load tests is determined as outlined in Section 4.4.1. No deflection measurements need be taken during this test. The rate of loading should be such that the load cycle from zero to load to zero should take no less than three seconds.

The following test procedure is recommended:

1. Apply the prescribed load and verify it using a load measuring device such as a load cell

2. Cycle this load the required number of times while keeping check on its magnitude

3. During the cyclic regime monitor the load and adjust to the correct magnitude if necessary.

4. Repeat steps 1 to 3 for each load level until all the cycles with the jack in the compression mode are completed

5. Alter the jack so that it operates in the tension mode

6. Repeat steps 1 to 3 until all the cycles with the jack in the tension mode are completed.

7. Apply the presecribed nominal ultimate load and maintain it for a period of one minute

8. Either remove the load or continue loading until failure occurs.

If a jack capable of applying repeated loading in both tension and compreesion modes is not available, it may be convenient to load the wall from opposite ends to obtain the two different directions of racking force.

5.3 Wall Racking and Uplift.

Bracing walls which also support the roof structure may be subject to a combination of racking and uplift forces. Most external bracing walls fit into this category. The racking forces to be applied to test such a wall assembly are determined from section 4.4.1, the uplift forces can be determined from Section 4.4.2.

It is not practicable to conduct repeated load tests for racking and uplift. Therefore the following recommendations relate to static testing only. The procedure for a serviceability test should be as outlined in Section 5.2.1.1 with the following amendment.

2. Increment the racking load by 20% of the racking serviceability load and increment the uplift load by 20% of the uplift serviceability load, record all deflections.

During the test care should be taken to ensure that the rig applying uplift forces does not inhibit racking deflection of the wall.

The procedure for conducting an ultimate load test should be outlined in Section 5.2.1.2 with the following amendments.

If no deflection measurements are to be taken the uplift force is to be applied at a rate such that the ultimate uplift test load is reached at a similar time to the ultimate racking test load.

If deflection measurements are to be taken step 2 should state

2. Increment the racking load by 12½% of the ultimate racking test load and increment the uplift load by 12½% of the ultimate uplift test load, record all deflections

5.4 Roofing

As previously mentioned, static load tests alone are not considered appropriate for the testing of cyclone wind effects on roofing. The repeated load test is considered to give the best estimate of likely performance of roofing and its fasteners during a cyclone. Of course the test to the predetermined ultimate load is a necessary part of the repeated load test, so a static load really is part of the design criteria.

The preferable size of assembly to be tested has been discussed in Section 2.2.2 and the test apparatus has been recommended in Sections 3.3 and 3.4.

The design load for strength "D" and the nominal ultimate load are as defined in Section 4.4.2, thus the loads to which the assembly is to be cycled are determined from Table 4.4(c).

The assembly should be loaded in the sequence given in Table 4.4(c), using a cycling rate of approximately 3 hertz, and the ultimate load for strength be maintained for one minute. If the roof assembly is to be tested to failure, the test should be continued after the application of the ultimate load, otherwise the assembly may be unloaded.

5.5 Wall Cladding

The recommendations made so far relate to the performance of walls as bracing walls. However if external walls are clad with sheet material that may lose strength during load cycling, this material should be tested similar to roof sheeting. The cyclic regime recommended in Table 4.4(c) should be used. The test apparatus should be similar to that recommended for sheet roofing in Section 3.3, but the test span should be related to the spacing of the girts.

The design load for strength "D" should be based on the design pressures given in Table 4.2 (a).

If the wall system is to be tested using a repeated loading sequence, the magnitude of loads and the format of cycles should be as given in Table 4.4(a). For a repeated load test the load at failure must be not less than the product of γ times D, when γ is the appropriate value given in Table 4.4(b). Where more than one test is conducted the lowest load at failure must be not less than the product of γ and D.

5.6 Exploratory Testing

So far the implication of this document has been that the assembly is to be tested for a given loading condition which relates back to a specific degree of exposure and a given combination of pressure coefficients. Whilst this is the usual procedure, an alternative approach that may be made during the developmental stages of a product is to conduct a static load test to determine a reasonable approximation of the failing load. This can then be used as a basis for further testing. Such an approach is eminently suitable for repeated load testing where a reasonably accurate estimate of the strength of the assembly is desirable. The following procedure is therefore recommended to be used as an exploratory test for a product that needs to be tested to a repeated loading criteria.

1. Conduct a simple static test to failure

2. Convert the load at failure to an equivalent pressure "F" acting on the structure.

3. Let G = 0.8 x F/2, 2 being the value of γ from Table 4.4(b) for one specimen tested to failure during a repeated load test. The factor 0.8 allows for some variability between the assembly tested and the one to be tested and also allows for some effect of cyclic loading on the assembly to be tested. It was chosen on an arbitrary basis, and is suggested as a guide only until more accurate information can be obtained.

4. Compare G to the design pressure values given in Table 4.2 (a) or 4.2 (b) as appropriate. If a value is not more than 10% greater than G, define D based on that value. Otherwise define D based on G or on a suitable value below G.

5. Conduct a repeated load test using D as recommended in Table 4.4 (a) or 4.4 (c) as appropriate.

The intent of step 4 is to relate the somewhat arbitrary value of pressure to a realistic one. However there are other parameters such as position on the roof or wall that may influence the choice of value for D. It is recommended that the value chosen for D be based on a pressure less than 90% of G as a first estimate for use in step 5. The results of step 5 will indicate whether the chosen value of D is satisfactory or should be changed.

6. TEST RESULTS

6.1 Wall Racking

6.1.1 Serviceability Test

From the serviceability test described in Section 5.2.1.1 two sets of deflection measurements would have been obtained, one with the applied load pushing and the other with it pulling. The measurements were to be taken at the four positions shown in Figure 5.2.1. The deflection at position 1 is a combination of three types of deflection, shear deflection of the panel, longitudinal translation and overturning. The shear deflection can be isolated using the following formula

$$\Delta_s = \Delta_1 - \Delta_3 - (\Delta_2 + \Delta_4)\frac{H}{L}$$

where Δ_1, Δ_2, Δ_3, Δ_4 are the deflections at positions 1, 2, 3 and 4 respectively
H is the wall height
L is the wall length

Note: In the above formula all deflections have been taken as being positive.

The shear deflection for each direction of load can be plotted against load as shown in Figure 6.1.1.

For framed walls the wall assembly is considered to be acceptable if the shear deflection at the serviceability load is not in excess of H/300. For solid walls such as masonry construction the wall is considered acceptable if no cracking occurs during the serviceability test.

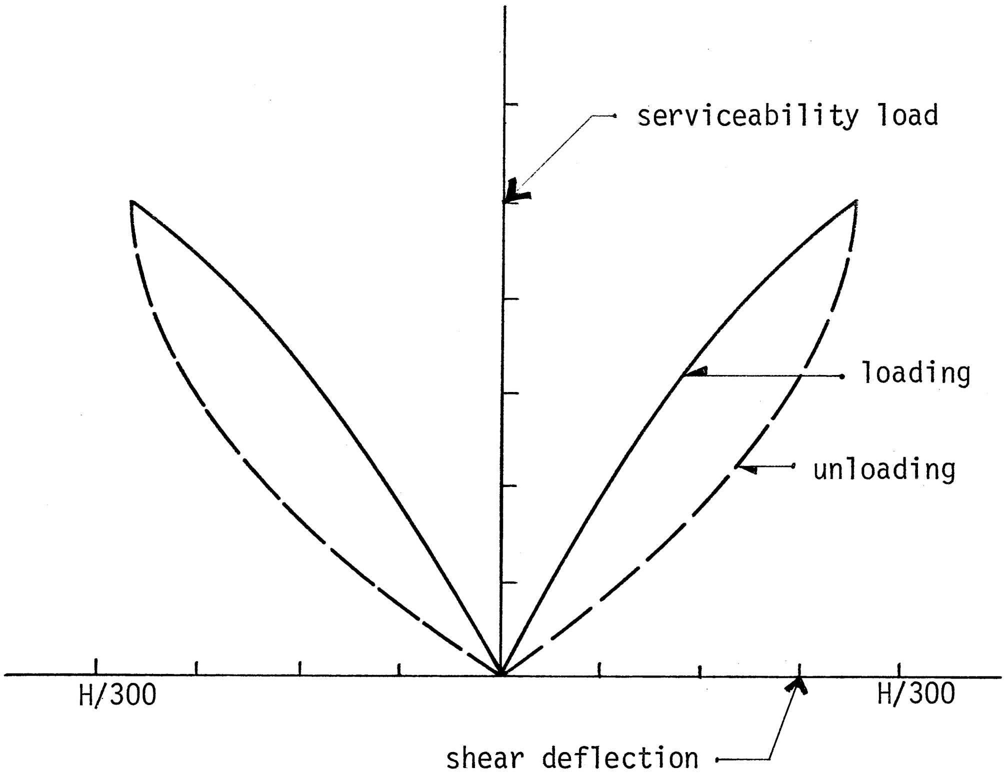


Figure 6.1.1 Load Deflection Curves for Serviceability

Other parameters which should be considered when assessing the performance of a wall assembly for serviceability are the absolute deflection at position 1 and the residual deflections. If the absolute deflection at position 1 is considerably greater (say 50% greater) than the shear deflection it indicates that there is too much movement of the wall assembly. The movement could be due to longitudinal translation which would be indicated by a large deflection at position 3, or by overturning as indicated by a large deflection of either position 2 or 4. If the reason for the excessive movement can be related to the test rig it must be corrected, but if it is related to some connection such as bottom plate-to-joist which has been made according to usual practice the use of such a joint in practice must be reviewed.

If the residual deflections read five minutes after the assembly has been unloaded, are greater than, say, 20% of the maximum deflections it indicates that the wall assembly has passed its yield point. This is often an indication that the assembly will not pass a subsequent ultimate test. However if the assembly does pass the ultimate test it is likely to have been seriously deformed. Due consideration must be given to the effects of such deformation in practice.

6.1.2 Ultimate Load in a Static Test

If deflection measurements have been recorded during this test a graph of applied load vs. shear deflection can be plotted. This graph should help in understanding the likely performance of such a wall assembly during a wind storm.

The criteria for acceptance in this test is that the assembly sustain a load equal to the nominal ultimate static load as defined in Section 4.4.1 for a period of one minute without failing. Failure is defined as the instability of the assembly to sustain any increase in applied load.

If the assembly successfully sustained the nominal ultimate static load and was then tested to failure, a new design load may be calculated from the following formula

$$\text{design load} = \frac{\text{static load at failure}}{\alpha}$$

where α is taken from Table 4.4(b)

Where a static test to failure was conducted on more than one wall assembly the new design load should be calculated using the lowest failure load and the appropriate value of α.

6.1.3 Repeated Load Test

Where a repeated load test has been conducted in accordance with the recommendations of Section 4.4.1 and no failure has occurred the wall assembly is deemed to have passed the test. The nominated design load can therefore be used as the design load.

If, after application of the nominal ultimate load, the wall assembly was then tested to failure there is little immediate benefit to be gained. Although the load at failure can be divided by the appropriate value of γ to determine a higher estimate of design load, this value cannot be used for design because the cyclic tests were not based on it. Thus the design load can only be increased by conducting another repeated load test based on this new design load.

6.2 Wall Racking and Uplift

6.2.1 Serviceability Test

The results of the serviceability test should be analysed as specified in Section 6.1.1 except that the formula for calculating shear deflection should be as follows

$$\Delta s = \Delta_1 - \Delta_3 - (\Delta_4 - \Delta_2) \frac{H}{L}$$

Again, for framed walls the assembly is considered satisfactory if the shear deflection at serviceability load does not exceed H/300. For solid walls no cracking should occur at serviceability load.

6.2.2 Ultimate Load In a Static Test

If deflection measurements were recorded during this test, graphs of applied load vs. shear deflection and applied load vs. uplift may be plotted. Such graphs will give a better understanding of the likely performance of such a wall assembly during a wind storm.

To satisfy the nominal ultimate load test, the assembly must sustain a racking load equal to that defined in Section 4.4.1 together with an uplift load as defined in Section 4.4.2. The load combination should be applied for a minute without any failure of the wall assembly.

If the wall assembly successfully sustained the combination of ultimate loads, and the two applied loads were then increased in the correct ratio until failure occurred, a new design load combination may be obtained by dividing each of the applied loads by the appropriate value of α from Table 4.4 (b).

6.3 Sheet Roofing

A roof sheeting assembly can be considered to have passed the test if, after application of the required number of cyclones and the static overload, there are no signs of failure.

Failure is defined as disengagement of the sheeting from the purlin. This can occur in any of the following ways.

(a) the sheeting pulling over the head of the fastener

(b) the fastener bending or deforming to lose hold of the sheeting

(c) the fastener breaking

(d) the fastener withdrawing from the purlin

Failure of the purlin rafter connection is not considered to be failure of the assembly, but rather to be poor laboratory practice. However if such failure does occur when using accepted fastening methods a review of these methods should be made.

After a roofing assembly has successfully passed its test, it may be of interest to apply a further static load of increasing intensity until failure occurs. Thus an estimate of the maximum strength of the assembly is obtained. This estimate should not be used to calculate a revised design load as is permissible with the static load test, but may be used as a basis for further cyclic load tests to determine a more accurate estimate of design load.

6.4 Tiles Roofing

As for sheet roofing, a tiled roof assembly can be considered to have passed the test if, after application of the test sequence specified in Section 5.4, there are no signs of failure.

For a tiled roof, failure is defined as disengagement of any cladding element from its supporting batten. Failure can occur in any of the following ways

(a) the fastener bending or deforming so as to lose its grip on the tile

(b) any portion of the tile fracturing and thus disengaging from the fastener

(c) the fastener breaking

(d) by any means, the fastener allowing the tile to become so loose as to allow the batten lug to lift over the batten.

Where the fastening medium is such that the lifting of the batten lug above the batten would not cause the tile to slide down the roof slope, definition (d) need not on its own constitute failure. An example of such fastening is a nail driven through a hole in the tile.

Tests to failure beyond the nominal ultimate load may be used as an indication of the strength of the assembly, but a repeated load test would have to be conducted before any higher design load could be recommended.

The results of tests on metal roofing tiles should be considered using the same definitions of failure as for sheet roofing.

6.5 Failure to Satisfy Test Criteria

The implication in this document so far is that an assembly is to be tested to ascertain whether it can withstand a predetermined load either without deflecting too far or without failing. It has been assumed that the test criteria were satisfied and therefore the test design loads, or in some instances increased design loads, could be recommended for design purposes. However, not all tests produce satisfactory results and therefore recommendations must be made as to the procedure to follow when the test criteria are not satisfied.

There are two alternative courses of action generally available if the test criteria are not satisfied, namely to accept a lower design value or to repeat the test on a modified assembly. These will be examined separately.

It is simple enough with a static test to determine an alternative load level if the desired one was not achieved. For a serviceability test if the test load caused a deflection greater than that prescribed, the load corresponding to the desired deflection can easily be obtained from a load-deflection curve plotted from the test results. For a static test to failure, if the nominal ultimate load was not achieved a design load can be obtained by dividing the failing load by the appropriate value of α from Table 4.4(b).

If the assembly tested for repeated loading passed the cyclic loading criteria but failed in the static overload test, a design load can be obtained by dividing the load at failure by the appropriate value of γ from Table 4.4(b). If however the assembly failed during the cyclic loading regime, no estimate can readily be made of its likely performance at a lower load. Therefore a reduced value of design load cannot be recommended, and either another similar assembly must be tested at a lower design load or a modified assembly may be tested to the original design load.

As the test load for most assemblies is usually based on a specific wind speed and a required set of exposure conditions, it is generally not practical to accept lower design loads for assemblies that do not satisfy the test criteria. Therefore further testing may be conducted.

Once a prototype assembly has failed to meet the test criteria some form of modification must be made before another assembly is submitted for testing to the same criteria. It is not acceptable to test an assembly identical to one that has failed to satisfy the test criteria.

7. TEST REPORTS

7.1 General

A test report should be relatively brief, but should contain enough information for the reader to draw his own conclusions. Apart from the obvious information such as where, when and by whom the tests were conducted, the following points should be considered when writing test reports.

(a) the type of test should preferably be contained in the title of the report

(b) test loads should be related back to the service conditions they are meant to represent

(c) details of the selection criteria for the assembly or its elements should be included

(d) the report should contain a brief description of the assembly including all important dimensions as well as the size and spacing of critical fasteners

(e) descriptions of the products should be sufficiently precise to enable them to be readily and exclusively identifiable

(f) descriptions of test apparatus should be very brief, if included at all

(g) a brief outline of the test procedure should be included

7.2 Wall Tests

The following points relate to the testing of wall frames and should be included in the test report along with those points previously mentioned.

(a) types of test and related test loads

(b) the number of wall assemblies tested

(c) if repeated loading is applied, a definition of the loading regime must be included

(d) method of application of the load and method of providing lateral restraint

(e) acceptance criteria

(f) if a test to failure was conducted record the failing load and a description of the failure

(g) recommend design loads for serviceability and strength

(h) a graph of any load-deflection data that was recorded

7.3 Roofing Tests

The following points, related to the testing of roofing, should be included in the test report.

(a) a description of the method of loading and any modelling techniques used

(b) a detailed description of the method of attaching the roofing to the battens/purlins

(c) the number of roof assemblies tested

(d) details of any asymmetry of the purlins that may cause additional loading on the roofing or its fasteners

(e) definition of the loading regime

(f) definition of acceptance criteria

(g) if a test to failure was conducted, record the failing load and a description of the failure

(h) recommended design loads for serviceability and strength

ACKNOWLEDGEMENTS

The author wishes to thank the members of the Cyclone Testing Station's Manufacturing and Supply Sector Sub-Committee for their co-operation and suggestions in preparing this report. Thanks are also due to Mr. L.D. Armstrong of CSIRO and Mr. J.W. Morgan of the Experimental Building Station for their helpful comments on the draft copy of the report.

APPENDIX 1

This appendix is concerned with the modelling technique of applying a concentrated load to a single span of roof sheeting in an attempt to reproduce the conditions likely to occur in a real roof.

Figure 1(a) indicates the real situation where there is a finite number of spans of roof sheeting extending from eaves to ridge, or from eaves to eaves in the case of a monoslope roof. Depending upon the building width and type of cladding used, the number of spans may vary from four to eight for domestic buildings with pitched roofs. It is common practice for manufacturers to recommend that the maximum span of sheeting adjacent to eaves and ridge be reduced below the recommended span for the rest of the roof. Recommendations for the maximum span at eaves and ridge vary from 0.6 to 0.8 of the recommended maximum internal span.

Figure 1(b) represents the idealized situation of the laboratory test, a length of roofing with encastré supports and loaded at midspan.

In order to correctly model both the load per fastener and the bening moment in the sheet, the idealized span "L" must be less than the batten spacing "S". How much less will depend upon the number of spans and the relative length of the end spans in the real roof. For a large number of spans of roof sheeting, the moment conditions of the central spans will approximate the encastré case for uniform loading, but the maximum moment will occur at purlin B or C, Fig. 1(a), because of the simple support condition at A. For span A B equal to S, the moment at B is approximately 25% greater than the encastré case for uniform loading. As span, A B is decreased the moment at B decreases, but the moment at C is increased. Thus it is either the moment at B or at C which provides the design criterion. The additional reactive forces on the fasteners caused by the inequality of moments at B and C should be considered when determining load per fastener.

If the test to be conducted relates to one type of roof sheeting supported over a given number spans, the moments and reactions can be calculated for the real case, equated to the model case, and the model span calculated.

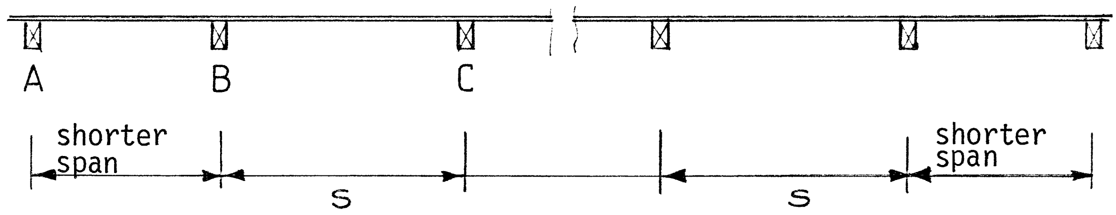


Figure 1(a) Schematic Diagram of Roof Showing Batten Spacing

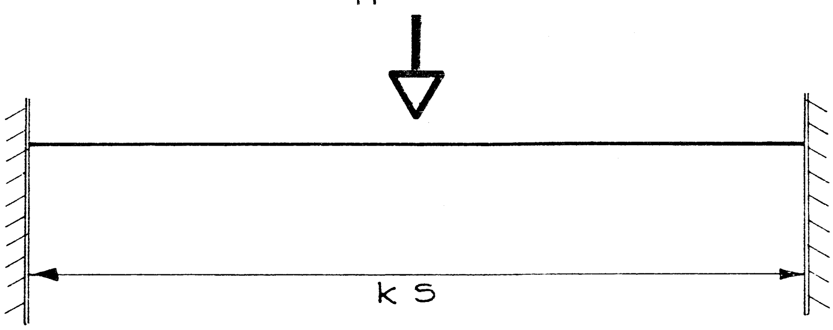


Figure 1(b) The Idealized Laboratory Model

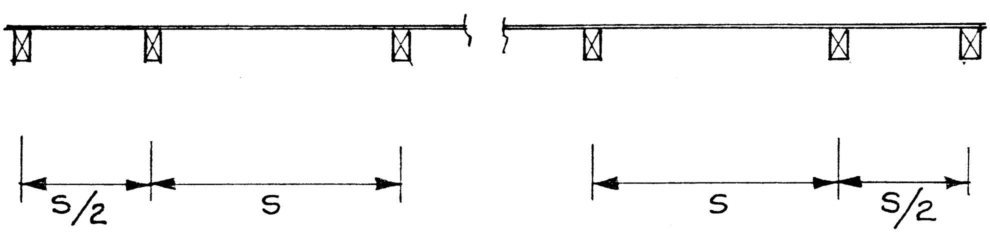


Figure 2 Arrangement of Spans to Produce Maximum Moment on Sheeting

It is more usual however, to want to estimate the likely performance of roof sheeting for any given number of spans and ratio of end spans that are likely to occur in practice.

As previously mentioned for the case of all spans equal, the maximum moment occurs at B. It can similarly be shown that for end spans less that 80% of internal spans, maximum moment occurs at C, and is greatest for the case where the end spans are 50% of the internal span. Figure 2 shows this configuration.

Regarding the number of spans to be used in determining maximum moments, Table 1 shows the maximum bending moments that occur for four, five, six and eight continuous spans. Also shown are the values of k where k s is the span to be used in the model test, and the increase in uplift force generated by the inequality of moments. The increased force has been used in the calculation of k. It has been assumed that four spans of roof sheeting would be the minimum number used in practice.

TABLE 1. Coefficients to relate uniform loading to midspan load

Number of spans (end span = 0.5x int.span)	Bending moment Coefficient (x ws^2)	Load per fastener coefficient (x ws)	k {see Fig.1(b)}
4	0.093	1.06	0.70
5	0.087	1.05	0.66
6	0.088	1.05	0.67
8	0.088	1.05	0.67

It can be seen from Table 1 that the maximum bending moments and load per fastener occur for the case of four spans. It is therefore recommended that the test be modelled on this case. Figure 3 gives details of the test configuration. It should be noted that test span of the roofing is measured between the inside faces of the purlins.

If deflection-span ratio has been chosen as a design criterion instead of bending moment, the case of four spans is still the configuration to be modelled, but the test span is increased to 0.77 times the batten spacing. Figure 4 illustrates the test arrangement.

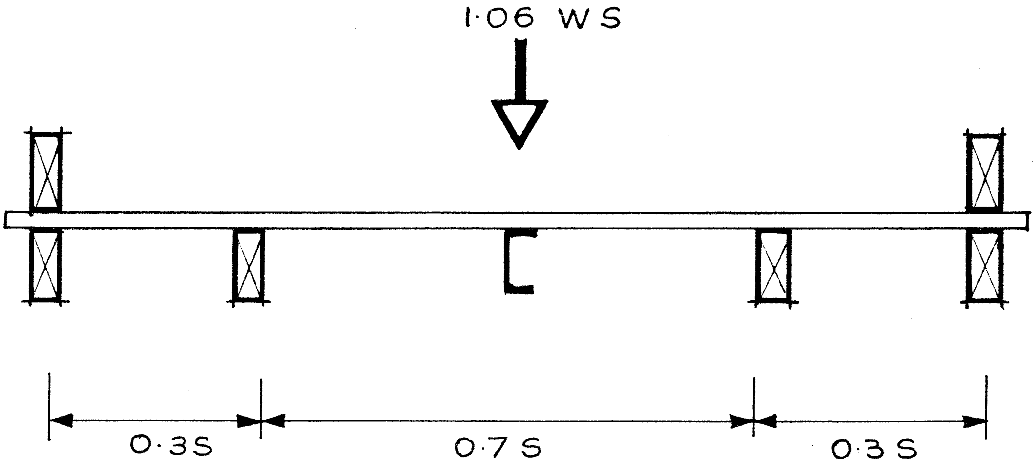


Figure 3 Recommended Configuration for Test when Bending Moment is Design Criterion

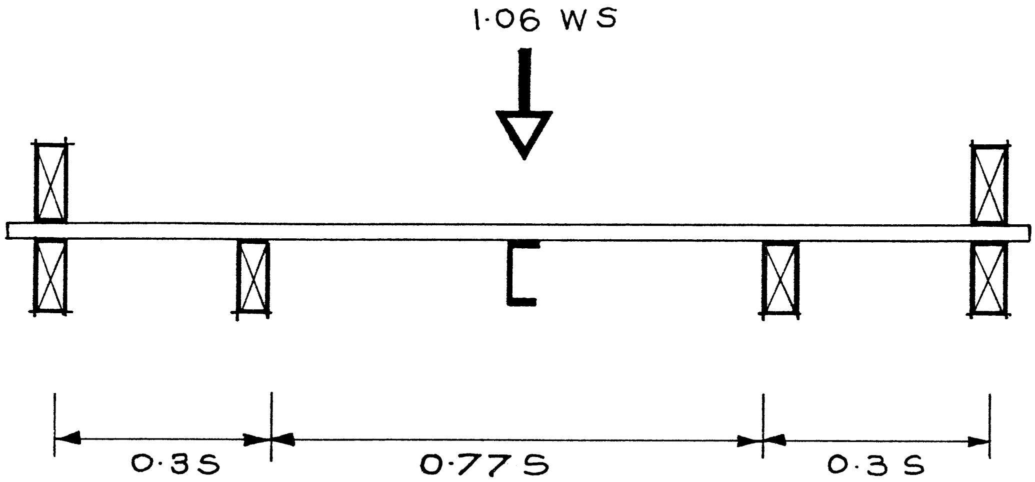


Figure 4 Recommended Configuration for Test when Deflection-span Ratio is Design Criterion

Note: in all Figures

S = maximum internal span of sheeting recommended by the manufacturer

w = uniform load per unit length