JAMES COOK CYCLONE STRUCTURAL TESTING STATION

CYCLONE TESTING STATION

INVESTIGATION OF DIAPHRAGM ACTION OF CEILINGS

Progress Report 2

TECHNICAL REPORT NO. 15

December 1982

DEPARTMENT OF CIVIL & SYSTEMS ENGINEERING
POST OFFICE JAMES COOK UNIVERSITY
TOWNSVILLE 4811

JAMES COOK UNIVERSITY

CYCLONE STRUCTURAL TESTING STATION

INVESTIGATION OF DIAPHRAGM ACTION OF CEILINGS - PROGRESS REPORT 2

George R. Walker
Geoffrey N. Boughton
David Gonano

TECHNICAL REPORT NO. 15

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

December, 1982

© James Cook University of North Queensland 1981
ISBN 0 86443 087 6
ISSN 0158 - 8338

Walker, George R. (George Redvers), 1938- .
Investigation of diaphragm action of ceilings.
Progress report 2.

1. Ceilings. 2. Wind-pressure. I. Boughton, G.N. (Geoffrey N.), 1954- . II. Gonano, David, 1959- . III. James Cook University of North Queensland; Cyclone Testing Station. IV. Title. (Series: Technical report (James Cook University of North Queensland. Cyclone Testing Station); 15).

690'.17

PREFACE

It should be noted that this progress report is a summary of interim test results obtained as part of an extensive research programme. The authors believe that it is of benefit to the building industry to publish their findings in this manner, but stress that any conclusions drawn from these tests should be considered to be interim until the final report is published. Whilst it is unlikely that subsequent tests will cause any major changes in the conclusions expressed herein, they may cause the data to be reviewed in the light of some new finding or a more detailed analytical procedure. The analysis used for these results probably tends towards a lower limit of the strength of ceiling diaphragms. Where a high degree of continuity exits between bracing walls the ceiling strength may be greater than concluded from the results of this report.

INVESTIGATION OF DIAPHRAGM ACTION OF CEILINGS

- PROGRESS REPORT 2

George R. Walker
Geoffrey N. Boughton
David Gonano

SYNOPSIS

The Department of Civil and Systems Engineering at James Cook University of North Queensland and the James Cook Cyclone Structural Testing Station are currently engaged in a major joint program of research related to the transmission of wind forces in domestic housing.

One of the major projects within this program is a study of the capacity of the ceiling structure to transmit horizontal forces from the external walls to the bracing walls by diaphragm action. This project, which is being undertaken within the Department of Civil and Systems Engineering, with assistance from the Cyclone Testing Station, is being supported by the Australian Housing Research Council.

This report describes the results of the second phase of tests on ceiling panel assemblies undertaken as part of this project. Twelve tests are described, nine on plasterboard ('Gyprock') ceiling systems and three on fibre cement ('Versilux') systems. The systems are considered representative of many of the systems used in domestic housing. The size of panels tested and the testing procedure were similar to those used in the first phase described in the first interim report.

The tests confirmed indications from the first phase that the capacity of ceilings to transmit horizontal forces is highly dependent on the details of attachment of the cladding material to the main structural frame of the dwelling. On the basis of the results interim recommendations on design strength for the systems tested have been made.

1. INTRODUCTION

This is the second interim report on a research project funded by the Australian Housing Research Council which is focussed on the action of ceilings in distributing lateral loads on dwellings to the shear walls.

The overall project involves three main aspects:

- experimental investigation of the behaviour of typical ceiling assemblies:
- correlation of results of tests on ceiling assemblies with predictions based on structural engineering theory and associated computer models;
- formulation of recommendations on the utilisation of ceilings for the transfer of horizontal loads based on these studies.

This report, as was also the first progress report, is concerned solely with the first aspect - i.e. the tests conducted on ceiling panels. These tests are being undertaken in three phases:

- a preliminary set of three tests representative of the range of common ceiling systems;
- a set of twelve tests examining in more detail the effects of differences in construction of common ceiling systems;
- a set of eight tests using a different testing arrangement to examine the influence of testing procedure.

The first progress report [1] described the results of the first phase. This report describes the results of the twelve tests conducted in the second phase. Of the twelve tests, nine were conducted on plasterboard ('Gyprock') systems and three on fibre cement ('Versilux') systems.

2. EXPERIMENTAL PROCEDURE

The ceiling panels were tested in the same manner as those in the first phase -i.e. as shear walls using the University Wall Testing Machine.

The basic arrangement is shown in figure 1. The basic framework used in all the tests comprised two 70 x 70 mm spotted gum vertical members at 2815 mm centres representing the top plates connected by 70 x 36 mm spotted gum members on edge at approximately 800 mm spacings representing the ceiling joists. The dimensions of the clad section of the panels were 2700 mm long by 2400 mm high.

The load was measured by a load cell mounted at the loading point and deflections were measured by mechanical dial gauges mounted as shown in figure 1.

Loads were increased in increments up to approximately thirty percent of the anticipated ultimate load, removed, and re-applied in increments up to failure.

3. DESCRIPTION OF TESTS

Full details of each test are given in the Appendix.

A summary of the tests is given in Table 1. This also includes Tests 1-3 from the first phase which were reported in detail in the first report. Tests 3-15 are the main subject of this report.

A typical load deflection curve is shown in figure 2. The basic characteristics of it are that it is non linear, softening and inelastic (hysteretic), and that it exhibits a peak load which is preceded by relatively ductile behaviour and followed by a relatively rapid decrease in load.

In Table 1 the ultimate load has been taken as the peak load, the equivalent design load as the ultimate load divided by 2.6 (following the recommendations for a single test of EBS Technical Record 440 [2]) and expressed per unit width, and the equivalent design stiffness as the ratio of the equivalent design load on the full width to the measured deflection at the equivalent design load. Because of the non linear inelastic nature of the load deflection curve this is an equivalent stiffness only but it would be appropriate for estimating deflections at the maximum permissable design load. It will tend

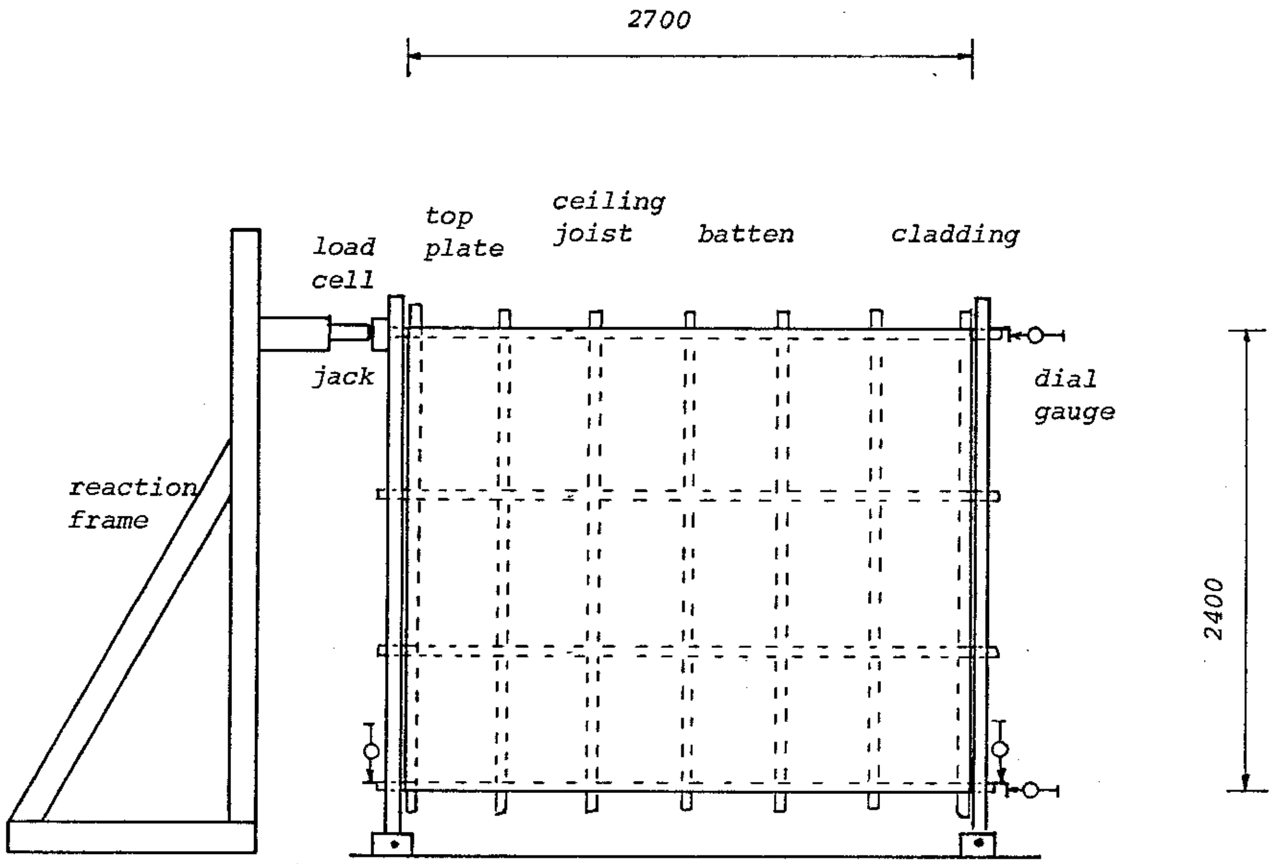


Figure 1 Typical Test Arrangement

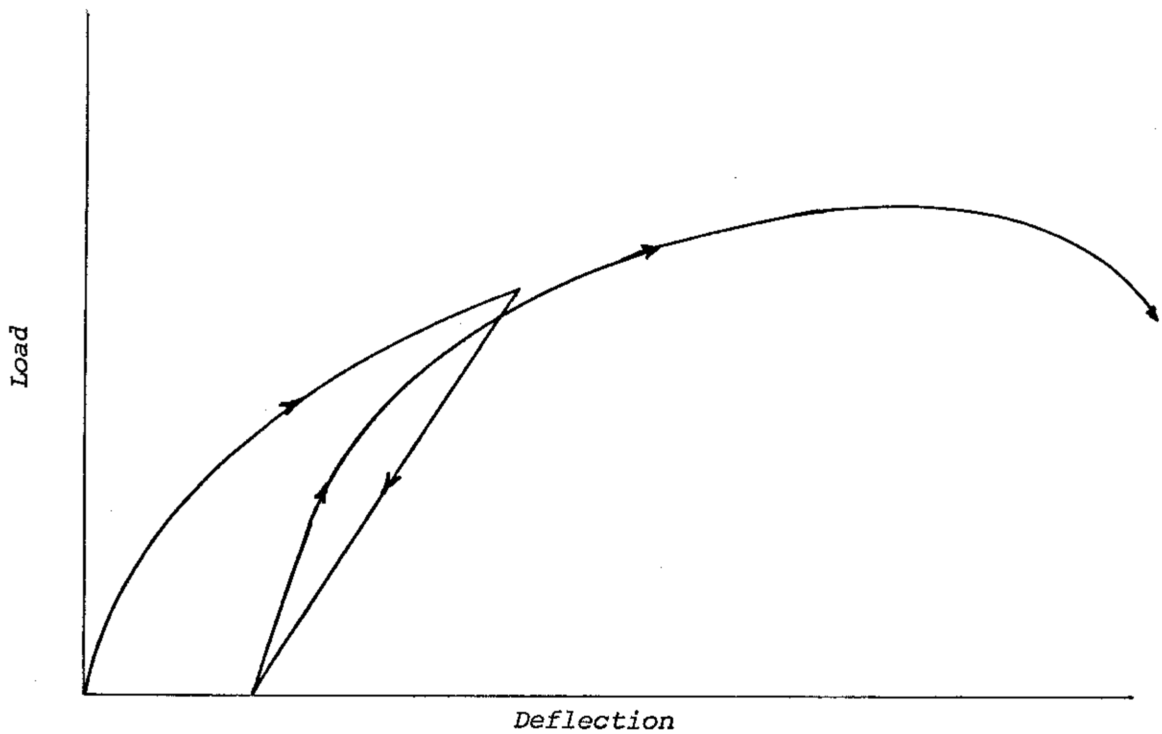


Figure 2 Typical Form of Load-Deflection Curve

TEST NO	CLADDING Material	CLADDING Size mm x mm	FASTENERS Type	FASTENERS Spacing mm	BATTENS Material	BATTENS Spacing mm	JOIST SPACING mm	ULTIMATE LOAD kN	EQUIVALENT DESIGN LOAD kN/m	EQUIVALENT DESIGN STIFFNESS kN/mm	COMMENTS
1	Versilux 4.5 mm	3 x 2400 x 900	25 x 1.8 Flex Sheet Nails	150 perim. 200 ctre.	Pine	450	900	12.0	1.71	-	
2	Gyprock 10 mm	2 x 2700 x 1200	8 x 30 Hi-Lo Type S Screw	300	Pine	450	900	3.6	0.51	0.55*	*Estimated
3	Gyprock 10 mm	2 x 2700 x 1200	6 x 25 Bugle Head Tek Screw	300	CSR Furring ch.	450	750	1.1	0.16	-	
4	Gyprock 10 mm	3 x 2400 x 900	8.18 x 25 Hi-Lo Type S Screw	300	-	-	395	5.2	0.74	0.84	Fixed diredtly to joists
5	Versilux 4.5 mm	3 x 2400 x 900	25 x 1.8 Flex Sheet Nails	150 perim 200 centre	-	-	395	6.0	0.85	0.80	Fixed directly to joists
6	Versilux 4.5 mm	2 x 2700 x 1200	25 x 1.5 Flex Sheet Nails	150 perim 200 centre	Pine	450	790	5.6	0.80	0.51	
7	Versilux 4.5 mm	3 x 2400 x 900	25 x 1.5 Flex Sheet Nails	150 perim 200 centre	Pine	450	790	12.7	1.81	1.31	Edge battens nailed to top plates

Table 1 Summary of Test Results

TEST NO	CLADDING Material	CLADDING Size mm x mm	FASTENERS Type	FASTENERS Spacing mm	BATTENS Materials	BATTENS Spacing mm	JOIST SPACING mm	ULTIMATE LOAD	EQUIVALENT DESIGN LOAD kN/m	EQUIVALENT DESIGN STIFFNESS kN/mm	COMMENTS
8	Gyprock 10 mm	3 x 2700 x 1200	8.18 x 25 Hi-Lo Type S Screws	300	Pine	450	790	8.0	1.14	1.24	Gap at edge of sheet filled with plaster
9	Gyprock 10 mm	2 x 2700 x 1200	6.2 x 25 Bugle Head Tek Screws	300	CSR Furring ch.	450	790	4.5	0.64	0.27	Gap at edge of sheet filled with plaster
10	Gyprock 10 mm	2 x 2700 x 1200	8.18 x 25 Hi-Lo Type S Screws	300	Pine	450	790	6.0	0.85	1.04	Nogging at edges
11	Gyprock 10 mm	2 x 2400 x 1350	8.18 x 25 Hi-Lo Type S Screws and glue	Screw 270 Glue 225	-	-	395	6.2	0.88	0.87	Glued and Screwed directly to joists
12	Gyprock 10 mm	2 x 2700 x 1200	6.2 x 25 Bugle Head Tek Screws	300	Lysaght steel battens	450	790	4.5	0.64	0.60	Battens pierce fixed to joists
13	Gyprock 10 mm	2 x 2400 x 1350	8.18 x 30 Hi-Lo Type S Screws	265	-	-	395	6.8	0.97	0.99	Fixed directly to joists
14	Gyprock 10 mm	2 x 2400 x 1350	8.18 x 30 Hi-Lo Type S Screws	265	-	-	395	5.7	0.81	0.70	Fixed directly to joists
15	Gyprock 10 mm	2 x 2700 x 1200	8.18 x 30 Hi-Lo Type S Screws	300	Pine	450	900	3.75	0.53	0.63	

Table 1 Summary of Test Results

(continued)

to underestimate deflections at lower loads and over estimate deflections at higher loads.

4. DISCUSSION OF RESULTS

4.1 Plasterboard Panels

4.1.1 Test 4

This test, with 900 mm wide plasterboard sheets attached directly to the ceiling joists, was undertaken as a comparison with Test 2 of the first phase in which 1200 mm wide plasterboard sheets were attached to pine battens.

An increase in ultimate load of the order of ten percent could have been expected due to the increased number of fastenings resulting from the smaller width of the sheets with some of this offset due to the use of shorter screws (the only size available at the time of the test). In the event a forty four percent increase in load capacity was observed suggesting that there are inherent advantages from a structural strength view point in attaching the plasterboard directly to the ceiling battens. A contributing factor may have been the higher strength of timber used in the ceiling joists causing a more rigid fastener behaviour in spite of the shorter length of the fasteners. This may also be a contributing factor to the increase in stiffness of the panels at design load.

The test suggests that the system would be adequate for W42 construction - i.e. dwellings in category 3 cyclone areas - providing the spacing between bracing walls is restricted to a maximum of 5.5 m and the internal width is not less than 7 m.

4.1.2 Test 8

During the Phase 1 tests it was observed that if loading was continued long enough for the plasterboard sheets to bear directly against the top plate a significant increase in strength and stiffness occured as a secondary phenonomen. Test 8 was designed to see if anything could be gained by filling the clearance gap between the plasterboard sheets and the top plate with plaster to ensure this contact during the whole loading process. The test was identical to Test 2 apart from the plastered edges adjacent to the top plates and also the shorter screws (again due to lack of availability of the normally recommended 30 mm long screws).

An increase of 120 percent in the ultimate load capacity was obtained and a similar increase in stiffness relative to Test 2 indicating a significant improvement in structural performance could be obtained using this technique.

The test suggests that the system would be adequate for W51 construction -i.e. dwellings in category 2½ cyclone area - providing the spacing of bracing walls is limited to a maximum of 6 m and the internal building width is not less than 7 m.

4.1.3 Test 9

This test was similar to Test 8 except that furring channels were used instead of pine battens. It was thus similar to Test 3 except that the clearance gap between the plasterboard edges and top plates was plastered.

The ultimate load was four times that assigned to Test 3 (furring channels without edge plastering) and twenty five percent greater than that obtained in Test 2 (pine battens without edge plastering) indicating a significant improvement in structural performance due to the plastering. It was however only a little over half as strong as the panel used in Test 8.

The panel was relatively flexible, being five times asflexible as the panel used in Test 8, and over twice as flexible as the panel used in Test 2. This flexibility, arising from the lack of restraint offered by the furring channels, presumably contributed to the much lower strength relative to that obtained in Test 8 by causing a greater concentration of forces at the compression corners of the panel.

The test suggests that the system would be adequate for W42 construction providing the spacing between shear walls is restricted to a maximum of 6 m, the internal building width is not less than 8.5 m and deflections of the order of span/700 can be tolerated; for internal widths not less than 7 m a maximum span between shear walls of 5 m in W42 construction is indicated.

4.1.4 Test 10

In Test 1 on 'Versilux' asbestos-cement sheeted panels a contributing factor to the relative high ultimate load capacity was the nogging between battens along the edges of the sheets allowing continous nailing around the full perimeter of each sheet of cladding. Test 10 was undertaken to determine the effect of nogging between battens along the outside edge of the plasterboard and screwing the plasterboard to it to give a continous set of fasteners around the full perimeter of the plasterboard sheeting. (It was only necessary on the outside due to the plasterboard cladding acting as a single unit following plastering of the joins.) The test was similar to Test 2 with the addition of the nogging and extra screws around the perimeter, and the use of 25 mm instead of 30 mm long screws.

A sixty five percent increase in ultimate load capacity relative to Test 2 was obtained together with an approximate doubling of the stiffness, suggesting a significant improvement in structural performance due to the nogging and extra perimeter nails.

The test suggests this system would be adequate for W42 construction providing the spacing between shear walls is restricted to a maximum of 6.5 m and the internal building width is not less than 7 m.

4.1.5 Test 11

This test with the plasterboard laid directly across the ceiling joists was similar to Test 4 but with the addition of walnuts of adhesive at regular spacings between the plasterboard and ceiling joists to reflect common practice in some areas.

An increase in ultimate strength of less than twenty percent with no marked increase in stiffness at design load relative to Test 4 suggested that the influence of the adhesive, if any, is small. The reason for this appears to be that the adhesive joint fails at a relatively low load (due to the weakness of the paper surface of the plasterboard).

The test suggests this system would be adequate to support a 6.5 m length of dwelling between bracing walls in W42 construction assuming an internal building width of not less than 7 m.

4.1.6 Test 12

The poor structural performance of the metal batten system used in Test 3 was primarily due to the inability of the clipping system used to attach the furring channels to the ceiling joists to satisfactorily transmit the forces generated by diaphragm action. This test was undertaken to investigate the adequacy of a metal battening system in which the metal battens were positively attached - in this case by two clouts per batten/ceiling joist intersection - to the ceiling joists. Apart from the steel battens and their method of attachment the system was identical to the furring channel and pine batten systems used in Test 3 and Test 2 respectively.

As expected the system performed much better structurally than the furring channel system used in Test 3 showing an increase in ultimate load of four times (the same as observed in Test 9 with plastered edges) as well as a big increase in stiffness. Somewhat more surprisingly it also performed better than the pine battened system used in Test 2 with a twenty five percent increase in ultimate load capacity and a marginal increase in stiffness being recorded. The reason for this is probably the connection system between the steel battens and the ceiling joists - see figure A.18 in the Appendix - which gives each of these joints a moment resisting capacity and thereby adds to the total load resistance and stiffness of the panel.

The test suggests that the system would be adequate to support a 6 m length of dwelling between shear walls in W42 construction provided the internal building width is not less than 8.5 m; for internal widths not less than 7 m a maximum span between shear walls of 5 m is indicated for W42 construction.

4.1.7 Tests 13 and 14

These two tests which were similar were also similar to Test 4 apart from the length of the screws which were 30 mm (as recommended by the manufacturer) rather than 25 mm as used in Test 4. The purpose of these tests was to investigate the repeatability - and thus the reliability - of the test results.

Both tests showed an increase in structural strength over that recorded in Test 4, one by 30 percent and the other by 10 percent, suggesting the length of screws does contribute to the strength. This occurred with Test 13 where an increase of almost twenty percent occured but in Test 14 a decrease in stiffness of the same order relative to Test 14 was observed. The tests suggest that unless Test 14 is anomolous due to some undetected error in the experimental procedure, significant variabilities exist both in regard to strength - these tests suggest at least of the order of fifteen to twenty percent - and even more so in respect of stiffness - for which these tests suggest a variability at least of the order of thirty to forty percent. The inconsistency is greater than anticipated from previous testing and, although the possibility of an anomolous result does exist, it indicates a need for caution in determining the significance of differences when comparing the results of individual tests.

On the basis of these tests a design load for this system of 0.95 kN/m width is indicated using the reduced load factor of 2.2 on minimum load which is permissable by EBS TR 440 [2] when two similar tests are undertaken. This suggests the system would be adequate to support a 7.0 m length of dwelling between shear walls in W42 construction for internal widths not less than 7 m.

4.1.8 Test 15

This test was similar to Test 2 using plasterboard laid across pine battens. Test 2 has been used as a basic reference for many of the comparisons and, in the light of the differences exhibited between Tests 13 and 14, there was concern that the ultimate load capacity obtained in Test 2 may have been on the low side, thus biassing some of the consequent observations.

The performance of this panel was almost identical to that observed in Test 2 with a marginal (four percent) increase in load and a somewhat larger apparent increase in stiffness, thus tending to confirm the results indicated by Test 2.

Using the reduced load factor allowable when basing design loads on two similar tests a design load of 0.59 kN/m width is indicated for this system. This suggests it would be adequate to support a 4.5 m length of dwelling between shear walls in W42 construction for internal widths not less than 7 m; and a 6 m length of dwelling between shear walls in W42 construction for internal widths not less than 9 m.

4.2 Asbestos Cement ('Versilux') Panels

4.2.1 Test 5

In this test the 'versilux' sheets were laid across the ceiling joists and fixed directly to them. There was no nogging. It was the 'versilux' equivalent of Test 4 which used plasterboard.

The recorded ultimate load capacity was half that recorded in Test 1, the only previous test with 'versilux' cladding, and in which the cladding was attached to pine battens and to noggings between the battens along the edges of the 'versilux' sheets. Both the strength and stiffness were similar to the equivalent plasterboard tests -i.e. with the plasterboard fixed directly to the ceiling joists.

The test suggests that this system is adequate for W42 construction providing bracing walls are restricted to a maximum spacing of 6.5 m and the internal building width is not less than 7 m.

4.2.2 Test 6

In this test the 'versilux' cladding was attached to pine battens as in Test 1 but no nogging was used. It was the 'versilux' equivalent of Test 2.

The recorded ultimate load was marginally (seven percent) less than that recorded in Test 5 with the 'versilux' fixed directly to the ceiling joists. This difference was much less than that recorded with the plasterboard where the reduction was of the order of forty percent. A reduction in stiffness of the order of thirty five percent relative to Test 5 was similar to that observed in the equivalent plasterboard tests.

The tests suggest that this system is adequate for W42 construction providing bracing walls are restricted to a maximum spacing of 6 m and the internal building width is not less than 7 m.

4.2.3 Test 7

This test was very similar to Test 1. The significant difference was that the edge battens were nailed to the top plate as well as to the ceiling joists, as failure in Test 1 occured as a result of failure of the connections between the edge battens and the ceiling joists.

There was a slight increase in strength (seven percent) relative to Test 1 failure occurring due to the cladding fasteners pulling through the cladding.

This confirms the opinion given following Test 1 based on observed distress of cladding fasteners that the panel was close to failure due to pull through of the cladding fasteners when the batten/ceiling joist connection failure occurred. It also confirmed that nogging between the battens along the edges of the cladding and then fastening around the full perimeter of each sheet can more than double the ultimate load capacity in the case of ceilings clad with individually acting sheets. The ultimate load capacity was also over double that observed for the equivalent plasterboard system (Test 10). The stiffness was over two and half times that observed in Test 6 which used pine battens without nogging and over sixty percent greater than that observed in Test 5 with the sheeting attached directly to the ceiling joists.

Treating this as a repeat of Test 1 a design strength of 2.02 kN/m width is indicated. This suggests that this system would be adequate for W60 dwelling construction - Category 2 cyclone area - providing maximum spacings between shear walls are restricted to 7.5 m and the internal building width is not less than 7 m.

5. DISCUSSION OF MECHANISMS OF FAILURE

5.1 Behaviour of Individual Cladding Connections

For most panels tested to date the ultimate load corresponded to the load just prior to the failure of all of the fasteners along one edge of the panel. The behaviour of individual fasteners is therefore important in determining the performance of the panel as a whole.

Some tests have been performed on individual fasteners by loading small test pieces in the plane of the sheeting. The series of individual fastener tests is not yet complete, so will not be treated in detail here, but the overall shape of the curve has significance in the discussion of failure mechanisms of whole panels. A typical load deflection curve for an individual cladding connection is shown in figure 3.

It can be seen from figure 3 that the shape of the load - deflection curve is characterised by a reasonably linear portion followed by a transition to plastic behaviour. The slope of the linear portion, and its range, vary with different types of sheeting materials. However the load at which plastic behaviour commences, and the deflection at failure, are both highly affected by the geometry

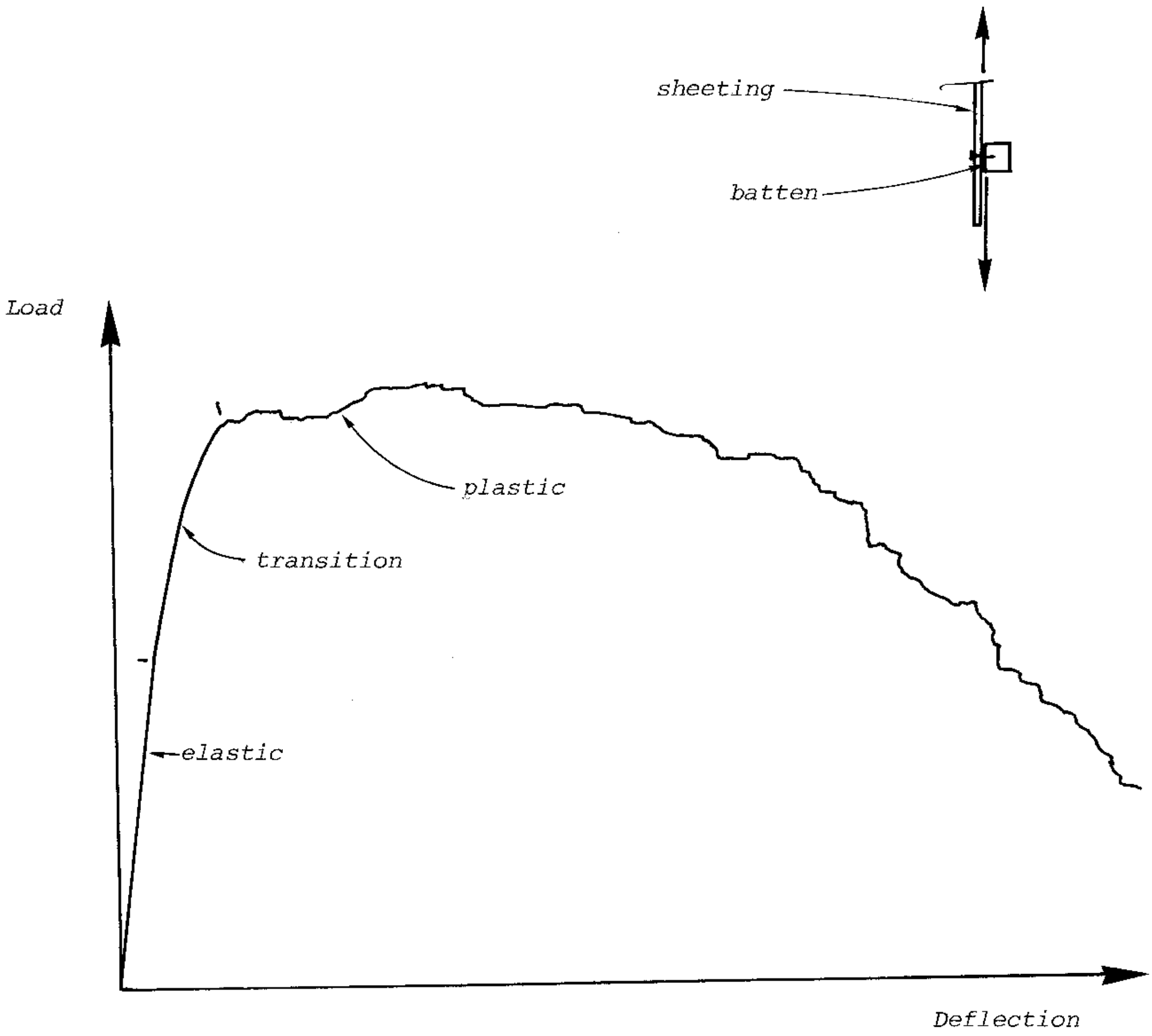


Figure 3 Load - Deflection Curve for a Single Fastener Loaded in-plane of the Sheeting.

of the system under test. This can be appreciated when the failure patterns of individual connections are studied Figure 4 shows a comparison of some typical failures of cladding connections under shear loads.

It can be seen that the load - deflection behaviour of the connections and particularly the deflection at failure is a function of the orientation of loading on the fastener. Where loads on the fasteners are directed away from the edge of the sheet towards the body of the sheet, the behaviour of the connections is more predictable and more closely resembles that shown in figure 4(iii).

5.2 Load - Deflection Curves for Tested Panels

The load - deflection curves for the ceiling panels were of a similar shape to those for the individual connections and showed the same linear, transition and plastic regimes (see figure 5).

However, characteristically for the panels, the linear portion of the curve was very small and the transition portion large.

5.3 Behaviour of Panels over the Linear Portion of the Curve

In each case the plasterboard panels rotated as single units with no distress evident on the plastered joints. As the overall stress in the material is very low (less than 0.03 MPa), the deformation of the sheeting material is concentrated near the fasteners where local bearing stresses are high. In the linear range, the deflections near the fasteners are assumed proportional to load on the fasteners, so the deflections can be deduced from the loads on each fastener obtained from structural mechanics. These deflections appear as shown in figure 6(i).

Asbestos cement clad panels behave slightly differently, as no medium is provided to transfer shear forces from one sheet to another. Each sheet rotates independently of the others. As the timber frame is rigid when compared to the flexibility of the sheeting/fastener system, all sheets in the panel rotate through the same angle. The deflections of all the fasteners appear as shown in figure 6(ii).

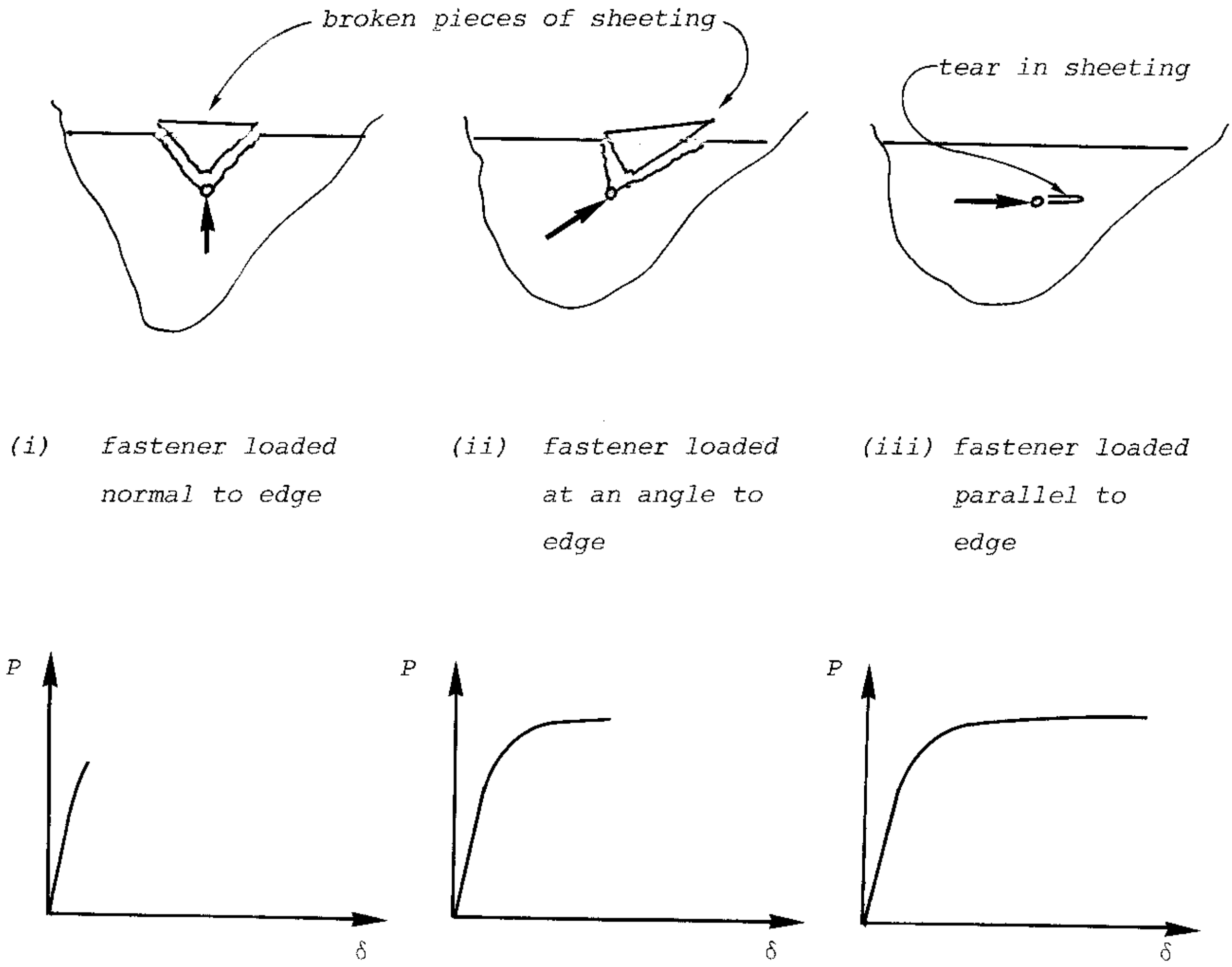


Figure 4 Effect of Load Direction on the Load - Deflection Behaviour of Individual Fasteners

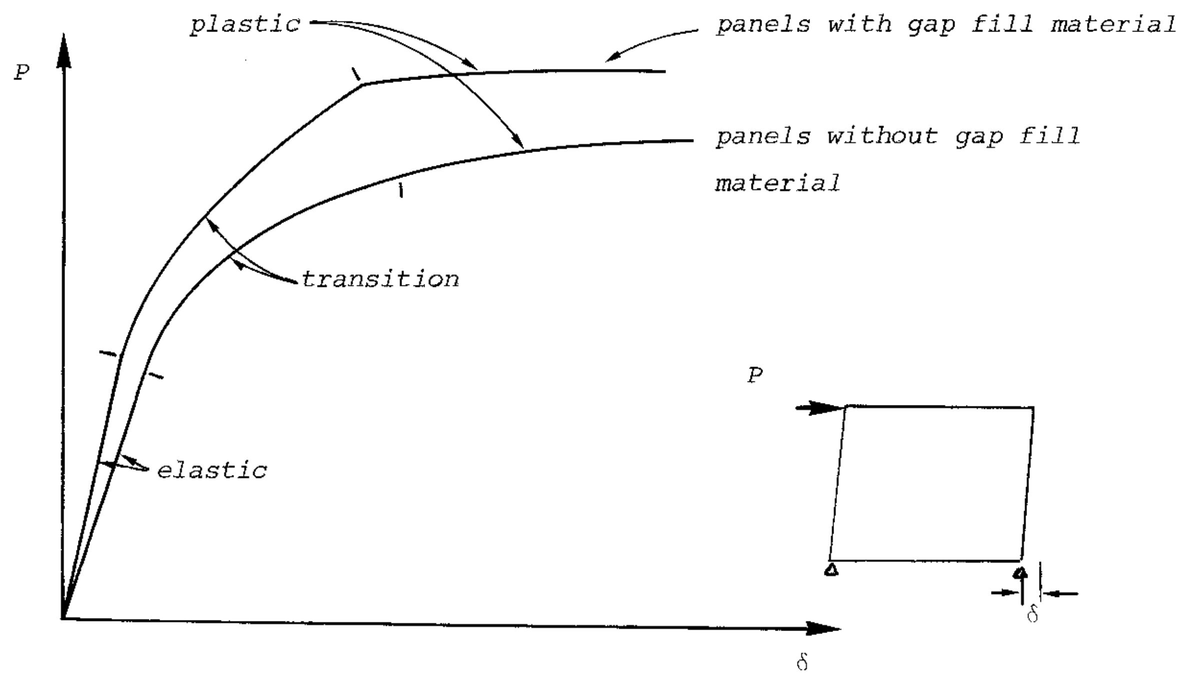


Figure 5 Load - Deflection Curves for Panel Tests

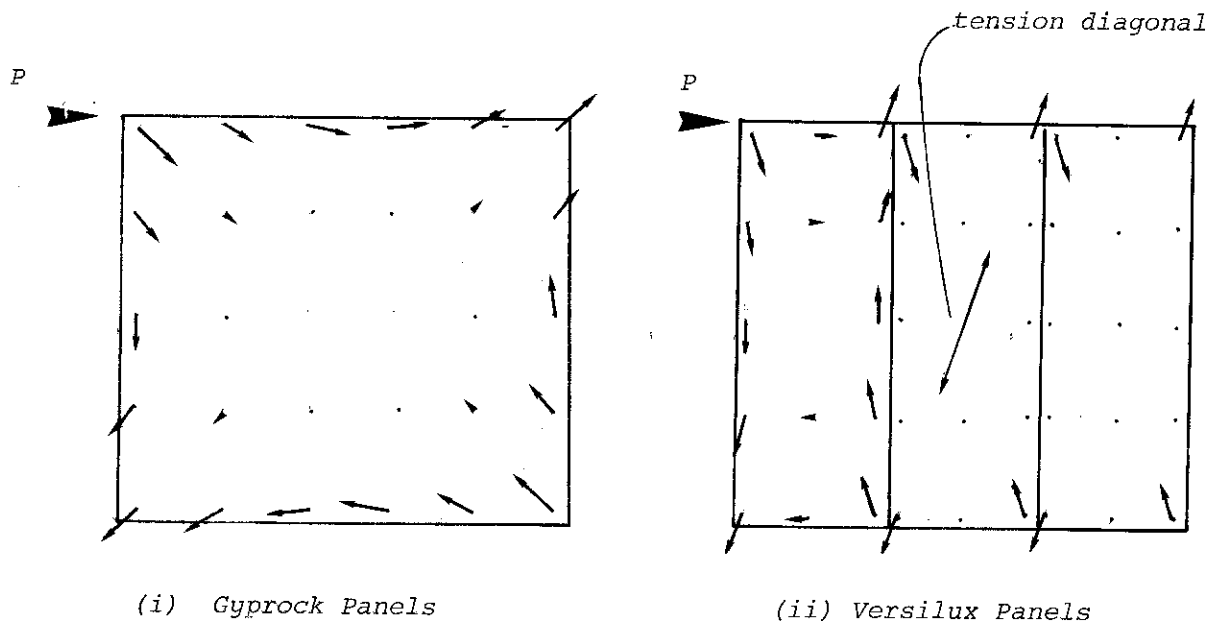


Figure 6 Deflections of Fasteners in Sheeting during the Elastic Portion of the Test

As the load carried by individual fasteners is proportional to the displacement of the fastener for all fasteners, the load on the whole panel is proportional to the displacement of the whole panel.

5.4 Behaviour of Panels in the Transition Portion of the Curve

As the load on the panel is increased, so fasteners near the corner of the panel approach their transition region. The load carried by these fasteners is then less than linear behaviour would indicate and so load shedding away from these fasteners occurs.

This causes the overall panel behaviour to deviate from linear behaviour. Upon further increase in load, fasteners at the corners of the tension diagonal fail, showing the behaviour illustrated in figure 4(i). The load at which this occurs is defined as the first failure load. Considerable load redistribution occurs and the panel behaviour deviates significantly from the linear behaviour. At this point other connections near the tension diagonal corners also pass into their transition region, but because the load - deflection curve for these connections resembles that shown in figure 4(ii) they can sustain load for much higher deflections. The deflection of the connections of the plasterboard and asbestos cement panels appears as shown in figures 7(i) and 7(ii) respectively.

5.5 Behaviour of the Panels at Ultimate Load

With further increases in load, more connections move into the transition portion of their load - deflection curve causing the deflection of the panel as a whole to be much greater than that predicted by linear behaviour. Significant redistribution of the load occurs and fasteners near the centre of the sheet which have a large plastic portion in their load - deflection curve as shown in figure 4(iii) carry higher loads then predicted by linear analysis. The shape of the load - deflection curve at the loads above the first failure load is determined largely by fasteners in the plastic behaviour regime.

However due to the fact that the load - deflection characteristics of fasteners in this regime are functions of not only the materials used, but also distance to the edge of the sheet and the orientation of forces on the fastener, more variables are introduced to the behaviour of the panel near ultimate load. The failure of individual fasteners by pulling through the sheeting or break-

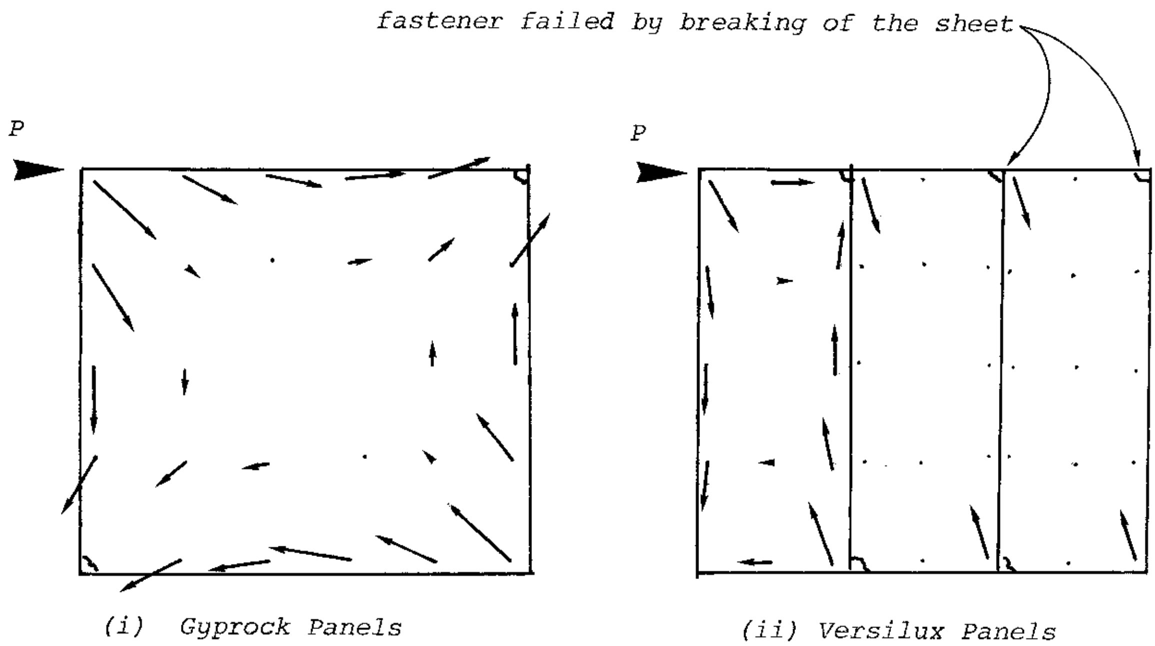


Figure 7 Deflections of Fasteners in Sheeting during the Transition Portion of the Test

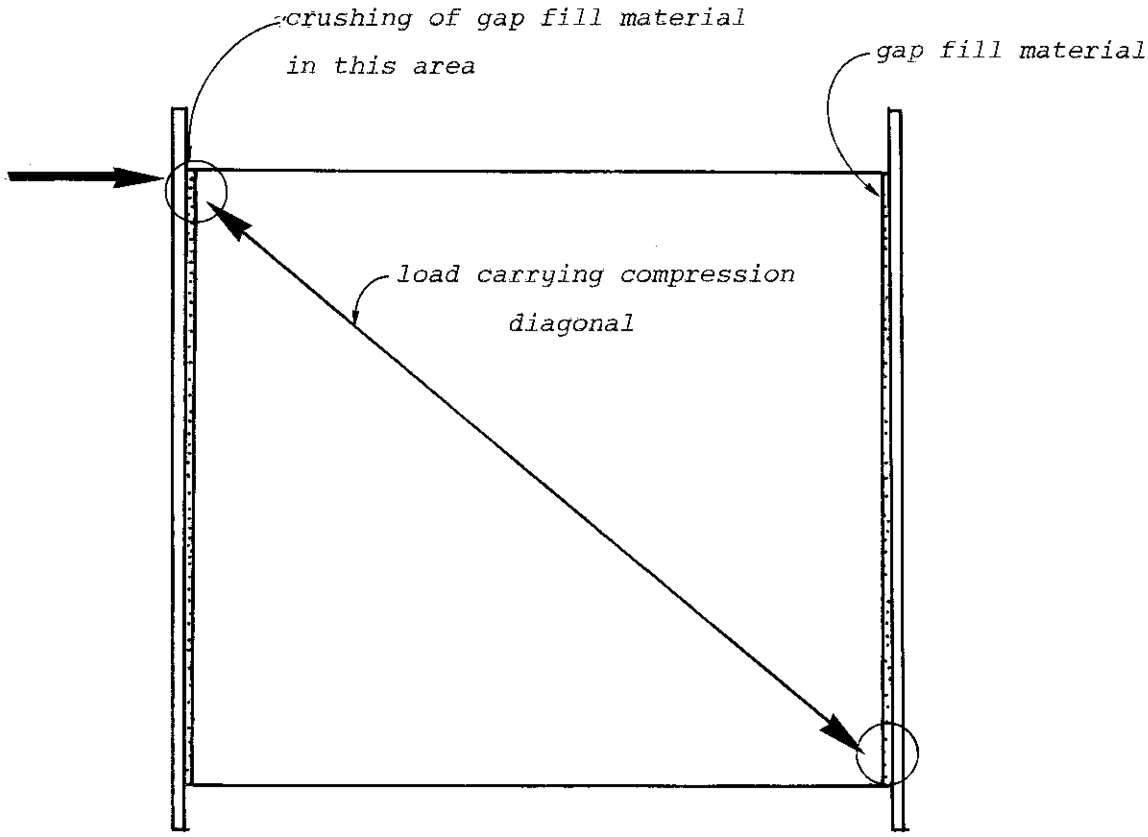


Figure 8 Bearing of Gap Fill Material along the Compression Diagonal

ing away from the sheeting through an edge, causes load on the remaining fasteners to change in both magnitude and direction. Thus the load - deflection curve for a particular fastener changes due to load redistribution as tests proceed. Typically characteristics change from those shown in figure 4(ii) towards those shown in figure 4(iii) which tends to prolong the plastic portion of the panel load - deflection curve.

At the failure point, failure of one fastener and subsequent load redistribution causes overloading of all remaing fasteners along that edge and hence all fasteners along the edge fail simultaneously. This results in a drastic reduction of load.

5.6 Behaviour of Panels with Fill Material Between the Edge of the Sheeting and the Top Plates

In the discussion so far, it has been assumed that the fasteners provide the sole means of transferring forces from the timber frame to the sheeting and back again. However where fill material is provided between the edge of the sheeting and the top plates, this material can transfer force directly from the frame to the sheeting and back to the frame by direct bearing. This increases the ability of the sheeting to carry load across the compression diagonal as shown in figure 8.

The overall panel behaviour, sketched in figure 5, shows the same behaviour regimes discussed in section 5.3, 5.4, 5.5. However the loads carried at a given deflection are higher than those carried by panels without the gap fill material due to the extra load carried on the compression diagonal.

At some point (in both tests near the first failure load) the gap fill material fails by crushing and the system become abruptly plastic with the gap fill material continuing to transmit load.

6. CONCLUSIONS

These tests, together with those described in the previous report [1], have confirmed that the capacity of ceilings to transmit wind loads from the walls to the shear walls is very dependent on the system and fastening.

Some general conclusion are:

- systems in which the cladding is directly attached to the ceiling joists appear to have a better structural performance than those which utilise battens if other things are kept the same. This was more marked with the plasterboard systems than with the 'versilux' asbestos cement systems tested. The latter difference may be due to the difference in behaviour between the systems, the plasterboard being representative of systems wher plastering along the joins causes the cladding to act as a single sheet, and the 'versilux' clad system being representative of systems where each cladding sheet acts independently.

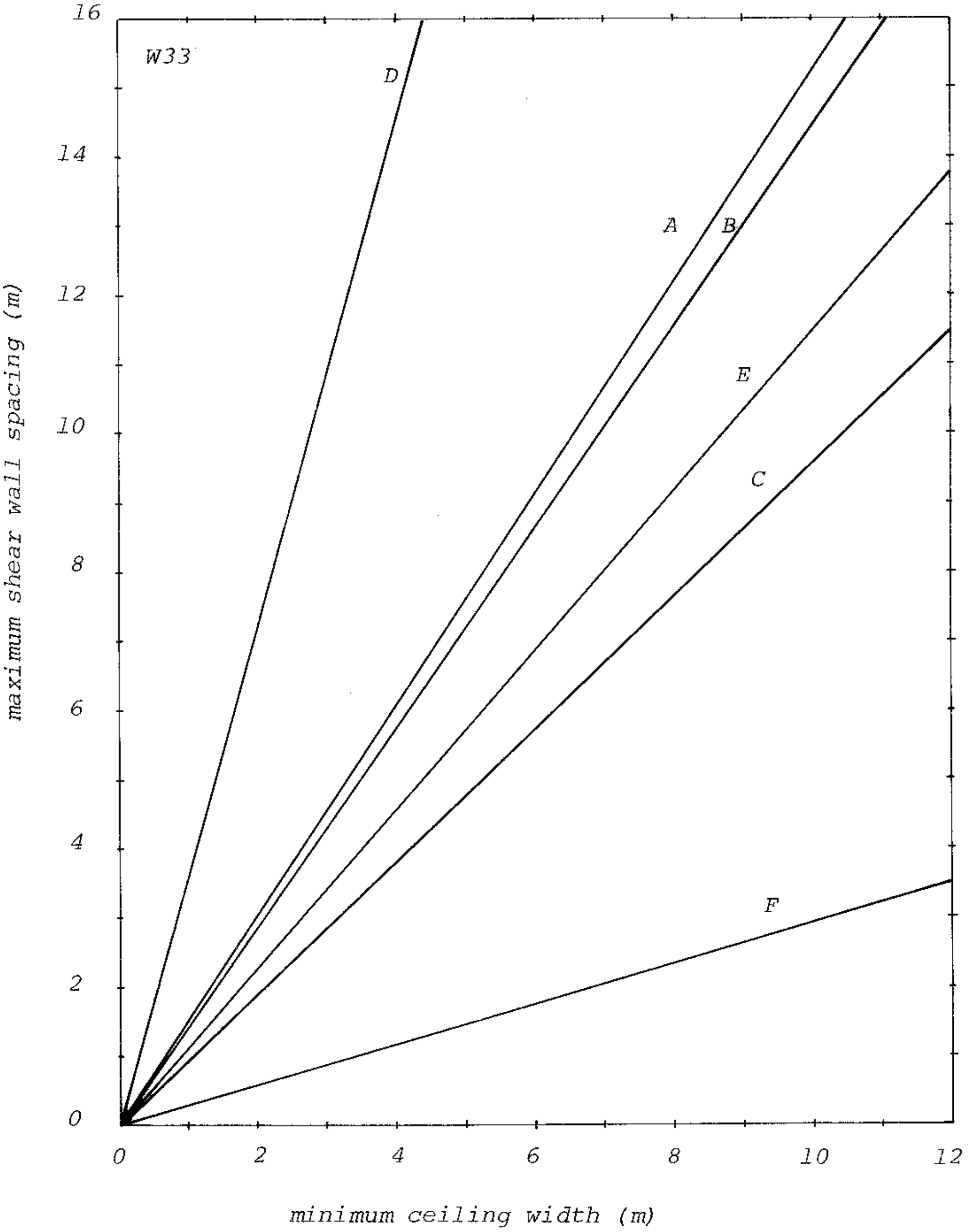
- significant improvements can be obtained by nogging along edges to allow fastening around the full perimeter.

- significant improvements could be obtained by plastering the edges of plasterboard systems.

On the basis of tests described in this and the previous report the design charts shown in figures 9-12, for W33, W42, W51 and W60 construction respectively can be obtained. These should be regarded as interim only. They suggest that where the ceiling is expected to provide the bracing in the plane of the roof for W33 and W42 construction some care is necessary in the choice of systems, particularly if the house is relatively narrow and spacings between shear walls are large; and that for W51 and W60 construction special attention may be necessary if severe restrictions on maximum shear wall spacings and/or minimum building widths are not to be adopted.

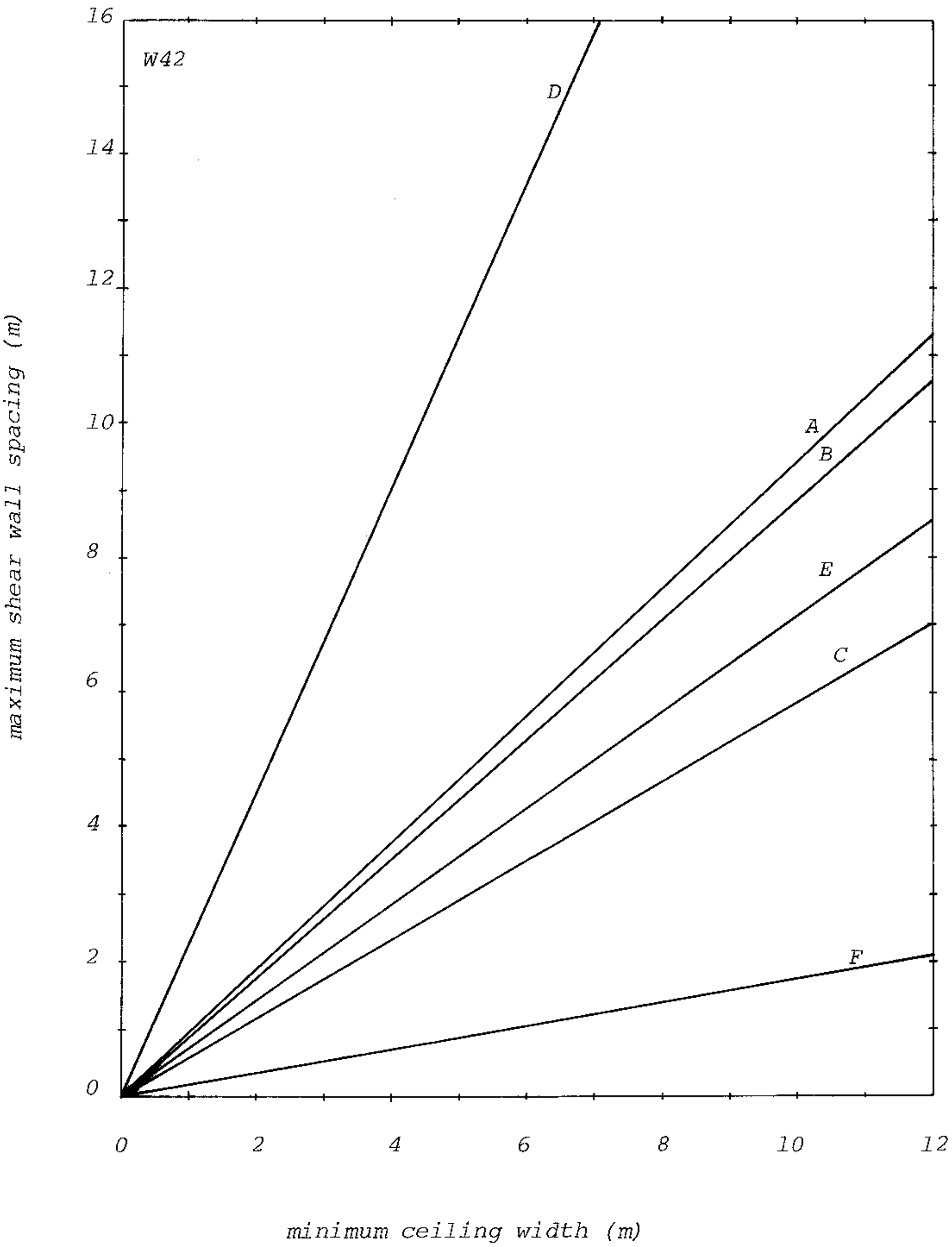
7. ACKNOWLEDGEMENTS

The work described in this report was undertaken as part of a research project on the behaviour of houses subject to wind being funded by the Australian Housing Research Council. The contributions of James Hardie Pty. Ltd. and CRS Pty. Ltd. who supplied the cladding materials are acknowledged.



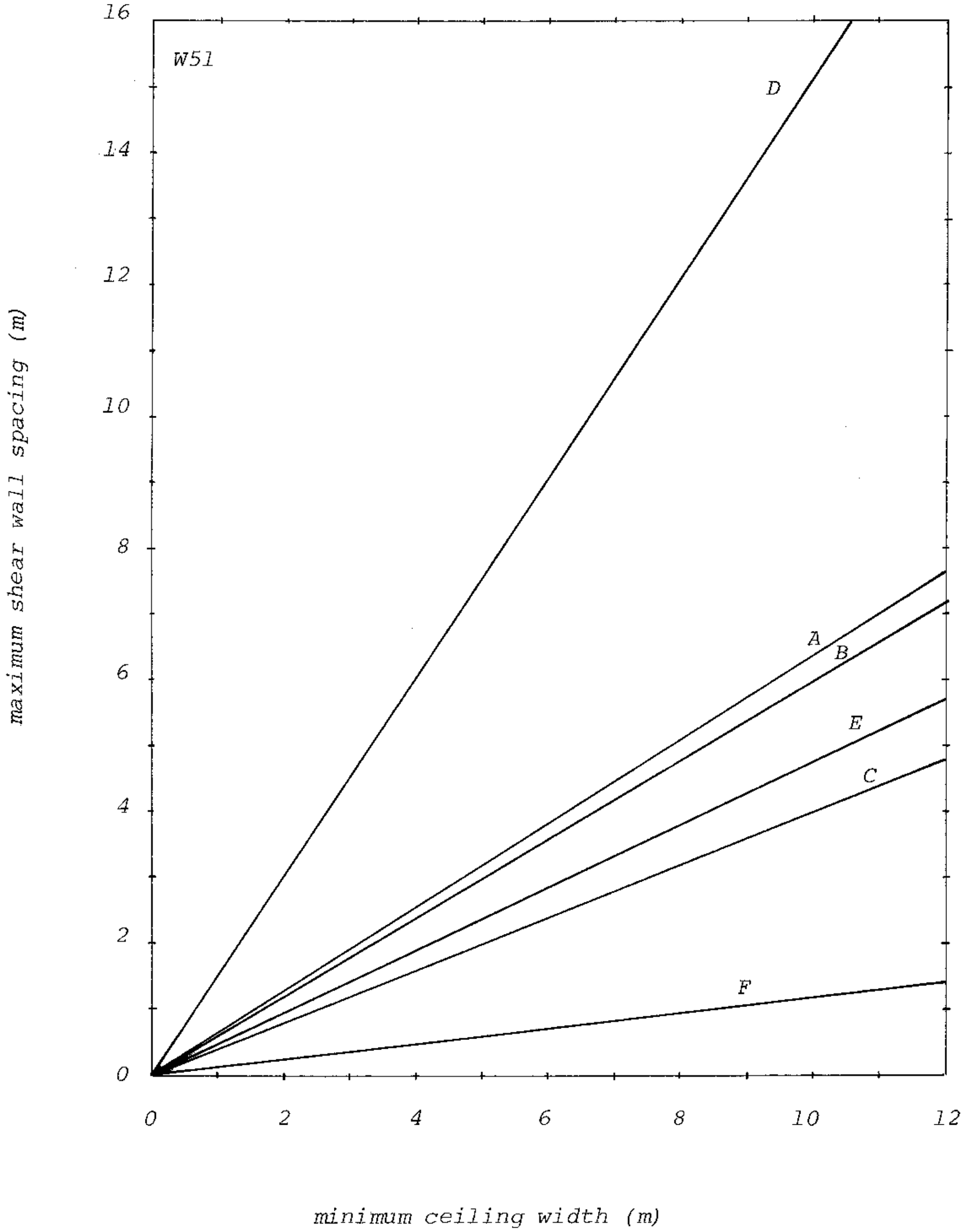
A - Gyprock and Versilux direct to joists as per Tests 13 and 5 respectively
B - Versilux on timber battens as per Test 6
C - Gyprock on timber battens as per Test 15
D - Versilux on timber battens and nogging as per Test 7
E - Gyprock on Lysaght battens as per Test 12
F - Gyprock on Furring Channels as per Test 3

Figure 9 Design Chart for W33 Houses



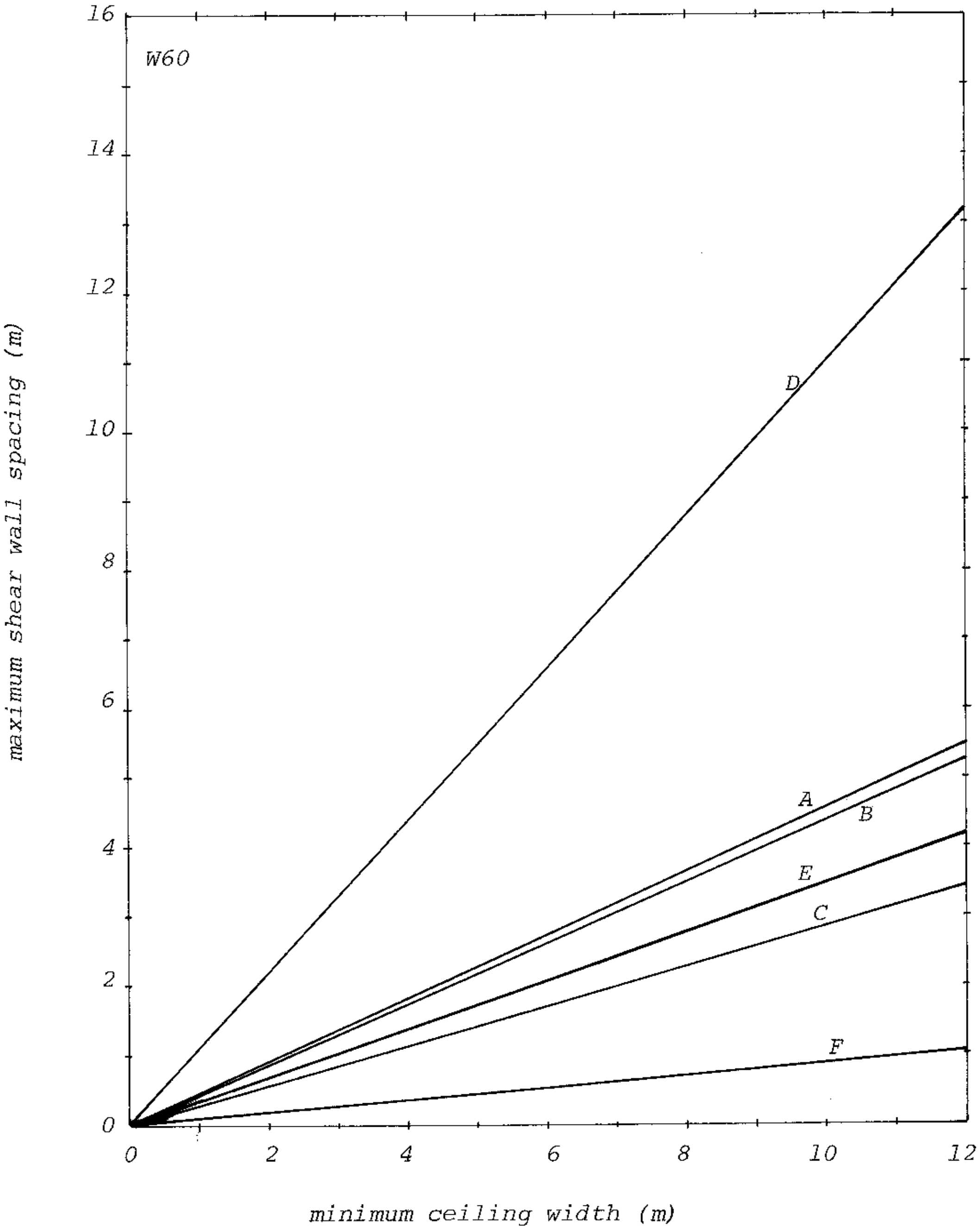
A - Gyprock and Versilux direct to joists as per Tests 13 and 5 respectively
B - Versilux on timber battens as per Test 6
C - Gyprock on timber battens as per Test 15
D - Versilux on timber battens and nogging as per Test 7
E - Gyprock on Lysaght battens as per Test 12
F - Gyprock on Furring Channels as per Test 3

Figure 10 Design Chart for W42 Houses



A - Gyprock and Versilux direct to joists as per Tests 13 and 5 repectively
B - Versilux on timber battens as per Test 6
C - Gyprock on timber battens as per Test 15
D - Versilux on timber battens and nogging as per Test 7
E - Gyprock on Lysaght battens as per Test 12
F - Gyprock on Furring Channels as per Test 3

Figure 11 Design Chart for W51 Houses



A- Gyprock and Versilux direct to joists as per Tests 13 and 5 respectively
B - Versilux on timber battens as per Test 6
C - Gyprock on timber battens as per Test 15
D - Versilux on timber battens and nogging as per Test 7
E - Gyprock on Lysaght battens as per Test 12
F - Gyprock on Furring Channels as per Test 3

Figure 12 Design Chart for W60 Houses

8. REFERENCES

1. Walker, G.R. and Gonano, D. Investigation of Diaphragm Action of Ceilings - Progress Report 1. Technical Report No. 10, James Cook Cyclone Structural Testing Station, November, 1981.

2. Guidelines for Cyclone Product Testing and Evaluation. Technical Record 440, Experimental Building Station, Sydney, 1977.

APPENDIX
DETAILS OF TESTS

A.1 TEST 4

A.1.1 Test Panel

The panel geometry used in this test was as follows:

distance between top plates	2815 mm
spacing of ceiling joists	400 mm

The cladding was screwed directly onto the ceiling joists.

The cladding consisted of three 2400 x 900 x 10 mm recessed edge 'Gyprock' sheets manufactured and supplied by CSR Pty Ltd. The sheets were fixed perpendicular to the ceiling joists and were fastened by 'Gypsum 8.18 x 25 mm Hi-Lo Type S' power driven screws at 300 mm spacing along each joist. (See figure A.1). The recessed joists between the sheets and the screw head depressions were cemented using the 'Gyprock GB100 System' with GBRM and perforated paper tape as supplied by the manufacturer.

A.1.2. Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to a load of 2.9 kN, unloaded, and then reloaded to failure in similar load increments.

A.1.3 Test Results

The observed load - deflection behaviour of the panel is shown in figure A.2. The deflection refers to the racking deflection of the panel over a height of 2400 mm. Failure occurred at a load of 5.2 kN as a result of the fasteners pulling through the cladding. No relative movement occurred between individual sheets and hence the entire cladding rotated as a single unit.

A.2 TEST 5

A.2.1 Test Panel

The panel geometry was exactly the same as that used for the previous plaster board test. (Test 4). The cladding consisted of three 2400 x 900 x 4.5 mm Versilux sheets manufactured and supplied by James Hardie Pty Ltd. The sheets

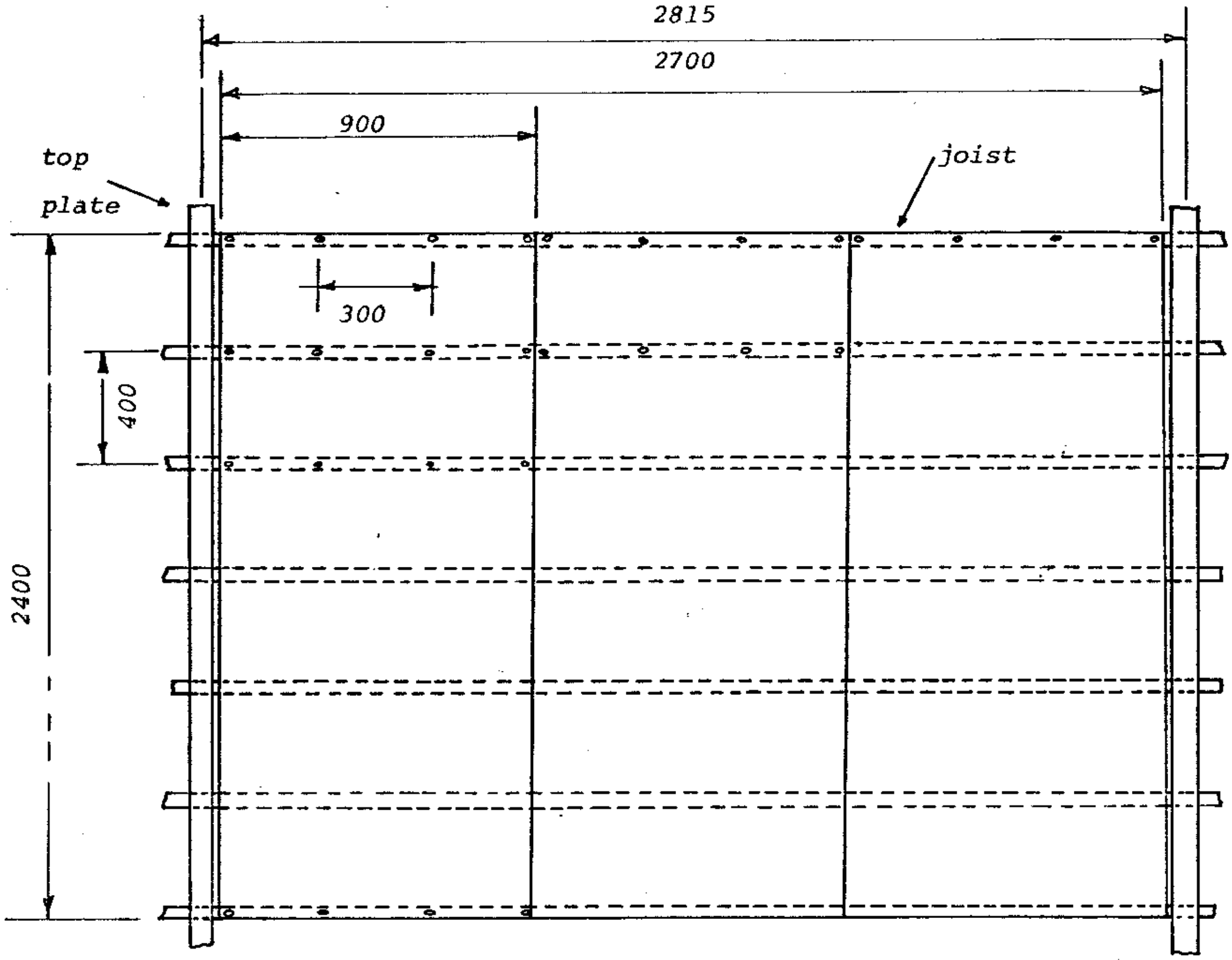


Figure A.1 Test Panel 4

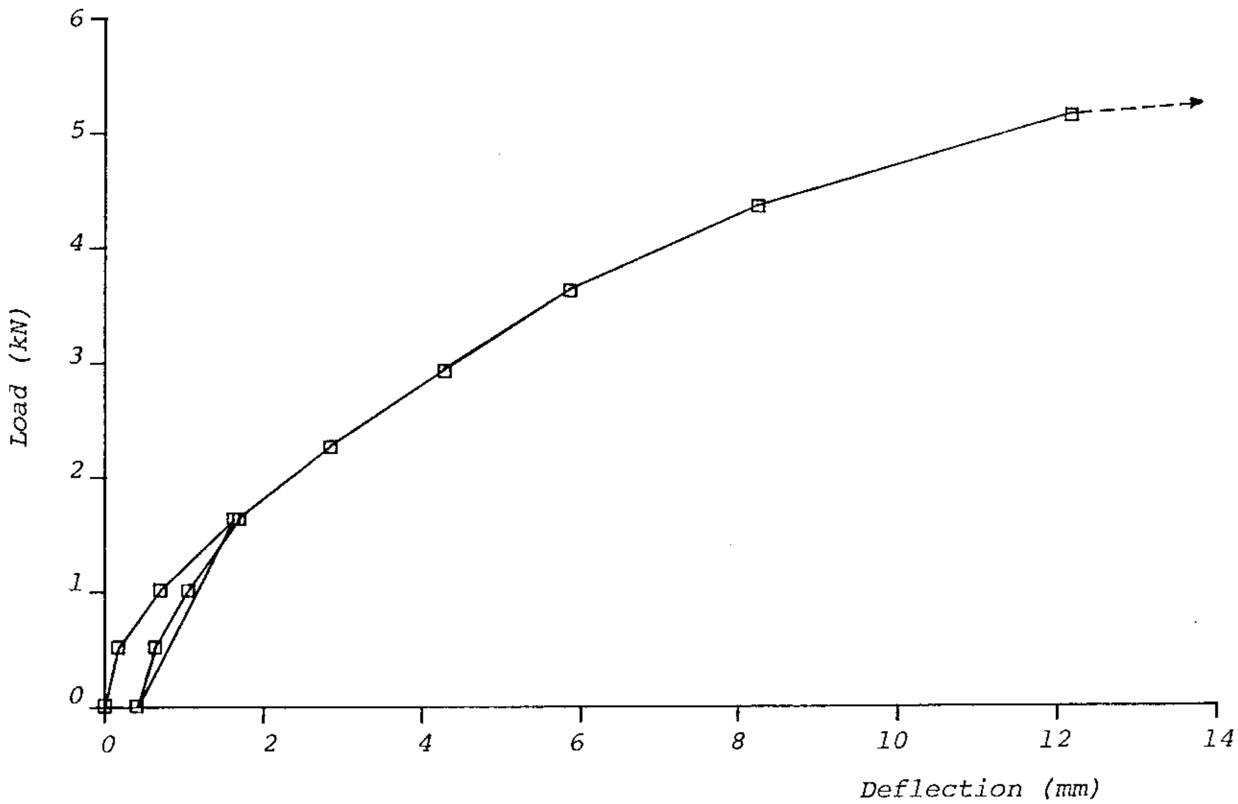


Figure A.2 Load - Deflection Curve Test 4

were fastened perpendicular to the ceiling joists using 25 x 1.8 mm Flex Sheet nails at 150 mm spacing around the perimeter of each sheet and 200 mm spacing in the centre of each sheet (figure A.3).

A.2.2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to 3.6 kN, unloaded and then reloaded to failure in slightly larger load increments.

A.2.3 Test Results

The observed load - deflection behaviour of the panel is shown in figure A.4. Failure occurred at a load of 6.0 kN as a result of fasteners pulling through the cladding. Individual rotation of the panel elements was also noted.

A.3 TEST 6

A.3.1 Test Panel

The panel geometry used in the test was as follows:

distance between top plates	2815 mm
spacing of ceiling joists	800 mm
spacing of ceiling battens	450 mm

The cladding consisted of two 2700 x 1200 x 4.5 mm Versilux sheets. The sheets were fastened perpendicular to the battens using 25 x 1.8 mm Flex Sheet nails at 150 mm spacing around the perimeter of each sheet and 200 mm spacing in the centre of each sheet (figure A.5). The timber battens were nailed to the ceiling joists by one 75 x 3.75 plain nail. The end battens were not nailed to the top plates. No end nogging was employed in the panel.

A.3.2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to 2.3 kN, unloaded, and then reloaded to failure in slightly larger load increments.

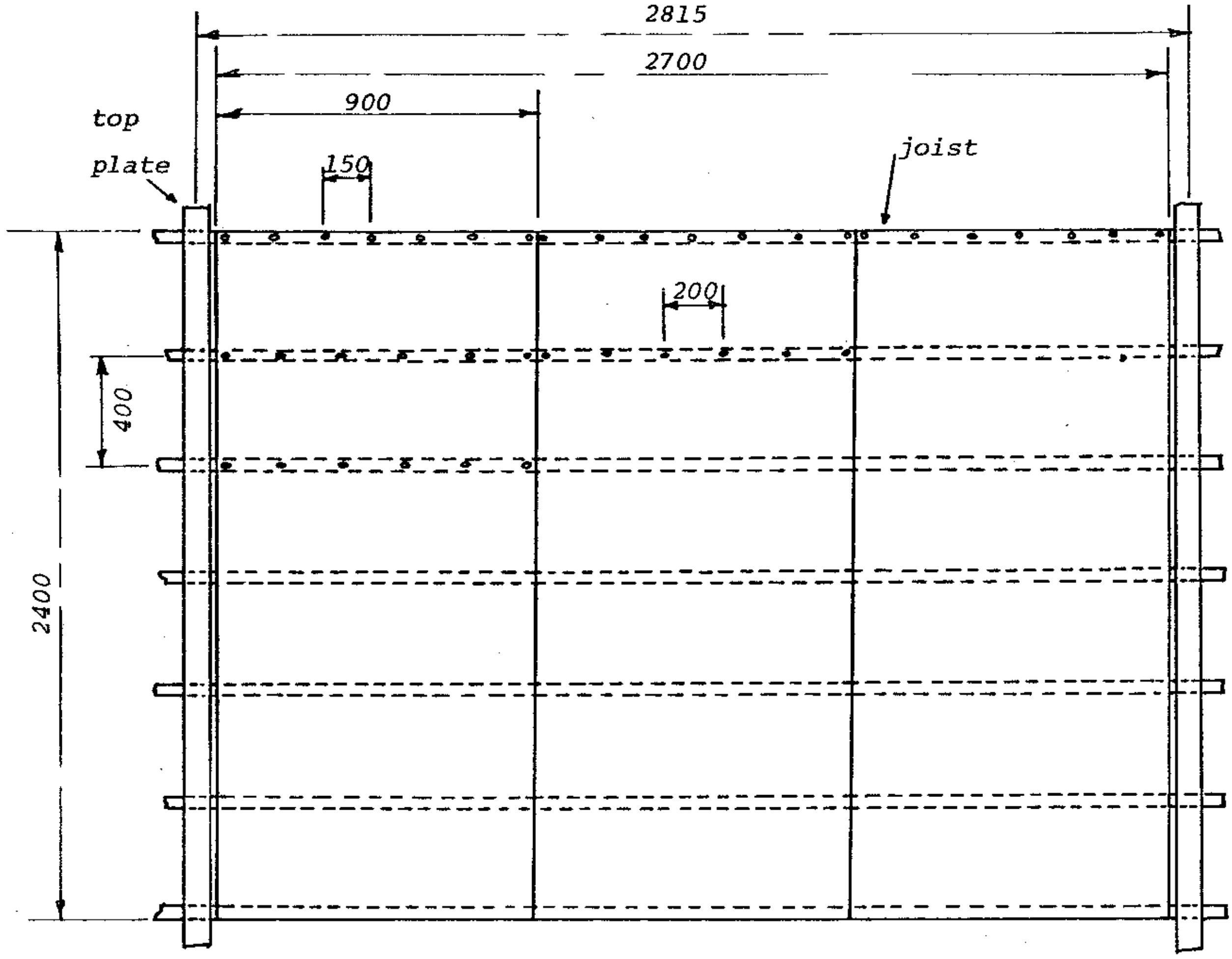


Figure A.3 Test Panel 5

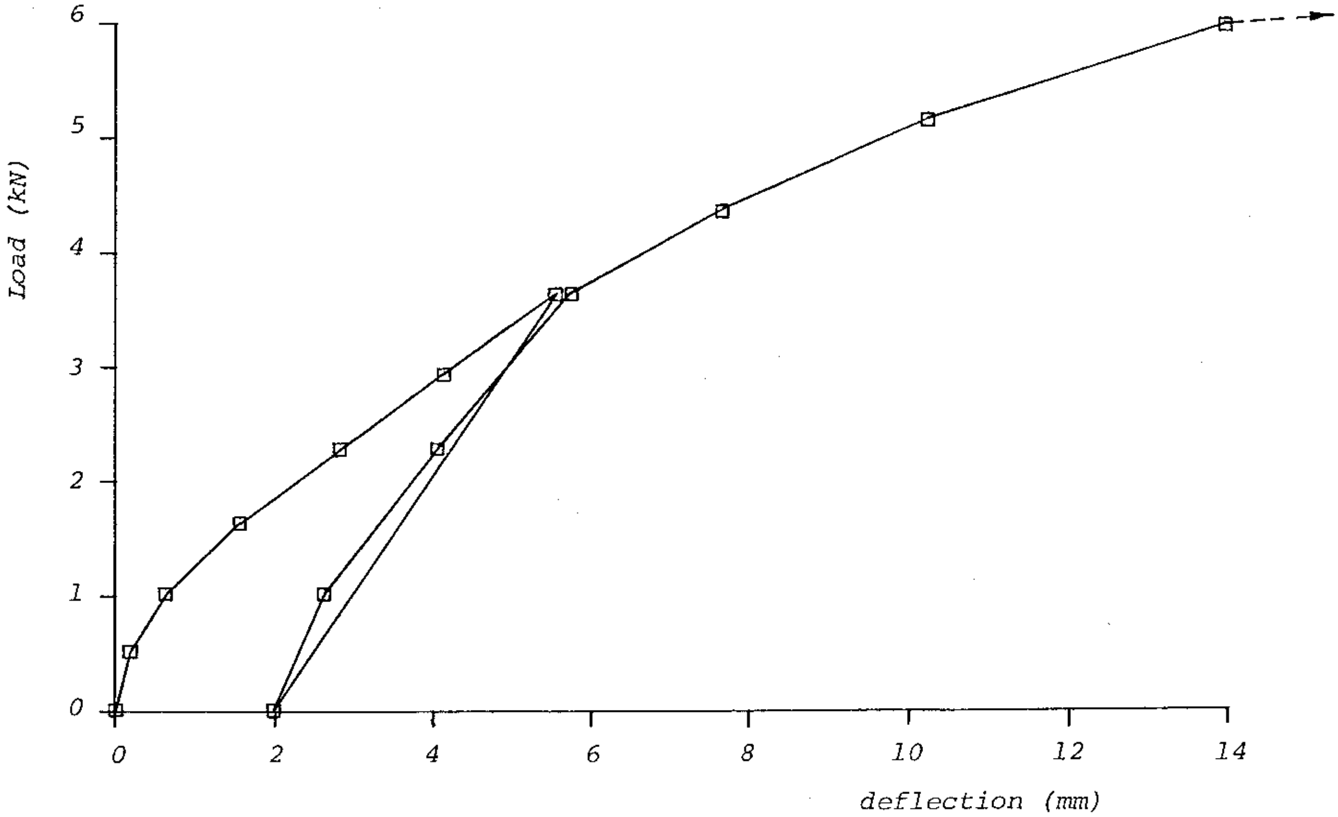


Figure A.4 Load - Deflection Curve Test 5

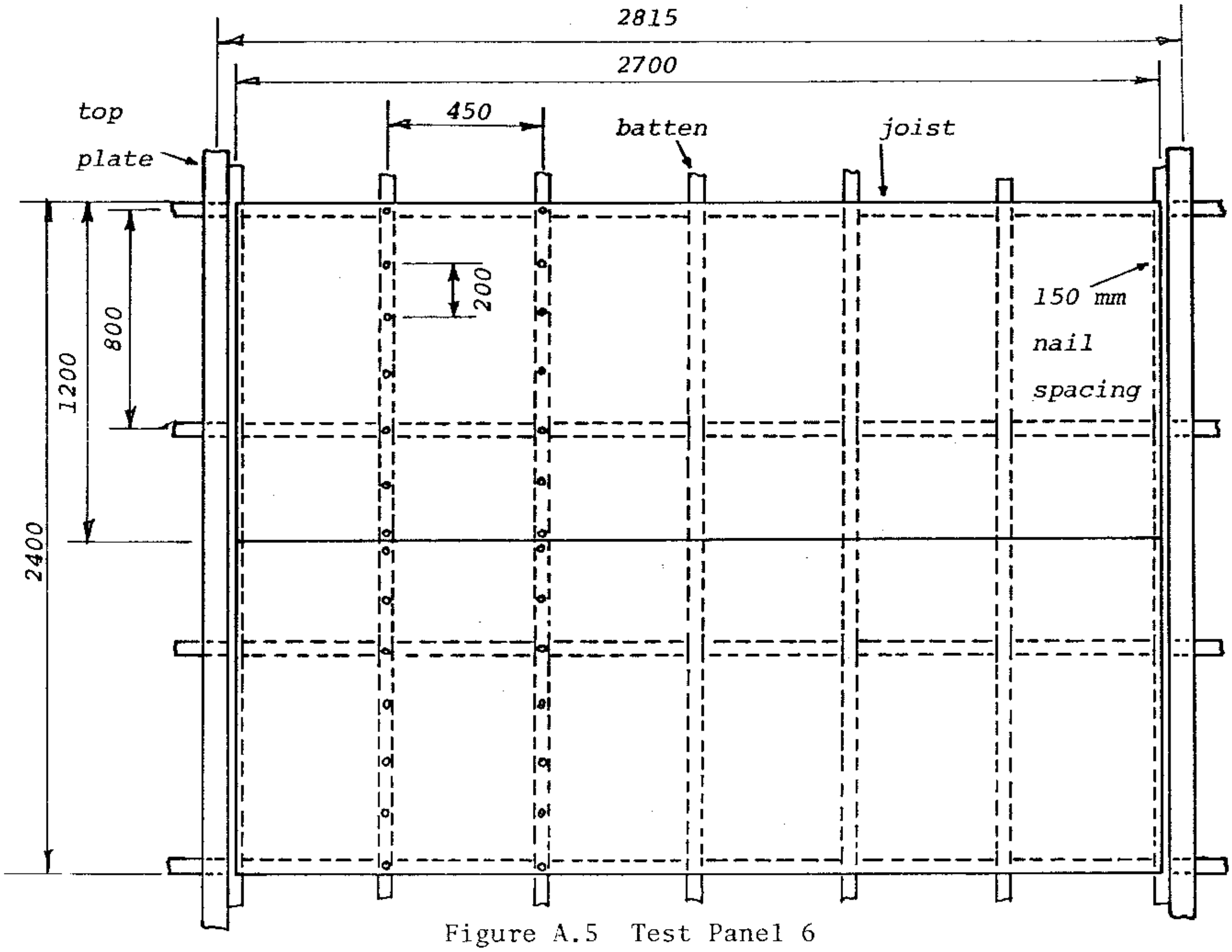


Figure A.5 Test Panel 6

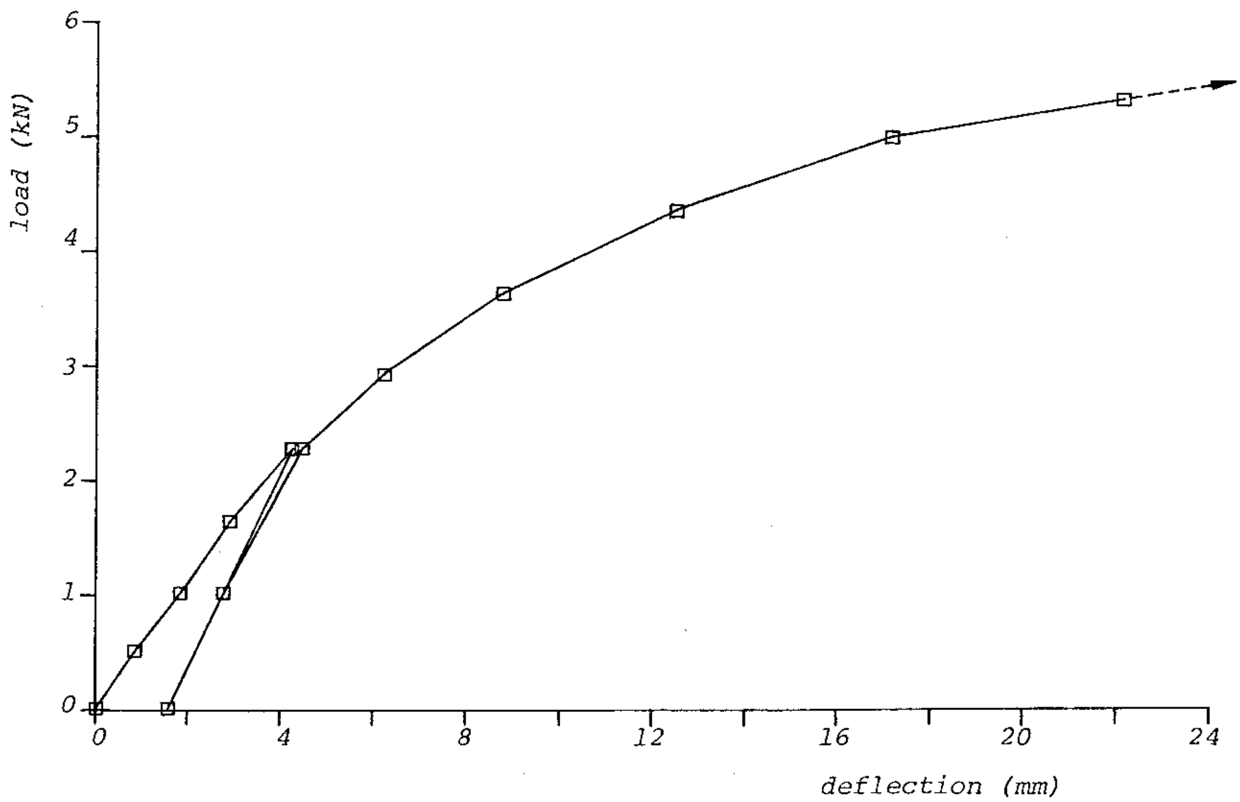


Figure A.6 Load - Deflection Curve Test 6

A.3.3 Test Results

The observed load - deflection behaviour of the panel is shown in figure A.6. Failure occurred at a load of 5.6 kN as a result of the fasteners pulling through the cladding. There was little relative displacement between the battens and the joist which can be attributed to the low failure load. Rotation of the individual panel elements did occur and at failure there was a 10 mm relative displacement between the two sheets.

A.4 TEST 7

A.4.1 Test Panel

This panel was identical to that used in Test 1, except that the end battens were nailed to the top plate as well as the ceiling joists.

The panel geometry for this test was as follows:

distance between top plates	2815 mm
spacing of ceiling joists	800 mm
spacing of ceiling battens	450 mm

The edge battens were nailed to the top plates by three 75 x 3.75 mm plain nails (figure A.7). All timber battens were nailed to the ceiling joist members by one 75 x 3.75 mm nail. End nogging between the battens was used in the panel. The nogging was of the same material as the battens and was skew nailed with two 50 x 2.8 mm nails at each end. The cladding consisted of three 2400 x 900 x 4.5 mm Versilux sheets which were fixed parallel to the battens. The sheets were fastened to the battens and nogging using 25 x 1.8 mm Flex Sheet nails at 150 mm spacing around the perimeter of each sheet and a spacing of 200 mm at the centre of each sheet (figure A.7).

A.4.2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to a load of 3.6 kN, unloaded and then reloaded to failure in slightly larger load increments.

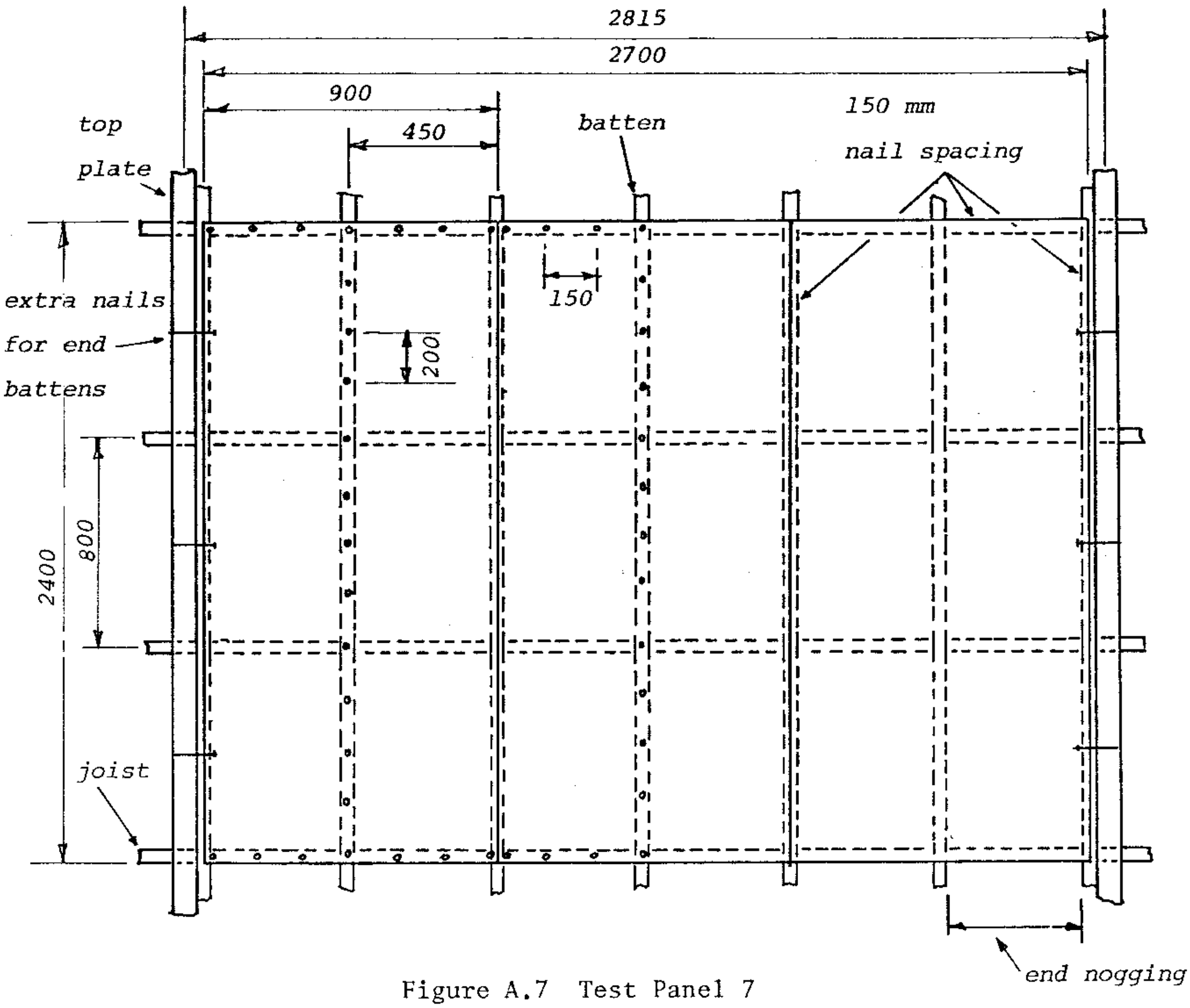


Figure A.7 Test Panel 7

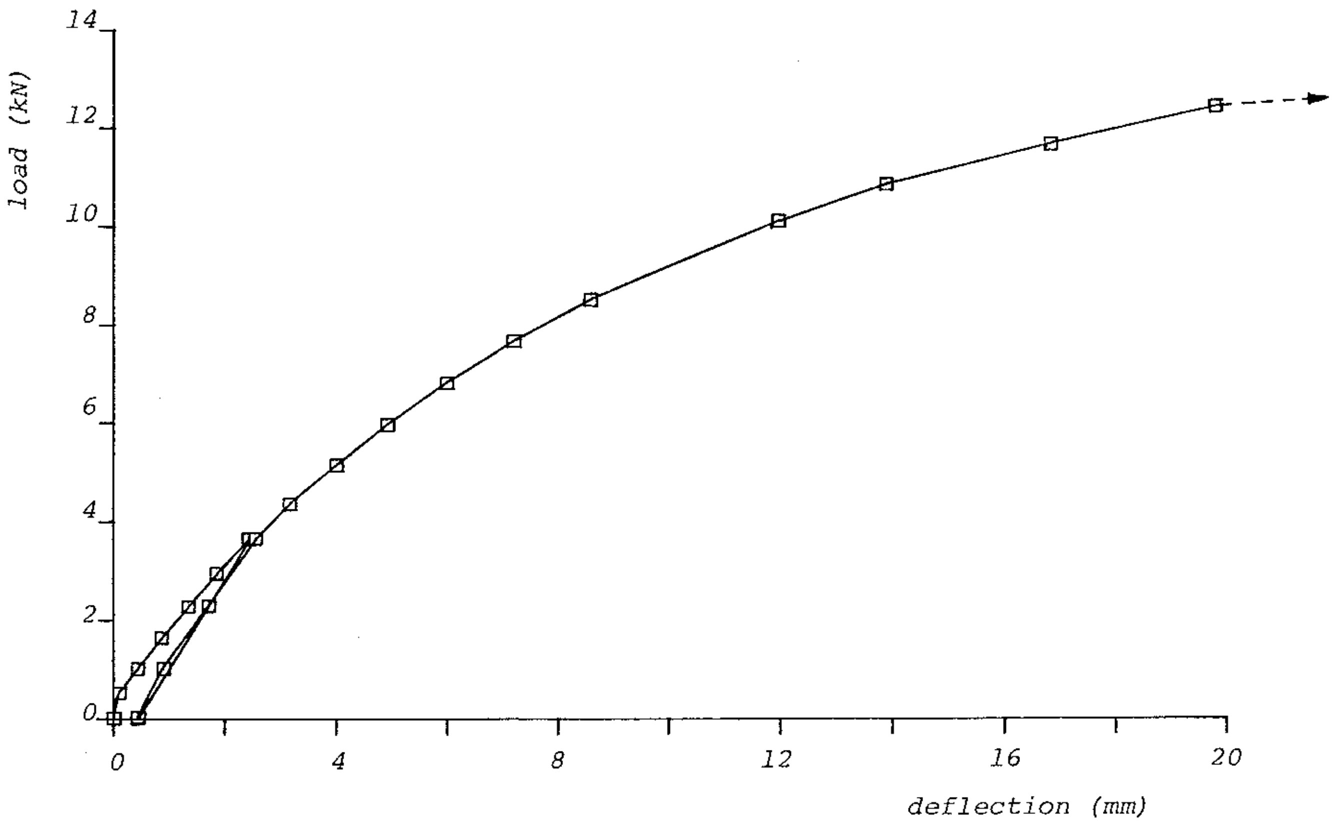


Figure A.8 Load - Deflection Curve Test 7

A.4.3 Test Results

The panel failed at a load of 12.7 kN as a result of the fasteners pulling through the cladding. The observed load - deflection behaviour of the panel is shown in figure A.8. The effect of nailing the end battens to the top plate as well as the joists was to restrict the relative displacement between the battens and joists to less than 5 mm.

Little rotation of the individual cladding elements occurred due to the small displacement of the battens relative to the ceiling joists.

A.5 TEST 8

A.5.1 Test Panel

In this test two 2900 x 1200 x 10 mm 'Gyprock' sheets were fixed perpendicular to the timber battens. The gap between the end of the sheets and the top plate was filled with plaster cement (figure A.9).

The panel geometry for this test was as follows:

distance between top plates	2815 mm
spacing of ceiling joists	800 mm
spacing of ceiling battens	450 mm

The sheeting was fastened to the battens by Gypsum 8.18 x 30 mm Hi-Lo Type S power driven screws at 300 mm spacing along each batten (figure A.10). The system for cementing of the joints and over the screws was the same as for the other plaster board panels. Test panels 2 and 15 were similar to this panel except that the gap between the ends of the sheeting and the top plate were not filled in panels 2 and 15.

A.5.2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to a load of 2.9 kN, unloaded and then reloaded to failure in slightly larger increments.

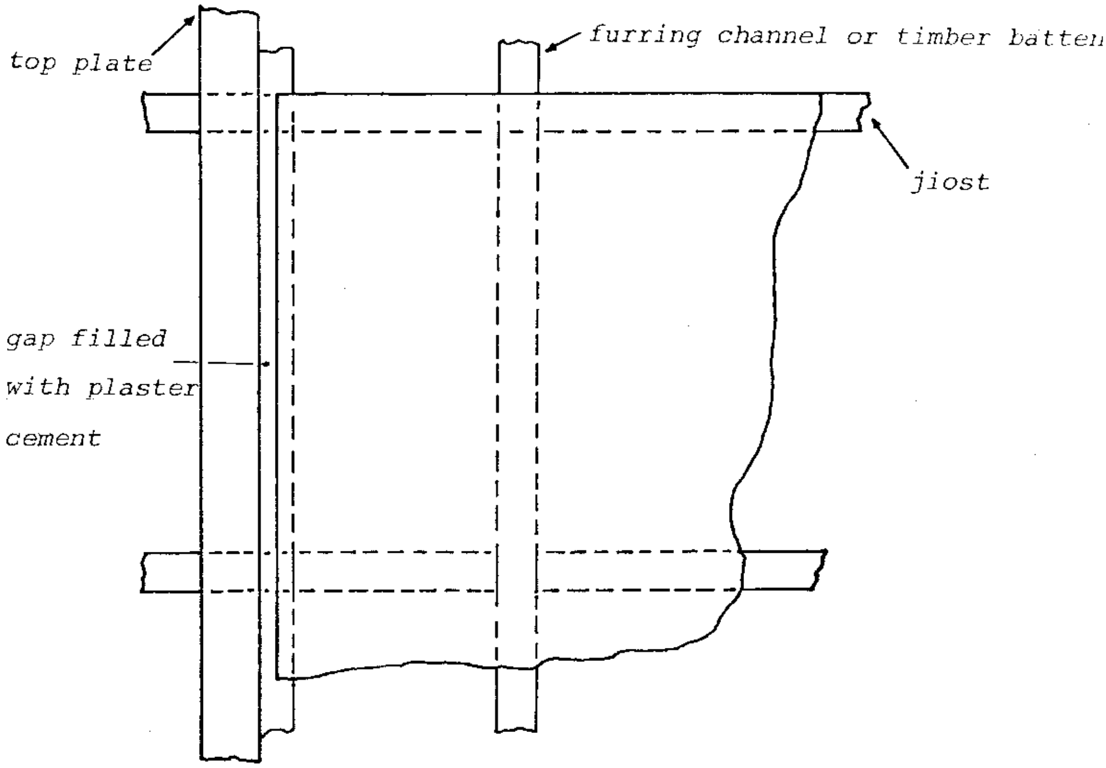


Figure A.9 Detail of Test Panels 8 and 9

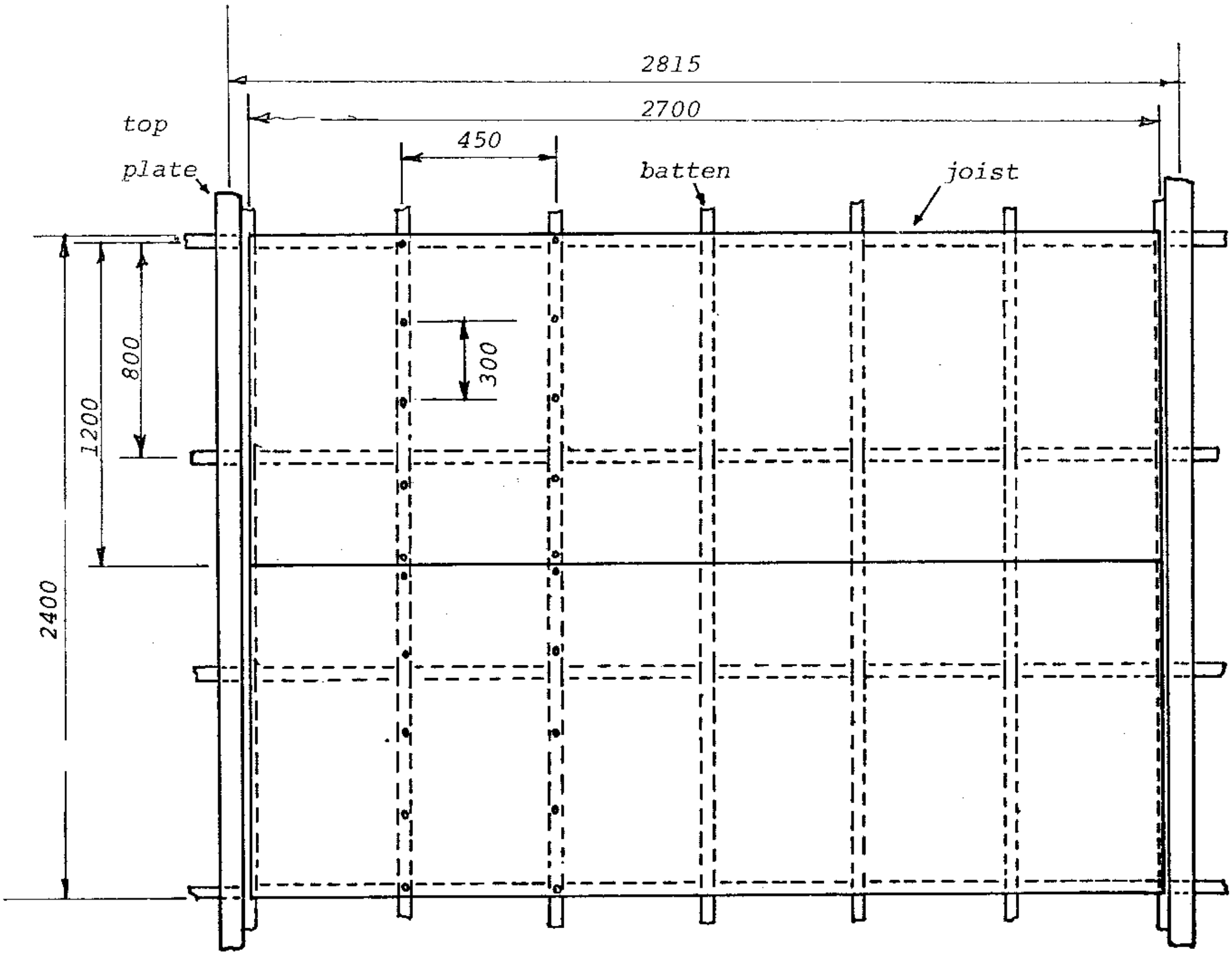


Figure A.10 Test Panels 8,9,10,12 and 15

A.5.3 Test Results

The panel failed at a load of 8.0 kN as a result of the fasteners pulling through the cladding. However, the nails pulled through the cladding only after considerable crushing of the gap fill material had occurred (figure A.11). Because some of the gap fill cement had not fully dried it may have been possible to attain a higher failure load. No relative movement occurred between sheets. The entire cladding rotated as a single unit. No significant relative displacement between the battens and the ceiling joist members was observed. The observed load - deflection behaviour of the panel is shown in figure A.12.

A.6 TEST 9

A.6.1 Test Panel

This test panel is identical to the previous test except 'CSR Rondo' furring channels were used instead of timber battens and Gypsum 6.2 x 25 mm Bugle Head Tek power driven screws instead of Gypsum 8.18 x 30 mm Hi-Low Type S power driven screws (figure A.10). The furring channels were fixed to the ceiling joists with direct fixing clips according the manufacturers instructions. The gap between the sheeting and the top plate was also filled (figure A.9). This test configuration was similar to that used in test 3 except that the gap between the sheeting and the top plate was not filled.

A.6.2 Loading Pattern

The panel was loaded in increments of approximately 0.25 kN up to 2 kN, unloaded, and then reloaded in similar increments to failure.

A.6.3 Test Results

The observed load - deflection behaviour of the panel is shown in figure A.13. The panel failed at a load of 4.5kN as a result of the crushing of the plaster board as shown in figure A.11. Continued loading resulted in the buckling and cracking of the sheet as shown in plate A.1.

It was also observed that the fasteners had shown little distress which indicates that the furring channels carried little of the load. The load tended to be carried by the cladding in direct diagonal compression. There

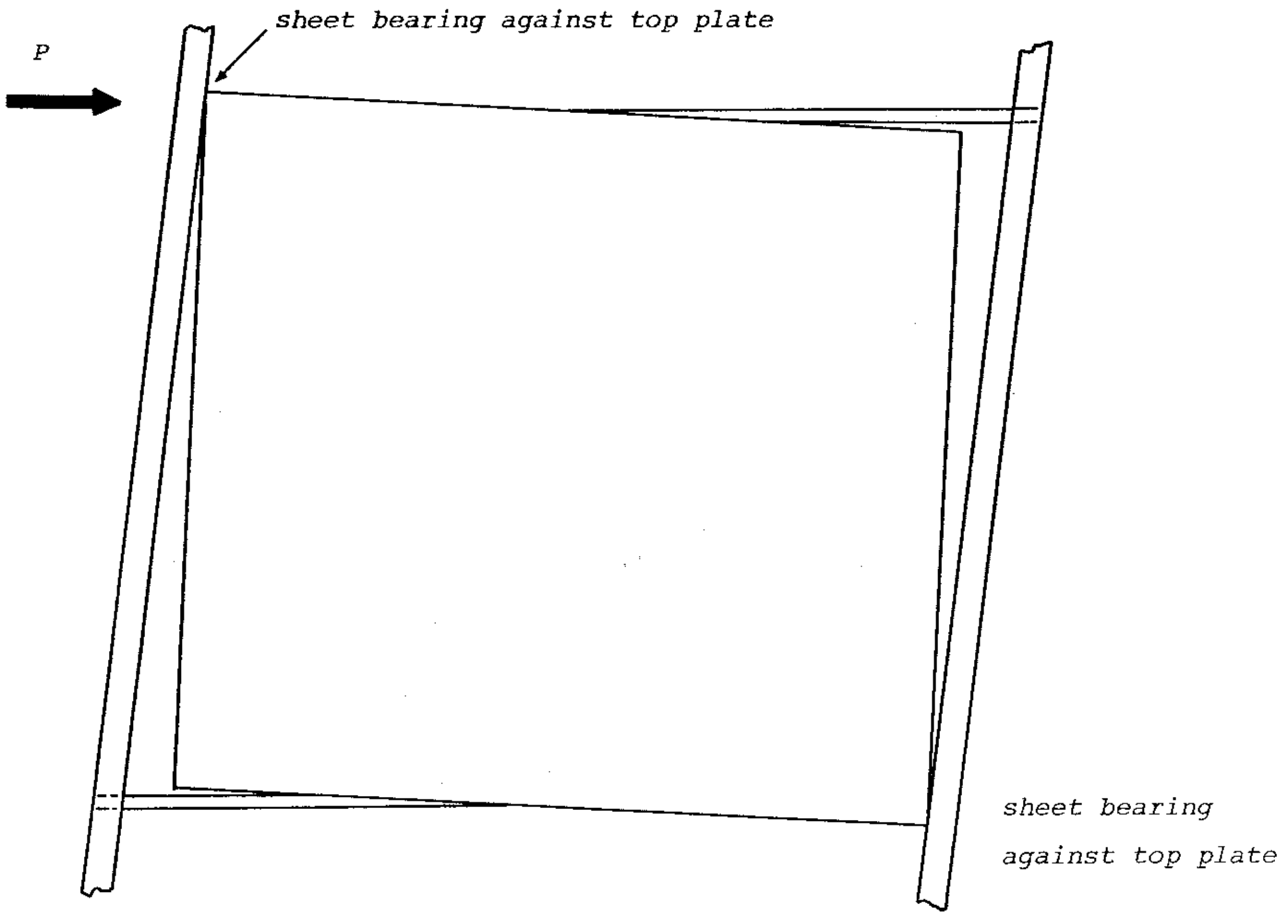


Figure A.11 Crushing of Plasterboard and Gap Fill Material

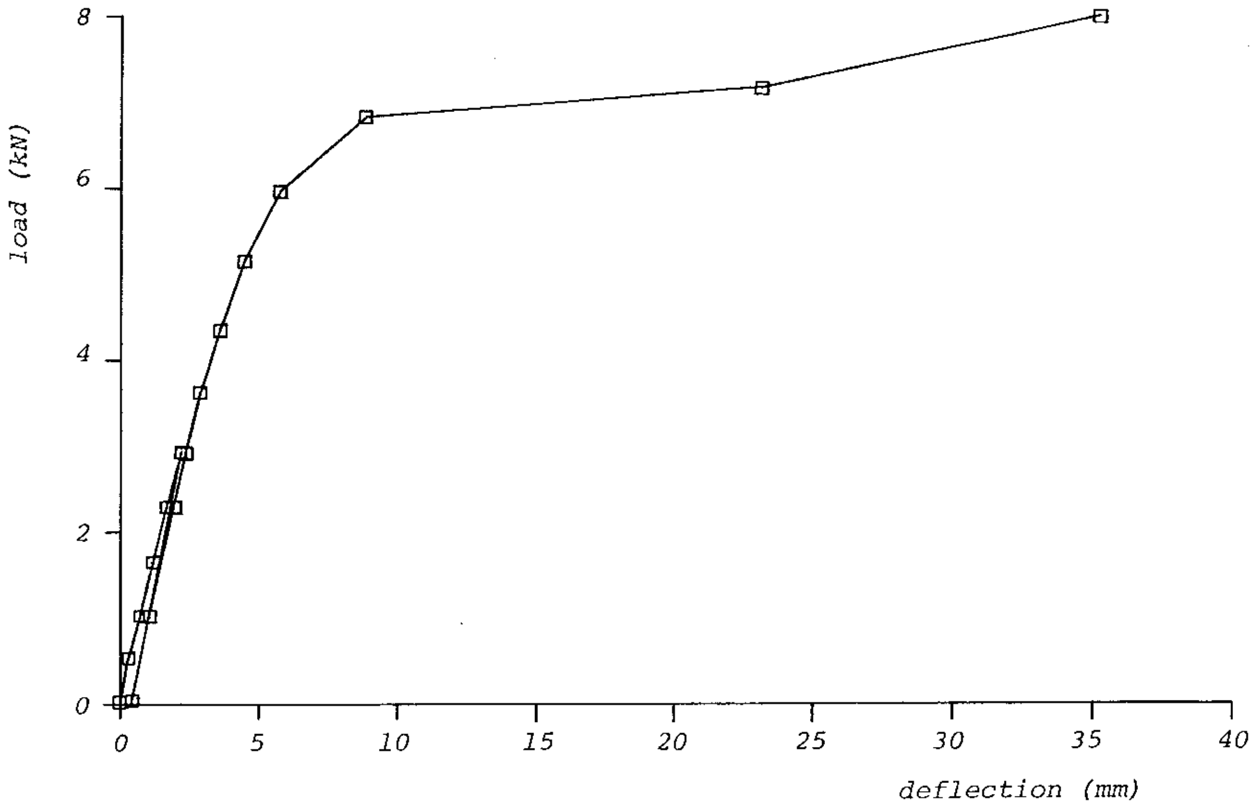


Figure A.12 Load - Deflection Curve Test 8

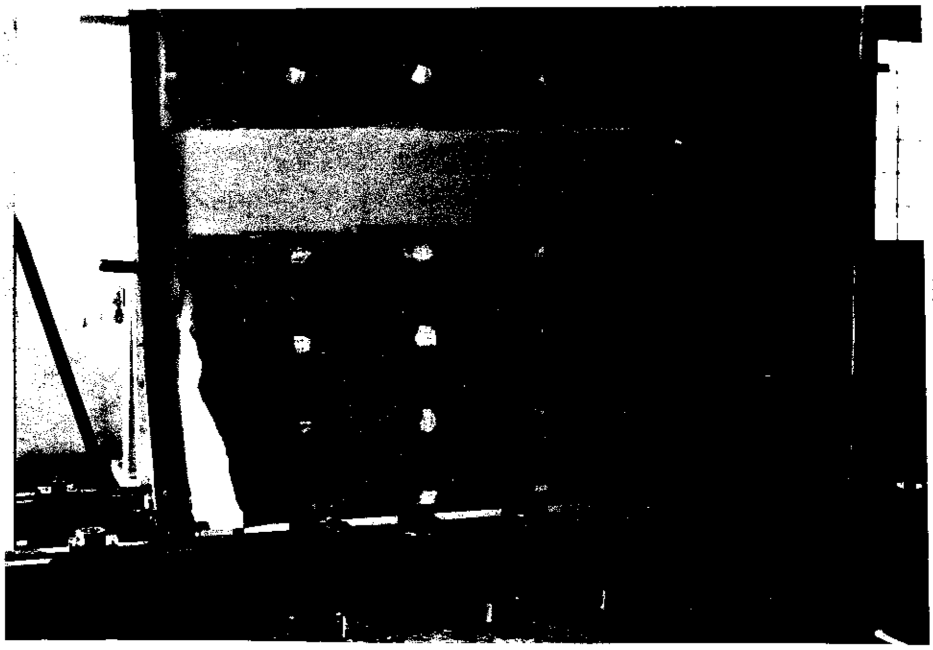


Plate A.1 Buckling of Cladding in Test 9

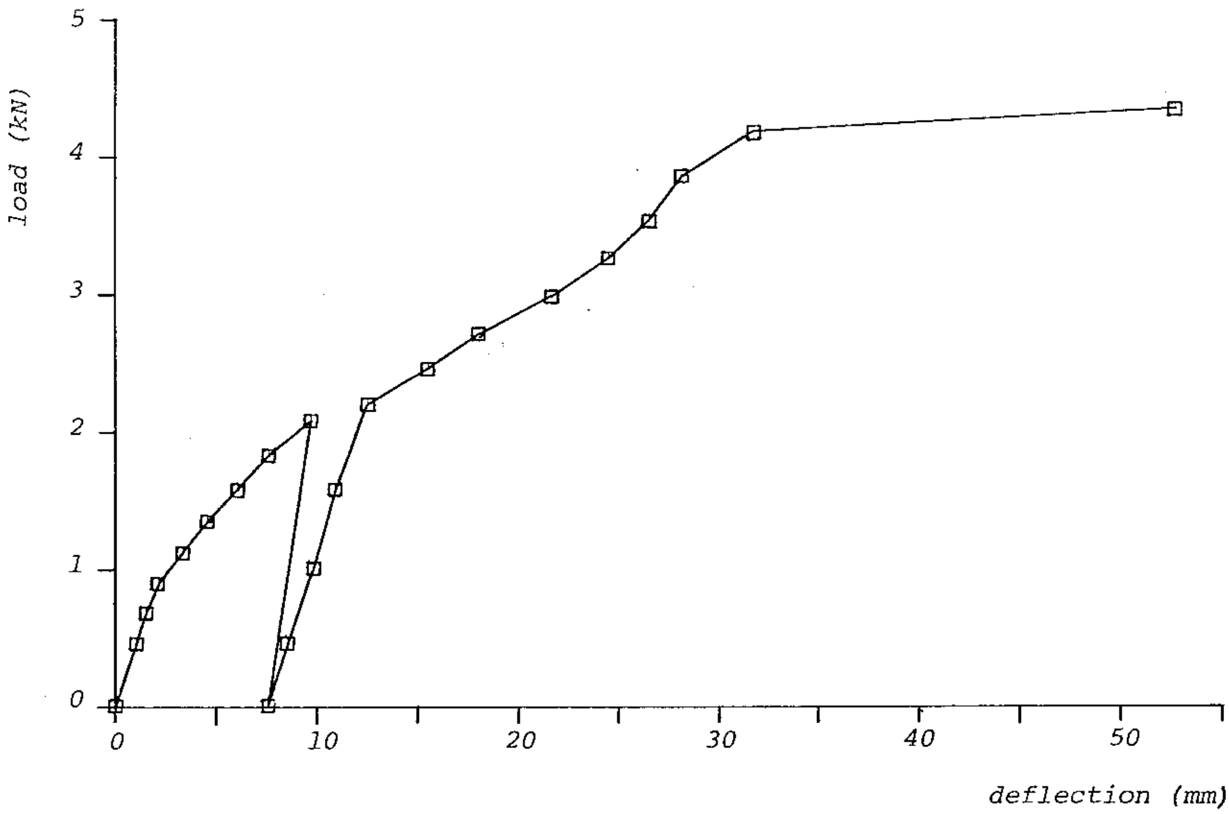


Figure A.13 Load - Deflection Curve Test 9

was a relative displacement between the end channel and the joist member of approximately 35 mm. The entire cladding rotated as a single unit.

A.7 TEST 10

A.7 .1 Test Panel

Two 2700 x 1200 x 10 mm 'Gyprock' sheets were fastened perpendicular to the timber battens.

The panel geometry, the type of screw and the screw spacing along the timber battens for this test were identical to test number 8 (figure A.10). However, nogging between the battens was introduced along the sides of the plaster board panel (figure A.14). The nogging was of the same material as the battens and skew nailed with two 50 x 2.8 mm plain nails at each end. The joint and the screw depressions were cemented using the previously detailed method. The gap between the cladding and the top plate was not filled.

A.7 .2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to a load of 2.3 kN, unloaded, and then reloaded in slightly larger increments to failure.

A. 7 .3 Test Results

The panel failed at a load of 5.3 kN as a result of fasteners pulling through the cladding. The observed load - deflection behaviour of the panel is shown in figure A.15.

The entire cladding rotated as a single unit. There was negligible relative displacement between the timber battens and the ceiling joists.

A. 8 TEST 11

A. 8 .1 Test Panel

In this test two 2400 x 1350 x 10 mm 'Gyprock' sheets were screwed and glued directly onto the ceiling joist (figure A.16).

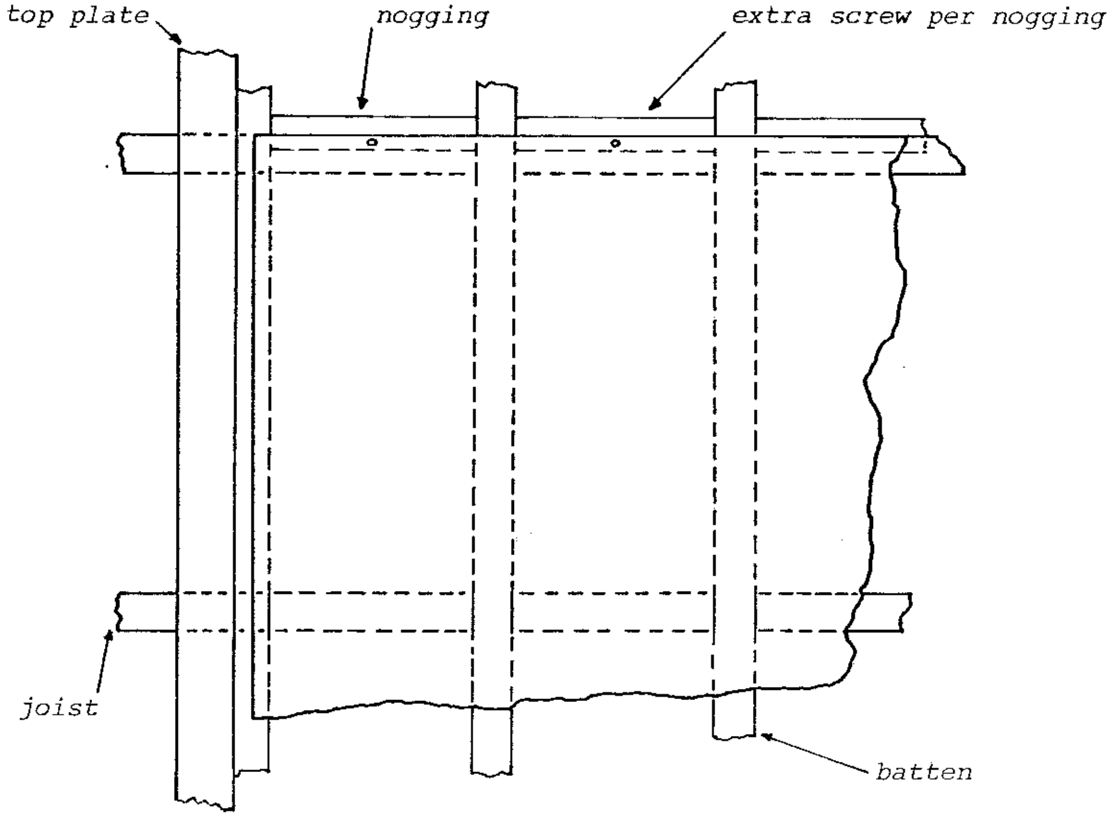


Figure A.14 Detail of Test Panel 10

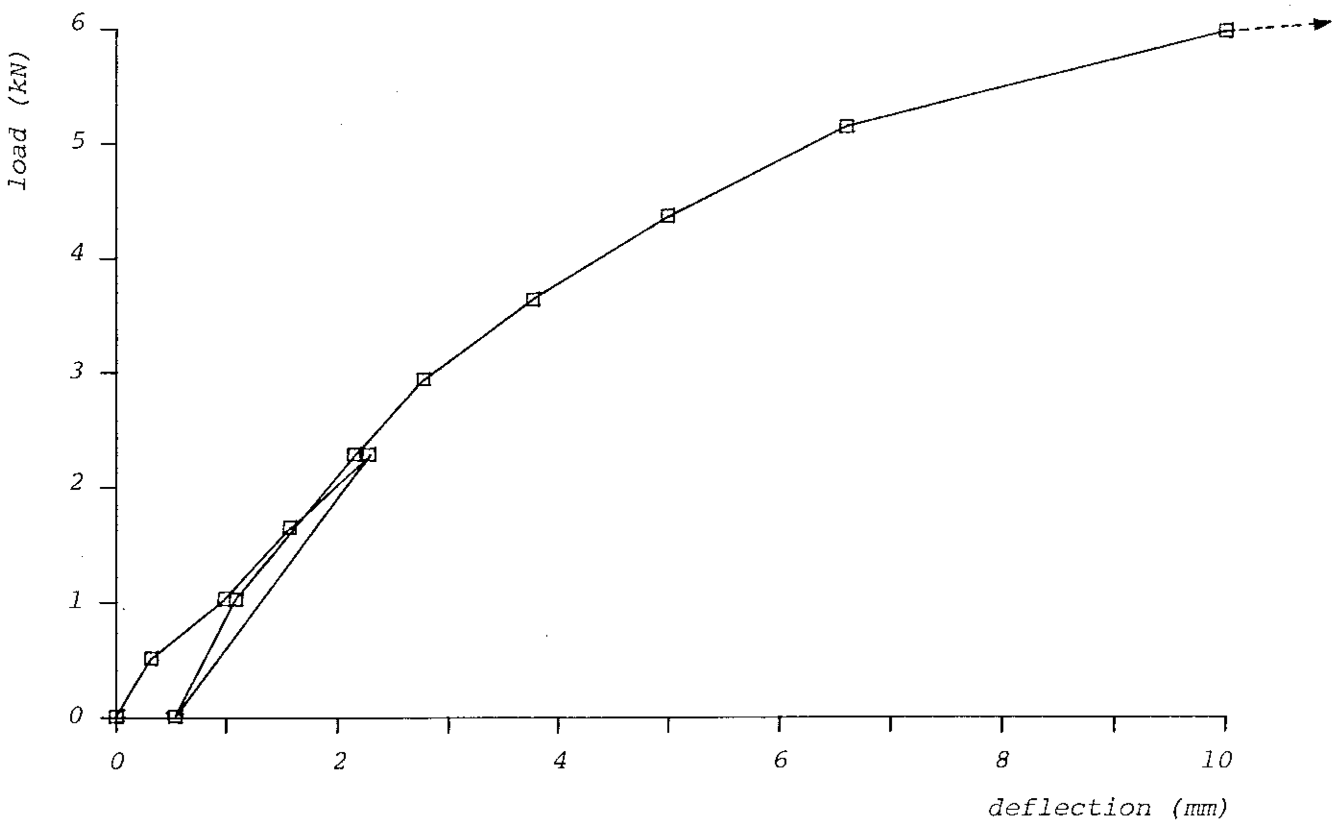


Figure A.15 Load - Deflection Curve Test 10

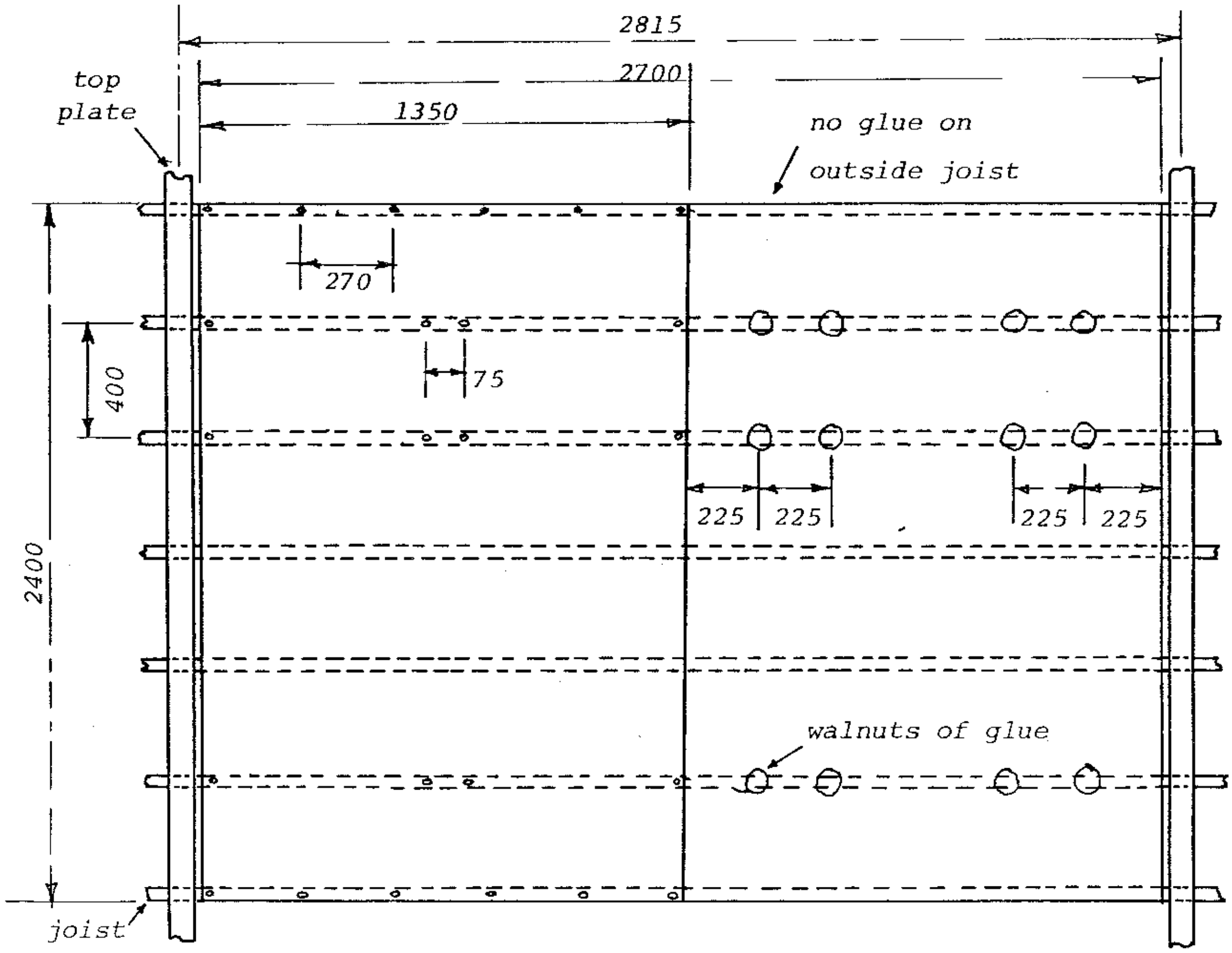


Figure A.16 Test Panel 11

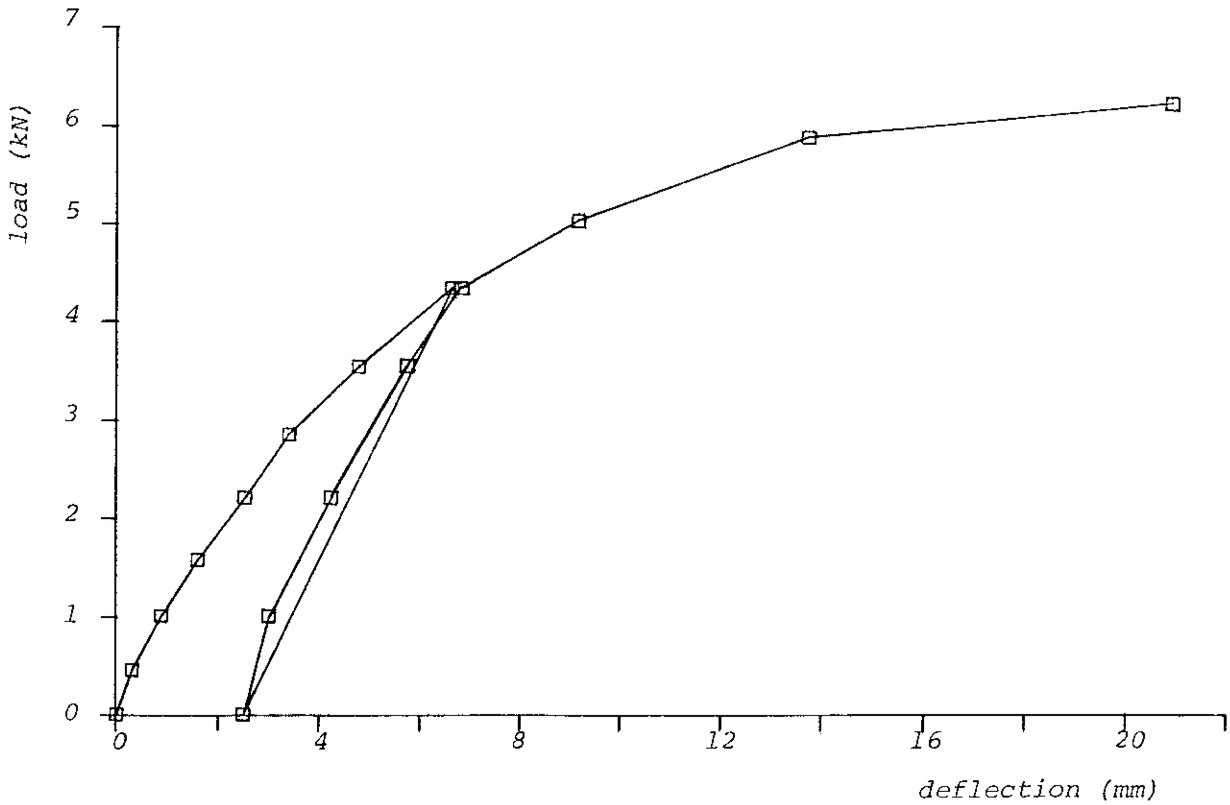


Figure A.17 Load - Deflection Curve Test 11

The panel geometry for this test was as follows:

distance between top plates	2815 mm
spacing of ceiling joists	400 mm

'CSR Stud Adhesive' was used and left to dry for four days after construction. The pattern for gluing and screwing is shown in figure A.16. The fasteners were Gypsum 8.18 x 25 mm Hi-Lo Type S power driven screws. The joint and the screw depressions were cemented using the previously detailed method.

A. 8 .2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to a load of 4.35 kN, unloaded, and then reloaded in slightly larger load increments to failure.

A. 8 .3 Test Results

The observed load - deflection behaviour is shown in figure A.17. The panel failed at a load of 6.2 kN due to a combination of the fasteners pulling through the cladding and of the glue failing at the plaster board surface. The entire cladding rotated as a single unit.

A. 9 TEST 12

A. 9 .1 Test Panel

Two 2700 x 1200 x 10 mm 'Gyprock' sheets were placed across the steel battens manufactured and supplied by Lysaght Brownbuilt Industries. The panel geometry and the screw spacing along the steel battens for this test were identical to test number 8 (figure A.10). The sheets were fastened perpendicular to the steel battens by 'Gypsum 6.2 x 25 mm Bugle Head Tek' power driven screws. The fixing of the steel battens to the ceiling joists is illustrated in figure A.18. The gap between the cladding and the top plate was not filled with plaster cement.

A. 9 .2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to a load of

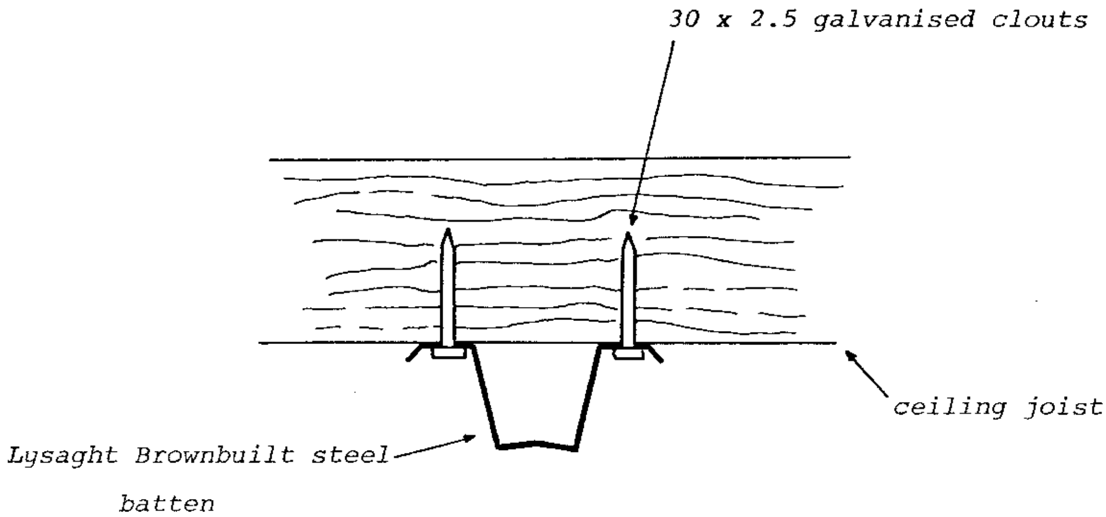


Figure A.18 Fixing of Steel Battens

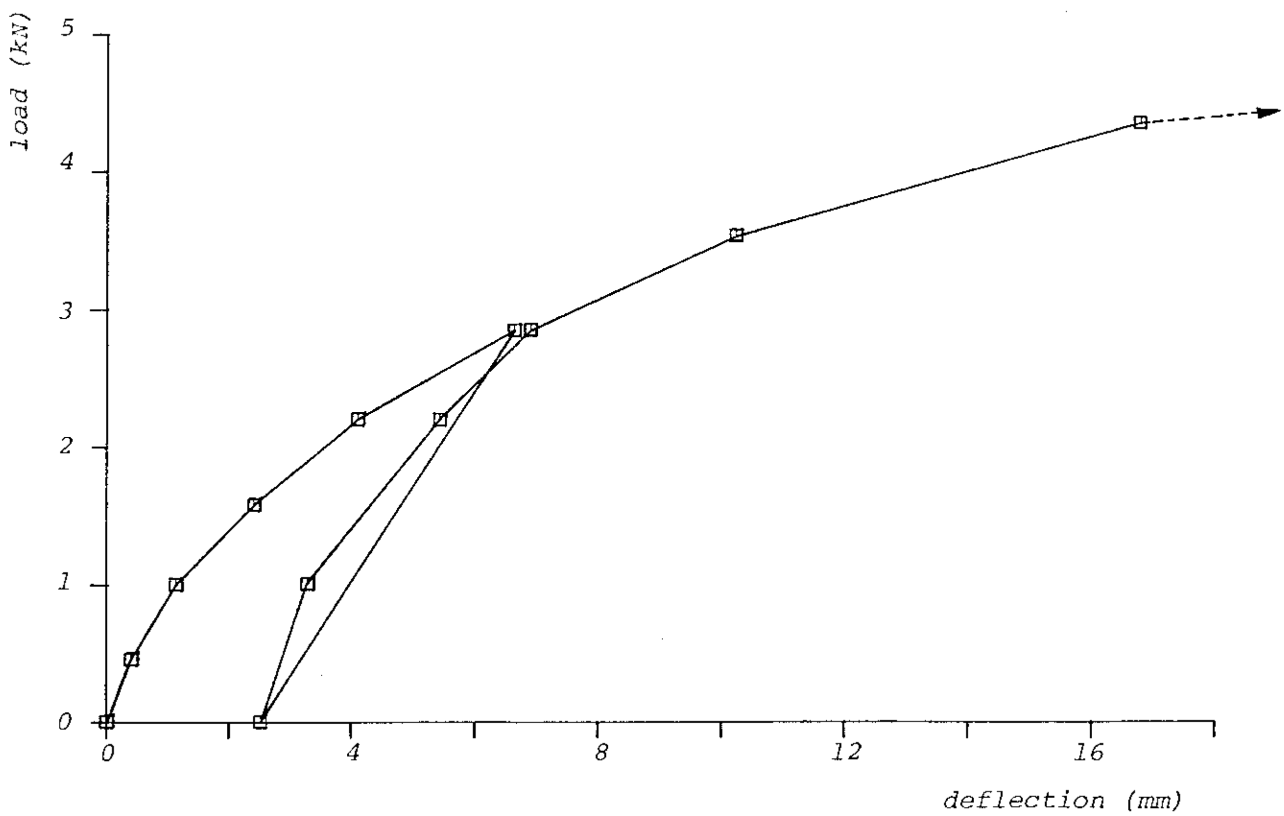


Figure A.19 Load Deflection Curve Test 12

2.8 kN, unloaded, and then relaoded in slightly larger load increments to failure.

A. 9 .3 Test Results

The panel failed at a load of 4.5 kN as a result of the fasteners pulling through the cladding. The observed load - deflection behaviour is shown in figure A.19. The end battens showed no displacement relative to the ceiling joist. The entire cladding rotated as a single unit. It was observed that the fasteners on the battens most distant from the loading point were inclined downwards while those closest to the loading point were inclined upwards. The inclination of the fasteners corresponded to the direction of rotation of the cladding.

A.10 TEST 13

A.10.1 Test Panel

The panel geometry for this test was as follows:

distance between top plates	2815 mm
spacing of ceiling joists	400 mm

The cladding was screwed directly onto the ceiling joists. The cladding consisted of two 2400 x 1350 x 10 mm 'Gyprock' sheets. The sheets were fixed perpendicular to the ceiling joists and were fastened to the joists by 'Gypsum 8.18 x 30 mm Hi-Lo Type S' power driven screws at 270 mm spacing along each joist (figure A.20). The recessed joint and the screw head depressions were cemented by the previously detailed method. Panel 4 was similar to this panel except that the cladding consisted of three 2400 x 900 x 10 mm 'Gyprock' sheets however the areas covered by each panel were the same.

A.10.2 Loading Pattern

The panel was loaded in increments of approximately 0.5 kN up to load of 2.9 kN, unloaded and then reloaded in slightly larger load increments to failure.

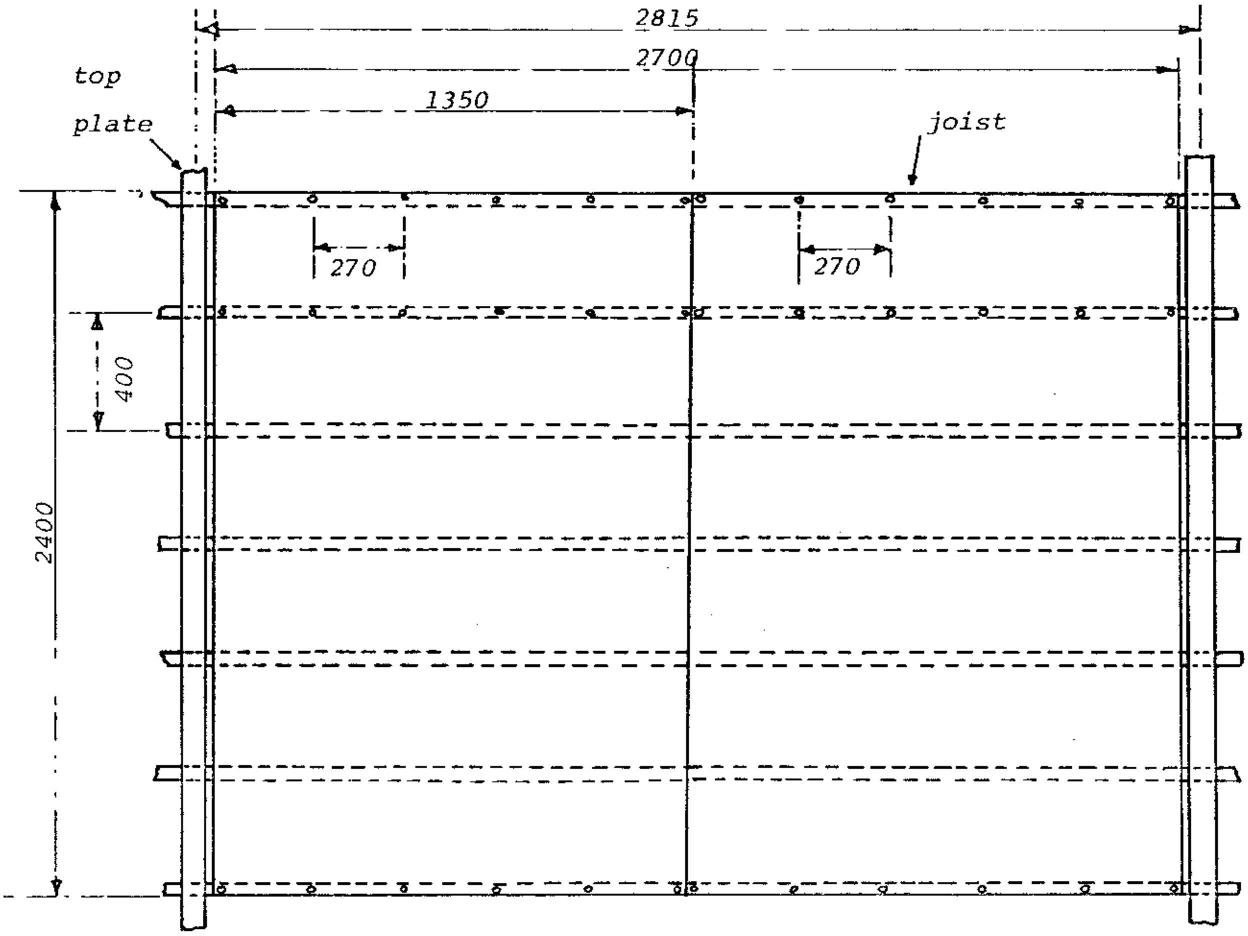


Figure A.20 Test Panels 13 and 14

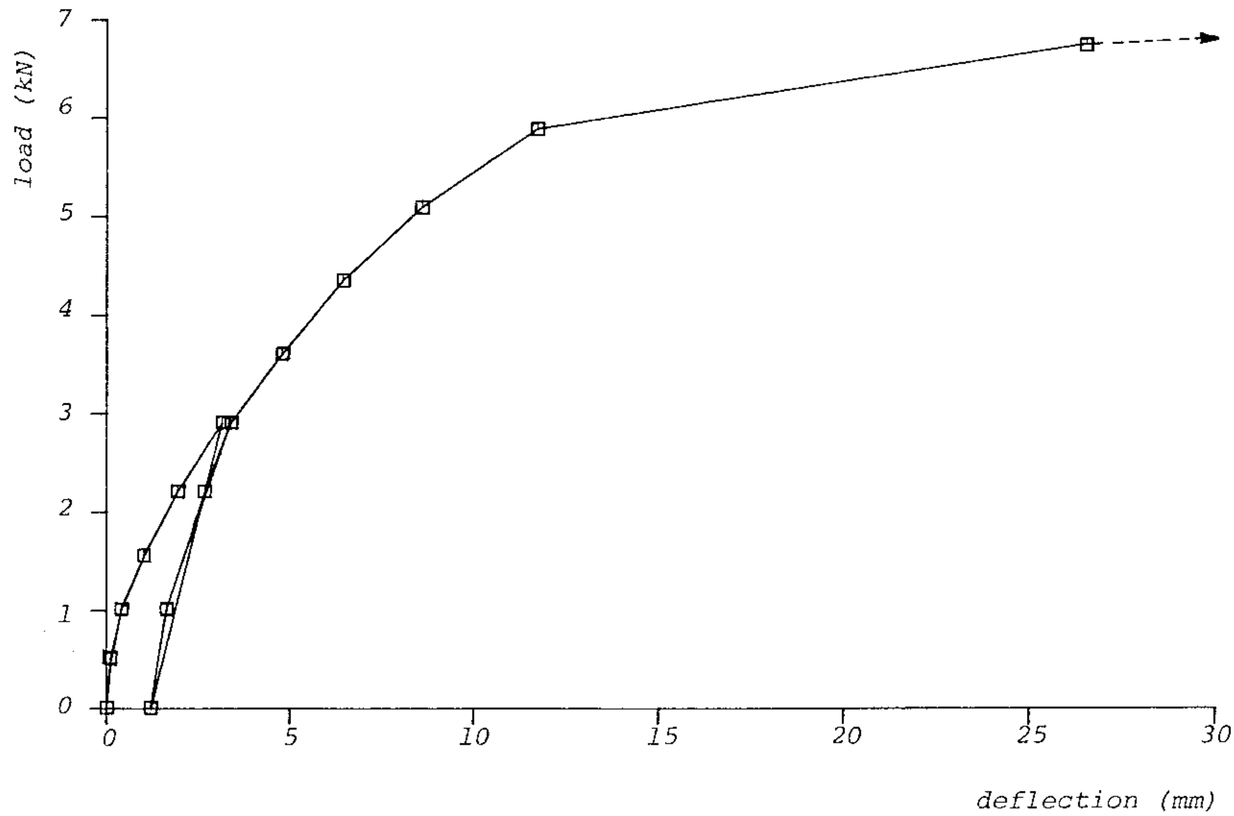


Figure A.21 Load - Deflection Curve Test 13

A.10.3 Test Results

The panel failed at a load of 6.75 kN as a result of the fasteners pulling through the cladding. The observed load - deflection behaviour of the panel is shown in figure A.21. The entire cladding rotated as a single unit.

A.11 TEST 14

A.11.1 Test Panel

Test panel 14 was identical to the panel used in Test 13 (figure A.20).

A.11.2 Loading Pattern

The panel was loaded in increments of approximately 0.5 kN up to a load of 2.2 kN, unloaded, and then reloaded to failure in slightly larger load increments.

A.11.3 Test Results

The observed load - deflection behaviour of the panel is shown in figure A.22. Failure occurred at a load of 5.1 kN as a result of fasteners pulling through the cladding. The cladding rotated as a single unit with the recessed joint showing no distress.

A.12 TEST 15

A.12.1 Test Panel

Two 2700 x 1200 x 10 mm 'Gyprock' sheets were fastened perpendicular to timber battens. The panel geometry, the type of screws and the fastener spacing along the battens for this test were the same as test number 8 (figure A.10). The sheets were plastered by the conventional method. The geometry and materials used in the panel were identical to those used in Test 2, however the support stiffness in this configuration was higher.

A.12.2 Loading Pattern

The panel was loaded in increments of approximately 0.6 kN up to a load of

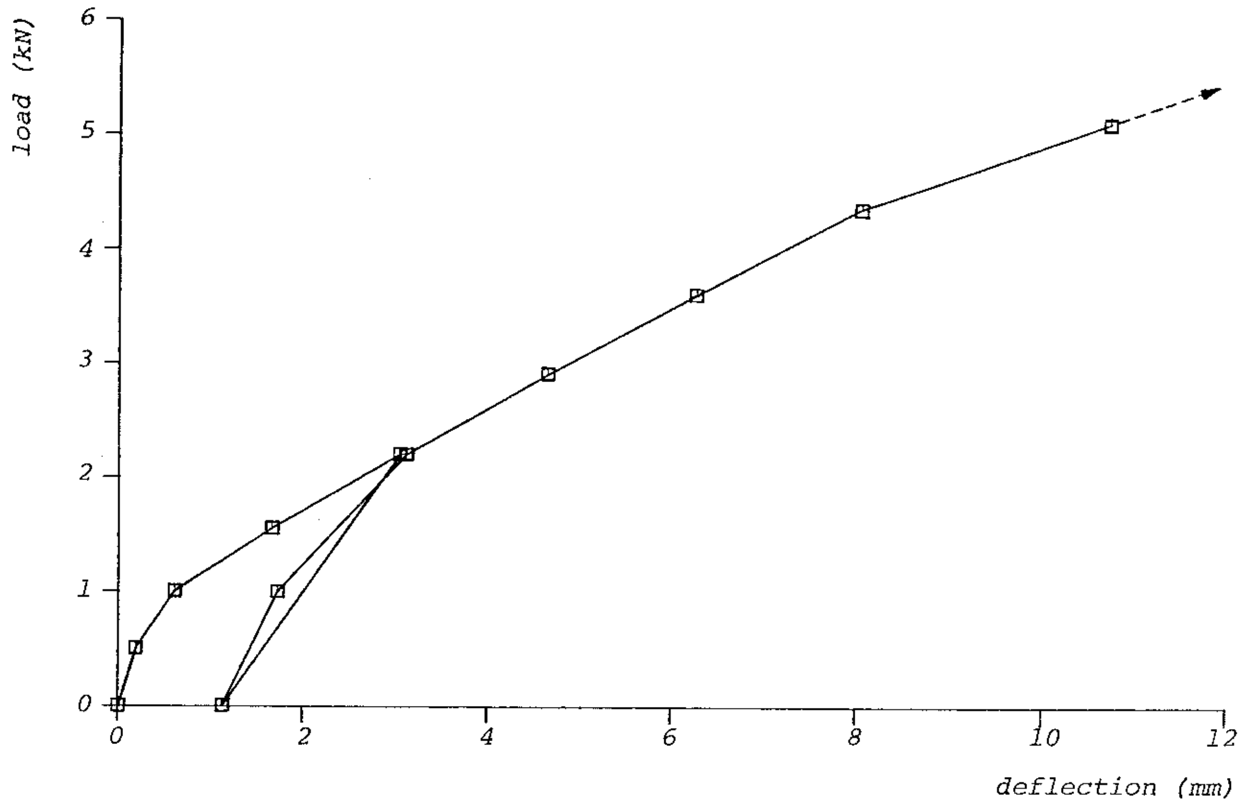


Figure A.22 Load - Deflection Curve Test 14

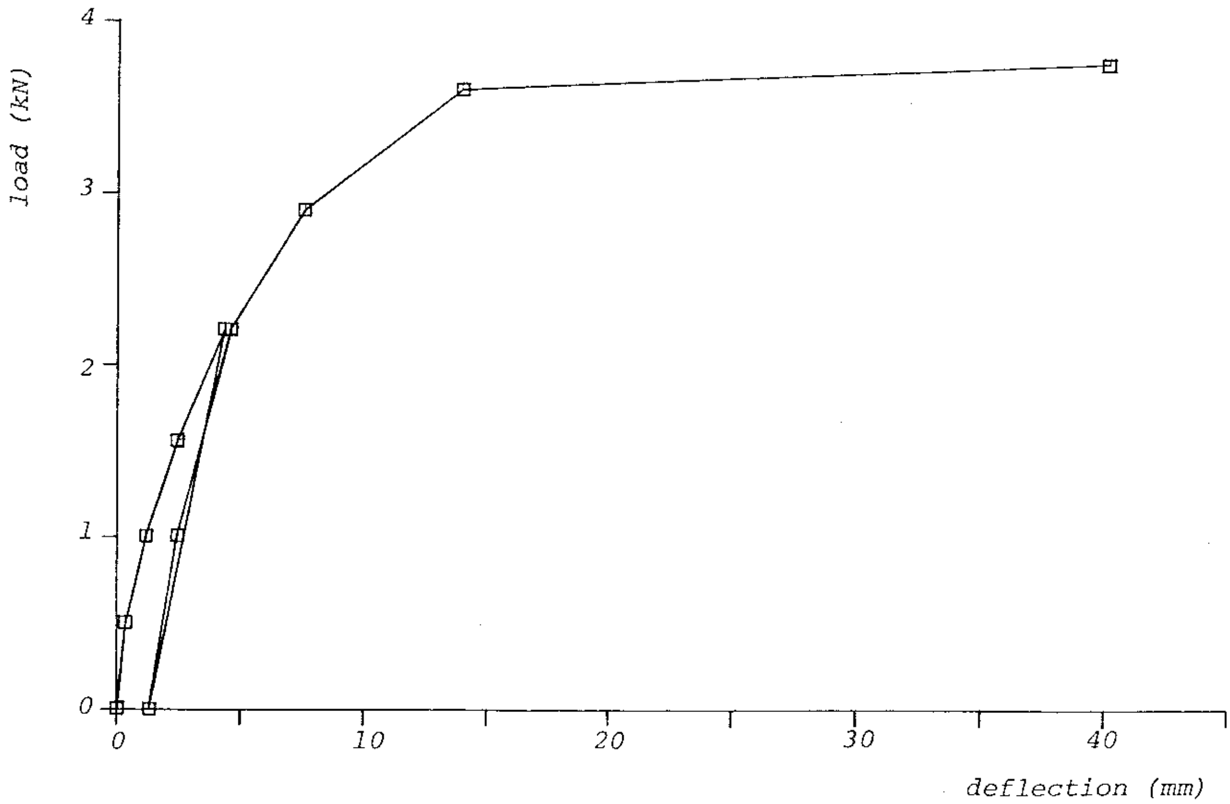


Figure A.23 Load - Deflection Curve Test 15

2.2 kN, unloaded and then reloaded to failure.

A.12.3 Test Results

The panel failed at a load of 3.75 kN as a result of fasteners pulling through the cladding. The observed load - deflection curve is shown in figure A.23. The entire cladding rotated as a single unit. There was no relative displacement between the timber battens and the ceiling joists.