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THE END RESTRAINT OF TIMBER FRAMED PANELS IN WALL BRACING TESTS

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PREFACE

This report on a project carried out at the Judgeford research station of the Building Research Association of New Zealand, describes the development and testing of an improved end restraint detail to be incorporated in the standard wall racking test procedure as described in BRANZ Technical Paper P21.

ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance of R.C.Cooney and A.B.King of the BRANZ Fire and Structural Engineering Group. Thanks are also extended to T.P.Neal, formerly on the Association's staff, for his early work on the project.

This report is intended for research workers and testing organisations concerned with the racking performance of timber framed wall bracing panels.

THE END RESTRAINT OF TIMBER FRAMED PANELS IN WALL BRACING TESTS

BRANZ Study Report SR2

J.T.Gerlich

REFERENCE

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KEYWORDS

From Construction Industry Thesaurus - BRANZ edition: Bracing; Cyclic; Earthquake loads; Frames; Gypsum plasterboard; Loads; New Zealand; Panels; Plywood; Racking forces; Restraining; Testing; Test procedures; Timber; Uplift; Walls; Windloads.

ABSTRACT

Building Research Association of New Zealand (BRANZ) Technical Paper P21 'A wall bracing test and evaluation procedure' describes a test method which was developed primarily for use with New Zealand Standard NZS 3604 'Code of Practice for light timber frame buildings not requiring specific design'.

The test is controlled by monitoring the in-plane horizontal deflection at the top of the specimen as load is applied there. Panel rotation due to lifting of the panel ends can contribute a large proportion to this horizontal movement. Boundary conditions in practice offer vertical restraint to a wall bracing panel. Many alternative methods of representing actual end restraint in a laboratory test situation have been proposed both within New Zealand and overseas.

The current (1982) P21 paper models 'in service' uplift restraint by adding two studs at each panel end. This detail relies on nails loaded in withdrawal, providing minimal restraint, and its performance under cyclic loading has proved unsatisfactory.

This report proposes a restraint detail based on actual connections with nails loaded in shear. Comparative testing was carried out. Uplift of the panel ends, using the new detail, was reduced to approximately one third that recorded with the current P21 detail. For test panels lined with 7.5mm plywood the racking resistance improved by an average of 30 per cent. For test panels lined with 9.5mm paper-faced gypsum plaster board, panel stiffness improved but was offset by earlier failure of sheet to frame fixings.

CONTENTS

FIGURES

INTRODUCTION

The P21 Test Method

The most common test method used in New Zealand for determining the performance of wall bracing panels when subjected to in-plane horizontal racking loads is described in Building Research Association of New Zealand Technical Paper P21 (Cooney and Collins, 1982). The procedure determines a rating in terms of "bracing units" which may be used to satisfy the provisions of NZS 3604: 1981 'Code of practice for light timber frame buildings not requiring specific design.' It also enables the determination of permissible design loads for a particular construction which may be used in engineering design to resist lateral loads as outlined in NZS 4203: 1984 'Code of practice for general structural design and design loadings for buildings', since 100 bracing units equates to a working stress design load of 5kN.

The wall bracing panel under test is cyclically loaded through the top plate with 1 mm incremental deflections until a limiting deflection, X (H/300 or 8 mm for most timber framed panels), has been attained in each direction. Alternatively a load limit may be used as the control and the coincidental deflection assigned the value X. Ductility is checked by cyclically loading the specimen to 5X displacement. Degradation of load carrying ability is assessed over four cycles at this displacement.

On the basis of loads achieved at the limiting deflection X, the panel's performance in terms of bracing units is calculated. Reduction factors may have to be applied depending on symmetry of performance, recovery after loading, resistance to repeated loading and ultimate loads achieved. Alternatively, the panel can be rated at lower deflection limits.

Non-loadbearing walls can, within NZS 3604, be designated as bracing panels. The P21 paper mentions wind uplift as a possible critical load case in conjunction with racking loads. Because of the low probability of its occurrence simultaneously over all panels, no specific adjustments are required in the test situation. Gravity loads may be applied to the specimen in a situation where a wall carries a permanent dead load.

Representing Boundary Conditions

The laboratory test is controlled by monitoring the in-plane horizontal deflection at the top plate of the panel where the load is applied. This deflection is the result of several actions within the specimen. These are: panel flexure, panel shear, panel rotation as a result of perimeter nail slip, and base slip and rotation of the panel as a result of uplift at the panel ends. The first three actions are functions of the type of panel being tested and not affected by laboratory test conditions. Base slip and uplift are related to the boundary conditions in practice and considerable care is required in translating these conditions to the test situation. Base fixity and slip are generally easy to simulate and control. Accurate modelling of uplift restraint has proved more difficult.

Uplift due to flexibility in the attachment of the stud to the bottom plate and the bottom plate to the floor can, through panel rotation, contribute a major part to the racking deflection. Thus the amount of vertical restraint applied to the end of the specimen is of considerable importance when rating the panel.

The current P21 paper states that "representative vertical restraint" shall be provided. An example is illustrated using two additional studs at the ends of the panel, nailed through extended top and bottom plates into the end grain of the studs. Although this detail provides some additional restraint, it is often used out of context and its performance as a representation of actual boundary restraint has proved unsatisfactory (Cooney, 1981). The low capacity of the extra nails into end grain often results in excessive lifting of the test panel affecting stiffness and hence rating. The brittle mode of failure, common for nails loaded in withdrawal, affects the panel's performance under repeated cyclic loading.

In practice a bracing panel may be located anywhere within a structure. Vertical restraint will be provided by fixings to walls at right angles, roof trusses, ceiling framing members or upper storey joists. When a wall bracing panel is part of a longer wall, effective end restraint will be provided by the fixings of claddings and/or sheet linings, covering the continued wall, to the panel end stud. A wall bracing panel in a light timber frame building is never isolated and as construction proceeds around it, the restraint and thus the panel stiffness increases as was demonstrated by Tuomi and McCutcheon (1974).

When a bracing panel is subject to in-plane lateral loading, fixings to the surrounding structure will share load depending on their relative stiffness and hence resist panel rotation. Effective and progressive restraint is thus provided. This principle of load sharing, which occurs in timber framed buildings in practice, will result in elastic and ductile load-deflection characteristic of the restraint imposed by the surrounding structure.

The variability of building designs with respect to location of walls and openings, number of storeys, type and weight of the roof structure etc., will result in a great number of possible uplift restraint details. Full scale house testing is expensive and it is not practicable to test a full range of restraint types in a large number of building configurations. The way that load is commonly applied in such tests, as a line load at eaves level, may also not adequately highlight the uplift of wall bracing panels. It is desirable to test wall bracing panels with a restraint detail which is based on actual fixings and is, to a fair degree, representative of a realistic minimum restraint expected in practice.

The vertical restraint detail proposed in this report is based on the common wall junction detail which uses a minimum of three 100 x 3.75mm nails loaded in shear. The wall to which the bracing panel is connected is assumed to be restrained from lifting at loads below the capacity of these three nails in shear. To simplify the test set-up and to simulate a realistic minimum, additional restraint provided by ceiling framing members, upper storey joists etc, is ignored. The improved capacity of the proposed vertical restraint detail, its simulation of actual connections, combined with the ductile performance, is considered to more closely represent the effect of boundary conditions in practice on the performance of bracing panels.

OVERSEAS PRACTICE

United States

In the United States the most common wall bracing test used is described in ASTM E72-80:'Conducting strength tests of panels for building construction.' In this test complete end restraint is provided by the use of a pair of steel hold-down rods with a steel roller across the top plate. The test gives a good comparison between sheet materials, but it is difficult, if not impossible, to relate the test performance to expected performance in service.

Yancey (1976) investigated alternative test methods. The importance of end restraint was not overlooked and a number of alternatives have been studied including straps, hinges and a steel cable (Forest Products Laboratory, 1982). How closely these types of restraints represent boundary conditions in service is perhaps open to question. The ASTM E72 test method is unidirectional in loading and thus does not assess the performance of the specimen under repeated cyclic loading, nor does it consider ductility.

United Kingdom

The Building Research Establishment (BRE) researched a more comprehensive test method than ASTM E72 for inclusion in a British Standards Institution Code of Practice dealing with the structural design of timber walls (Building Research Establishment, 1984). End restraint is covered by the requirement that "...test panels should be installed in the test rig and fixed to the base by methods which simulate as closely as possible the fixings which will be used in service. Where the method of holding down the panel is not known at the time of test the fixings at the base should be such that no uplift or horizontal movement of the bottom plate is possible..." The BRE test specifies holding down the bottom plate but does not address the movement between stud and plate. No guidance is offered as to a test restraint detail which simulates in-service conditions.

Australia

The Australian wall racking test in most common use is the one described in Cyclone Testing Station Technical Report No.5: "Recommendations for the testing of roofs and walls to resist high wind forces."(Reardon, 1980). There are no specific requirements with regard to vertical end restraint other than that the panel be fixed "... in the same manner as would be used in practice ...". Anchor rods are commonly used in cyclone areas and are incorporated in wall racking tests. These provide a very effective end restraint and are consistent with local construction techniques.

EXPERIMENTAL WORK

Prototype Testing

The characteristics of the current P21 restraint detail which relies on nails loaded in withdrawal is not considered to be representative of in-service conditions. A new restraint detail was developed based on the common wall junction details with nails acting in shear (Figure 1).

A prototype detail comprised a 400mm long block of 100 x 50mm timber nailed to the end studs of the test panel using three 100 x 3.75mm nails. The block is held down firmly by tie rods through a steel capping plate (Figure 2).

The prototype detail was initially incorporated in a series of tests to P21 specification performed by Winstone Wallboards Ltd., the New Zealand manufacturer of paper-faced gypsum plaster board (trade name, Gibraltar board), in their Auckland laboratory. The restraint detail was effective during the early stages of the tests but as the displacement increased, a gap opened between the panel stud and the block. The nails driven through the block withdrew from the panel end stud (Figure 3). This behaviour is not expected to occur in this manner in service.

The prototype was subsequently modified by substituting a steel angle section for the steel capping plate (Figure 4). The horizontal leg is nailed through 4mm diameter holes into the end grain of the timber block using two 100 x 3.75mm nails. The vertical leg of this angle is bolted, finger tight (using a 12mm diameter bolt), through a slotted hole in the angle to the end stud of the specimen. This allows vertical movement of the stud but prevents separation between stud and block. A full specification is given in Figure 5.

Small scale cyclic testing was carried out on two samples of the prototype and the results compared with those from similar tests on the modified detail.

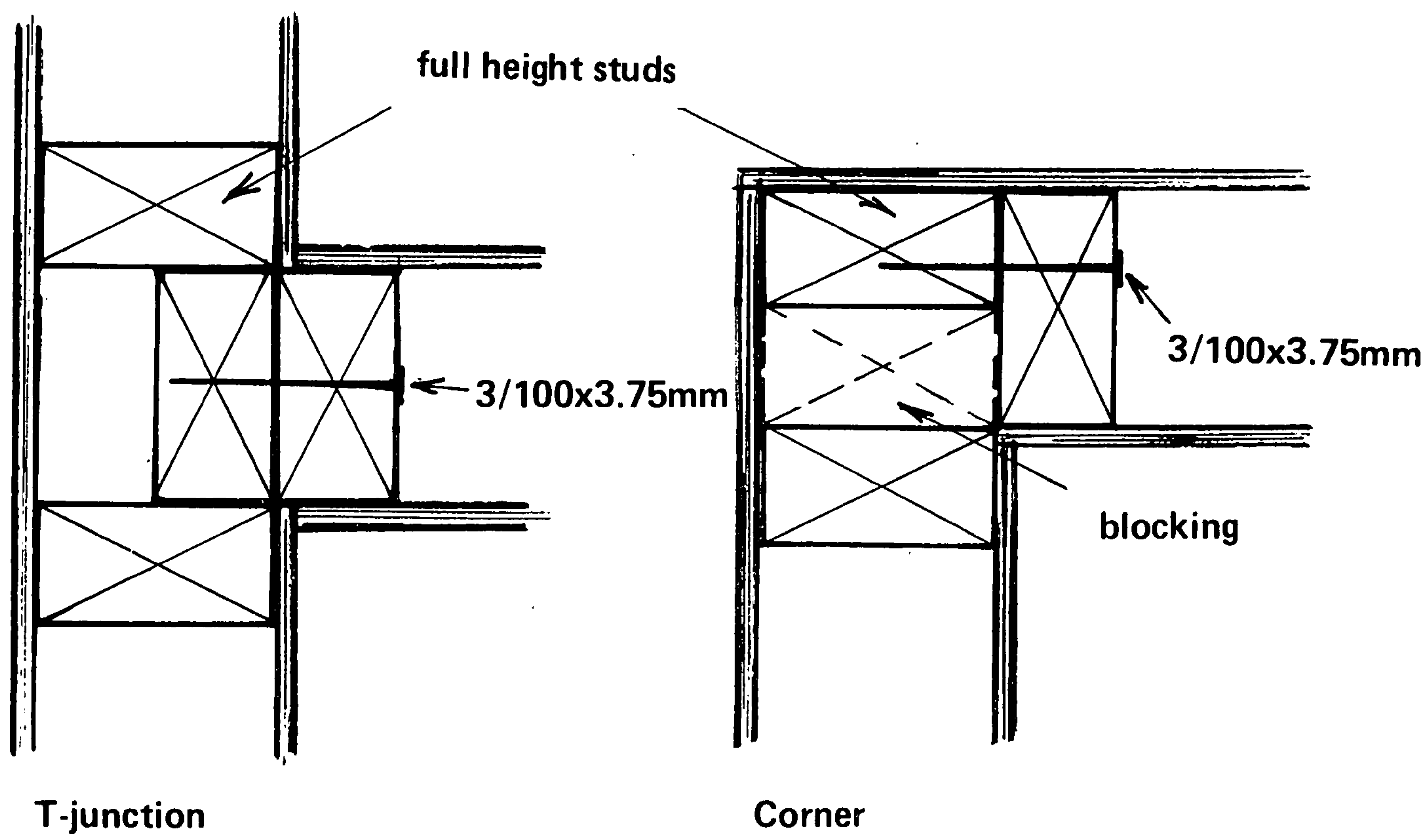

Figure 1: Common wall junction details

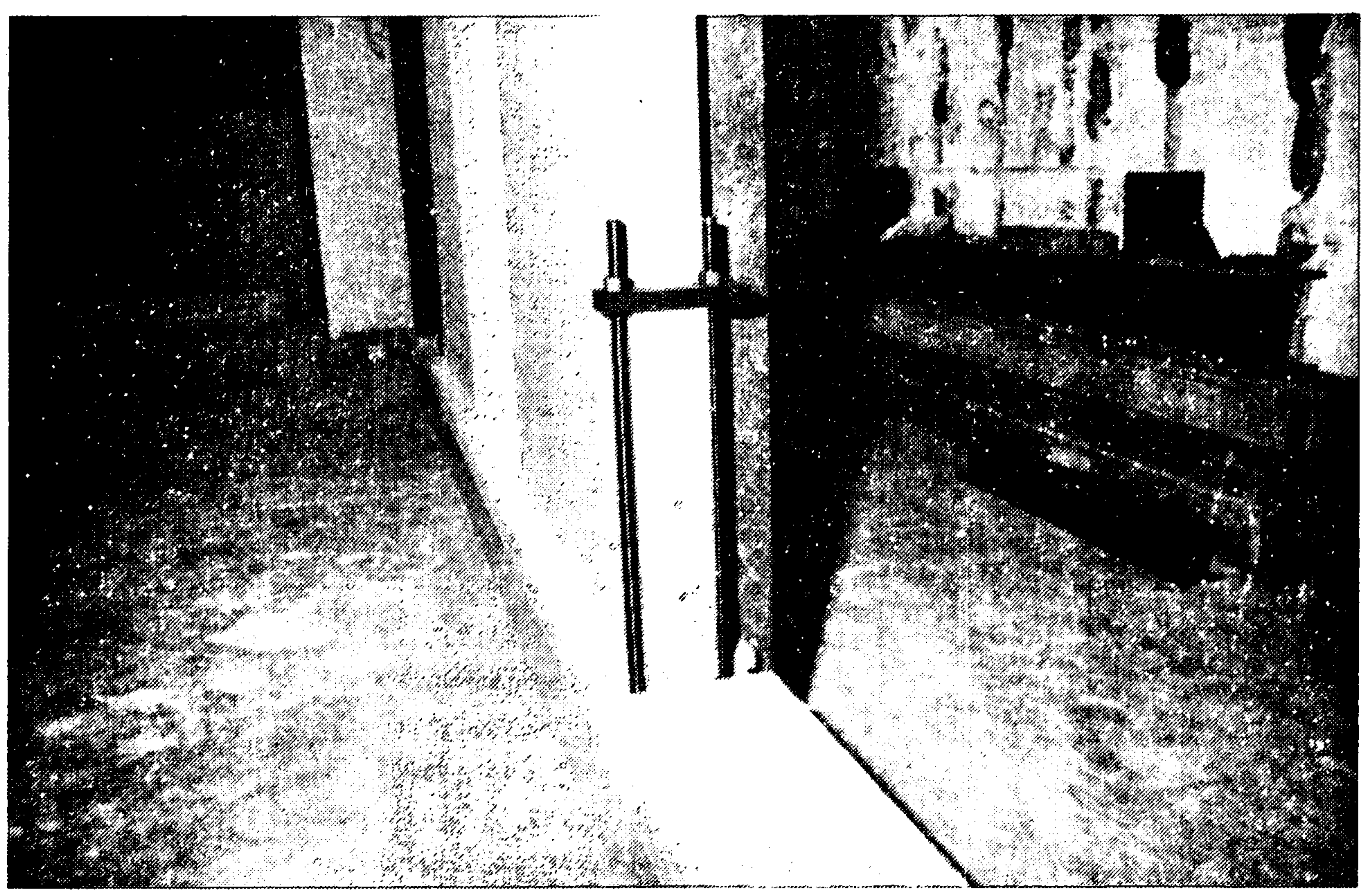

Figure 2: The prototype detail

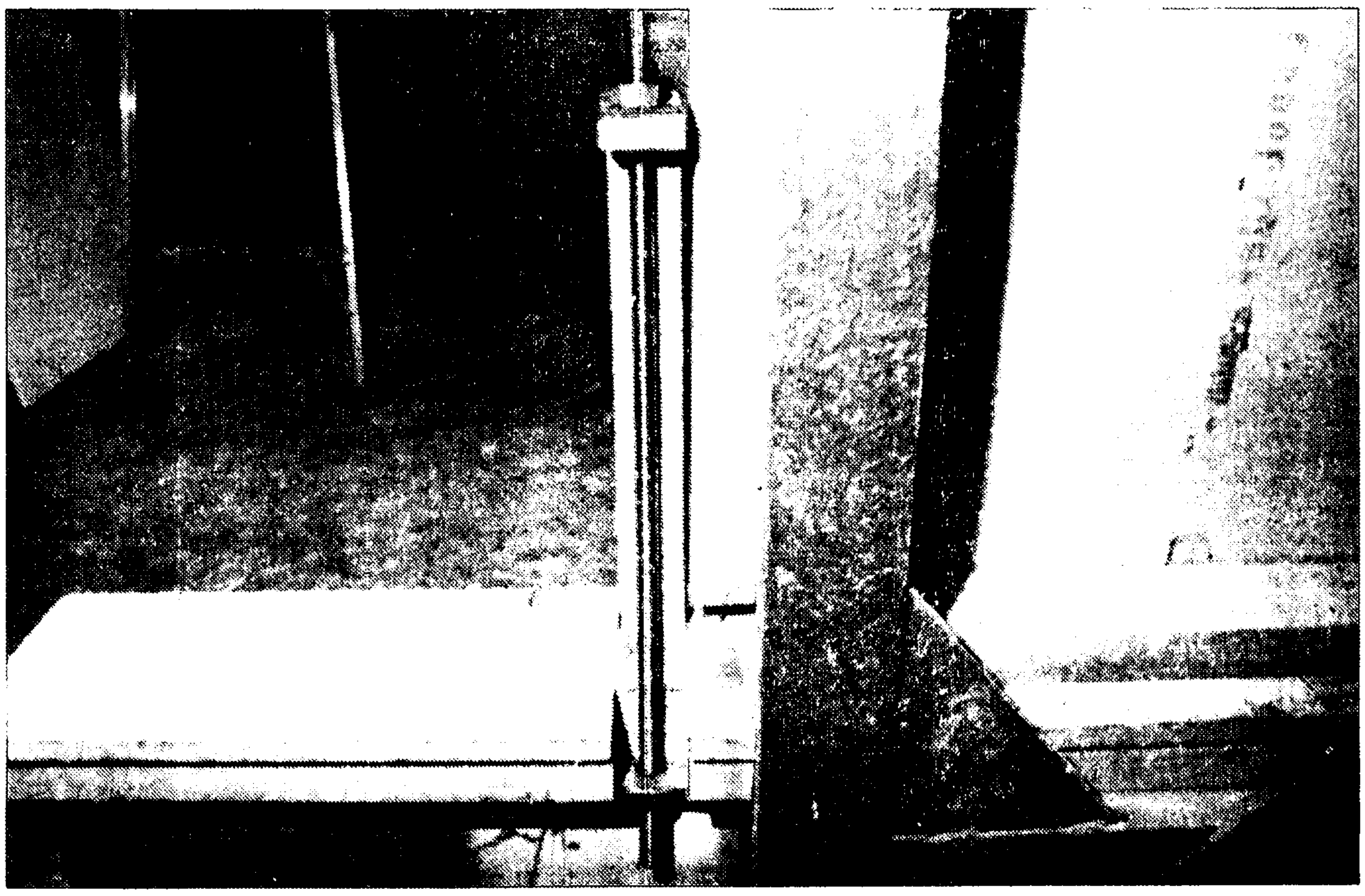

Figure 3: Separation between the panel stud and the block

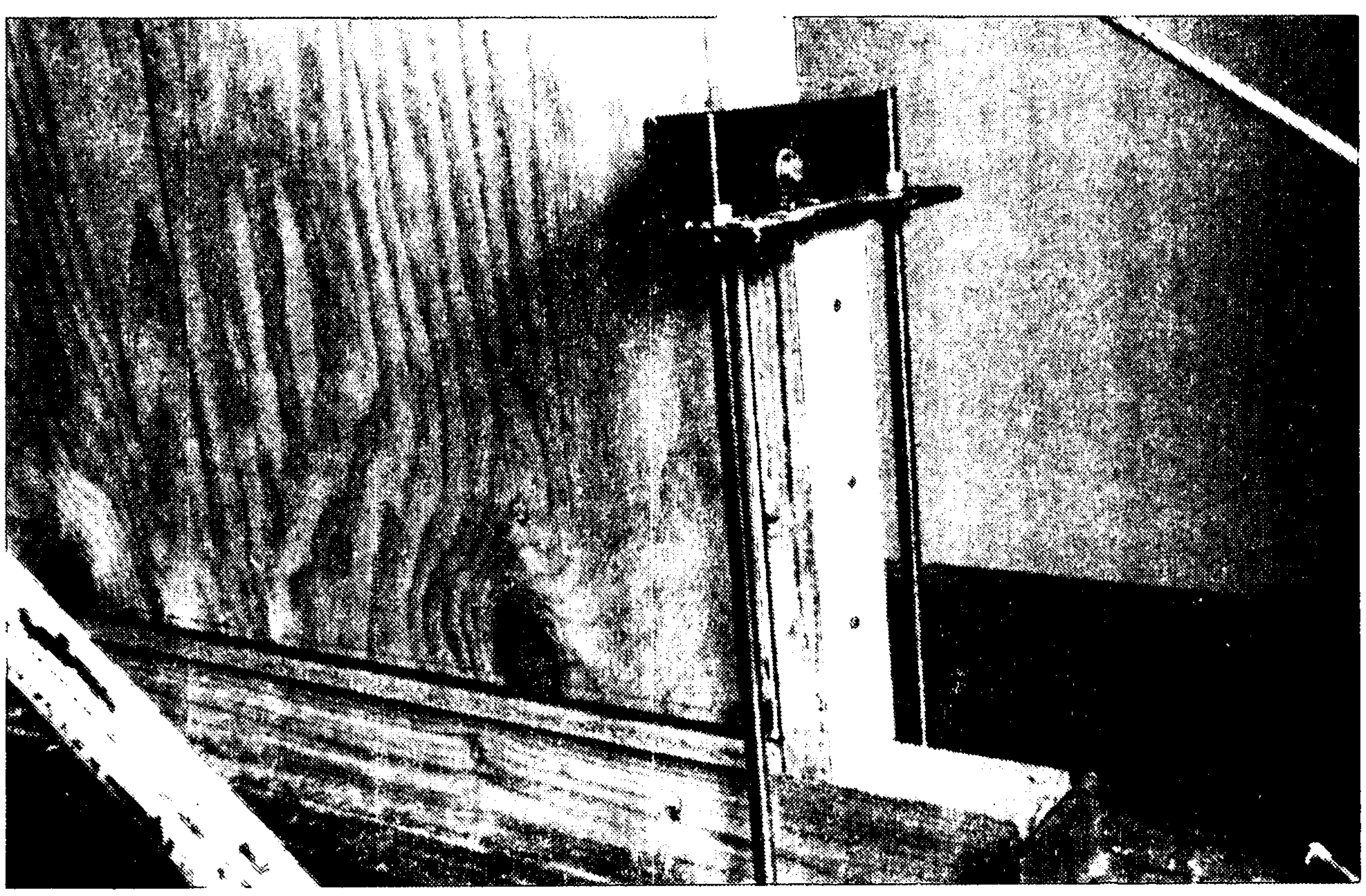

Figure 4: The proposed restraint detail

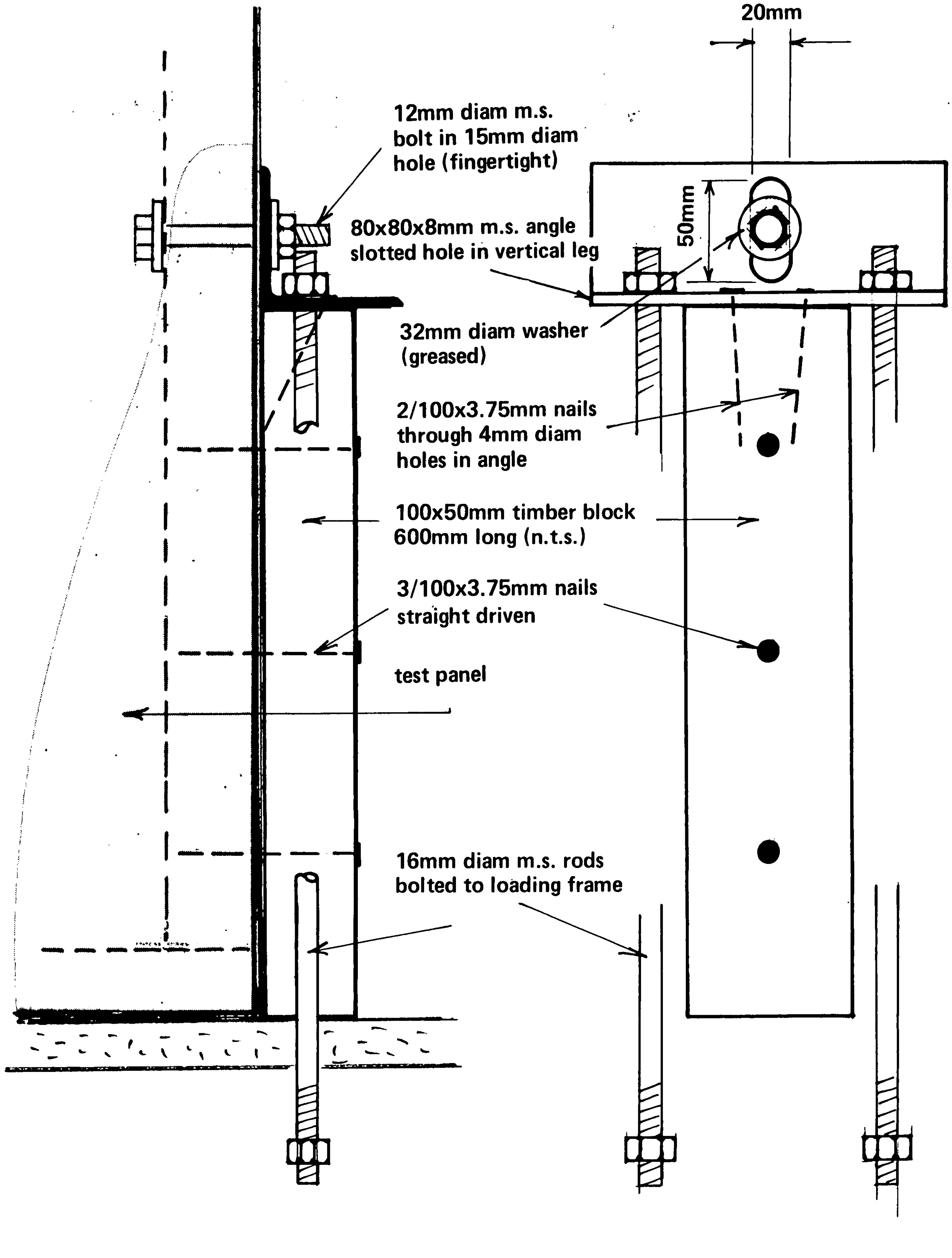

Figure 5: Specification for the proposed detail

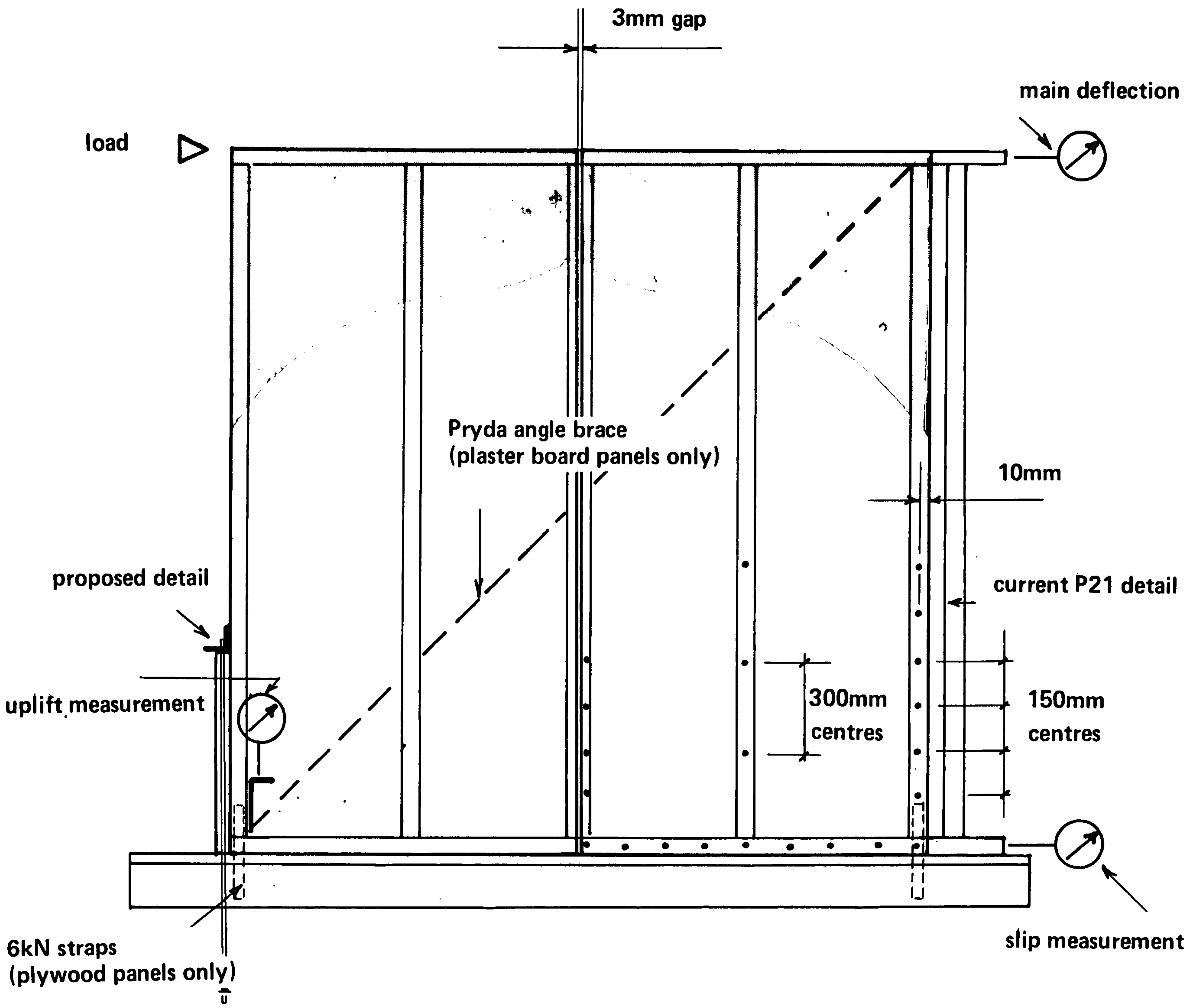

Figure 6: Wall bracing test set-up and specimen

The small scale specimens consisted of two 600mm long 100 x 50mm timber blocks, lapped 400mm and nailed together using three 100mm x 3.75mm nails. A tensile load was applied in line with the joint between the blocks. The specimens were subjected to four 20mm displacement cycles. The average load achieved at 20mm was 6.0kN in the first cycle degrading to 4.7kN in the fourth cycle. A second set of specimens was prepared using the metal angles at each free end. The loads achieved were 6.2kN and 5.6kN respectively. Separation of the blocks was observed for the prototype tests and prevented using the steel angles in the modified detail.

Wall Racking Tests

The test programme was designed to compare the performance of the two types of end restraint when incorporated in full scale racking tests. A comparison was made of the uplift as a percentage of the main deflection, observed panel performance and obtained ratings. Tests were carried out on both paper-faced plaster board and plywood panels. Construction details of all panels were generally in accordance with NZS 3604.

Test Arrangement

All tests were performed generally in accordance with the test procedure described in BRANZ Technical Paper P21. Deflection limits of 8 mm and 40 mm were selected for, respectively, the first and second stages of cyclic testing, since the panels were 2.4m high.

All tests were performed in a rigid steel loading frame. Load was applied using a 30kN closed loop hydraulic ram. Load was measured by means of a 100kN loadcell and digital indicator.

Linear Voltage Displacement Transducers (LVDT) were used to measure the displacement of different parts of the panel during testing.

Test data was collected and recorded using Hewlett Packard digital data logging equipment. In addition, load and displacement at the top plate level of the specimen were recorded on an X-Y recorder.

Load was applied to the specimen through the top plate, and the horizontal deflection was measured at the opposite end, at the same elevation. Steel rollers were provided as lateral guides at the top of the panel. One LVDT was placed vertically on the stud at the bottom of the loaded end of the panel to measure uplift. Another LVDT was placed horizontally at the other bottom end of the panel to measure any base slip (Figure 6).

Test Specimens

Framing Timber

All framing timber was No. 1 framing grade Radiata pine having an average basic density of 390kg/m3 and a moisture content of 13 per cent at the time of testing. Frames were constructed generally in accordance with NZS 3604 using two 100 x 3.75mm nails through top and bottom plates end nailed into the studs. In the case of the additional stud detail the three studs were laminated using a total of six 100 x 3.75mm nails, three from each side at nominally 600mm centres.

Plaster Board Panels

The first series of tests were carried out on six 2.4m square panels lined with 9.5mm thick paper-faced plaster board on one face only. On the opposite face a Pryda metal angle brace was fixed at a 45 degree angle and in accordance with NZS 3604 nailing requirements. The plaster board was fixed with 30mm x 2.5mm galvanised clouts. Nailing was at nominally 150mm centres around the perimeter of each sheet, 12mm in from the sheet edge and at nominally 300mm centres along intermediate studs. For Panel 6 only, the common joint between sheets was taped and stopped. Studs were placed at nominally 600mm centres (Figure 6).

Only one specimen with the current P21 end restraint detail was incorporated in the tests on panels lined with plaster board, to confirm known results from previous tests on similar 2.4m square panels.

Construction Schedule, Plaster Board Panels			
Panel	restraint	width	comments
1	none	2400 mm	
2	proposed	2400 mm	
3	proposed	2400 mm	
4	proposed	2400 mm	
5	current P21	2400 mm	
6	proposed	2400 mm	taped and stopped joint

Plywood Panels

The second series of tests was undertaken on panels lined with 7.5mm construction grade plywood on one face only. Two panel widths, 900mm and 2400mm, were tested. Four identical panels of each were constructed, two of which were tested using the additional stud detail, as currently outlined in the P21 test procedure, and two using the proposed restraint. The plywood was fixed to the frame using 30mm x

2.5mm galvanised clouts at 150mm centres around the perimeter, 10mm in from the sheet edge and at nominally 300mm centres along intermediate studs. Studs were placed at nominally 600mm centres for the 2400mm panels and at nominally 450mm centres for the 900mm panels.

In all cases, and in addition to the end restraints outlined above, the end studs of the plywood panels were fixed to the foundation beam using a building strap as specified for sheet bracing panels (NZS 3604, Clause 6.9.4.5). The strap was nailed to the foundation beam and end studs using six 30mm x 2.5mm galvanised clouts in each member. The strap detail has a nominal capacity of 6kN as indicated in NZS 3604. Small scale testing of three samples indicated an actual capacity of approximately 8kN. The failure modes were tensile fracture of the strap in one instance and nails withdrawing from the timber members in the other two cases.

Construction Schedule, Plywood Panels		
Panel	restraint	width
7 and 8	current P21	900 mm
9 and 10	proposed	900 mm
11 and 12	proposed	2400 mm
13 and 14	current P21	2400 mm

RESULTS AND OBSERVATIONS

Plaster Board Panels (Results for 2, 3 and 4 combined)

Ratings, Plaster Board Panels				
Panel	restraint	width	rating per panel	rating per metre
1	none	2400 mm	55 Bracing Units	23 Bracing Units
2	proposed	2400 mm	110 Bracing Units	45 Bracing Units
3	proposed	2400 mm	110 Bracing Units	45 Bracing Units
4	proposed	2400 mm	110 Bracing Units	45 Bracing Units
5	current P21	2400 mm	115 Bracing Units	48 Bracing Units
6	proposed	2400 mm	110 Bracing Units	45 Bracing Units

All panels were rated in accordance with P21 recommendations. Only Panel 5 could be rated at 8mm and 40mm. All other panels were rated at 4mm and 20mm because ductility demands were not achieved, failure occurring before the deflection limit of 40mm.

Tabulated results in kN, Plaster Board Panels							
	Brace in compression			Brace in tension			
Panel	8 mm	40 mm 1st	40 mm 4th	brace buckling load defl.	8 mm	40 mm 1st	40 mm 4th
1 (#)	3.2	3.2	-	4.0 at 24 mm	3.9	5.8	-
2	7.0	6.6	4.3	8.5 at 20 mm	7.2	11.2	8.7
3	7.2	9.6	4.3	9.2 at 15 mm	7.6	10.9	7.4
4	7.0	4.0	3.2	6.4 at 12 mm	7.2	12.2	7.7
5	6.6	8.0	5.6	8.4 at 15 mm	7.1	9.2	7.3
6	6.3	3.0	0.9	8.4 at 24 mm	8.1	11.5	7.0

(#) The first test was carried out under load control. The early load peak caused loss of control and subsequent excessive panel deflections beyond 40 mm. Only one cycle was carried out.

Observations

The tests on Panels No. 2,3,4,5 and 6 produced similar hysteresis loops for the first stage of testing up to a deflection of 8mm. The absence of end restraint in Panel 1 significantly reduced the load carried at 8mm.

When taken up to four full cycles at 40mm, lack of symmetry was apparent. The brace buckled when loaded in compression which resulted in an early loss of panel strength. The brace continued to carry load in tension resulting in a more predictable behaviour.

Panel 1 had no restraint which resulted in early lifting of the 'tension' stud with the brace loaded in compression. Failure of the plaster board fixings occurred mainly along the bottom plate.

Panel 2 was cycled once at 20mm and four times at 30mm before the final four cycles at 40mm. Movement of the nails indicated a distribution of load around the entire perimeter of both sheets. Load concentrations occurred along top and bottom edges where framing timbers separated.

Panel 3 behaviour was similar to that observed for Panel 2. In addition, two nails heads fractured from their shaft along the common centre stud.

In Panel 4 buckling of the brace was followed by failure of sheet fixings as all the nail heads fixing one of the boards pulled through the sheet along the common centre stud.

Panel 5 had two additional studs at each panel end, consistent with the example in the current P21 test method. Lifting of the outer studs at a top plate displacement of 40 mm was approximately three times the recorded uplift for the tests with the proposed restraint (24mm compared to 8mm). Failure of the plaster board fixings occurred mainly along the bottom plate.

Panel 6 had a fully taped and stopped common vertical joint. This proved sufficient to transmit shear between sheets and prevented slip along the joint. The two sheets behaved as one. Failure was brittle. Nail movement occurred mainly along the full length of the bottom edge and the vertical panel edge with the brace to top plate connection.

Base slip of the bottom plate was negligible in all cases.

Plywood Panels

Ratings, Plywood Panels				
Panel	restraint	width	rating per panel	rating per metre
7 and 8	current P21	900 mm	38 Bracing Units	42 Bracing Units
9 and 10	proposed	900 mm	45 Bracing Units	50 Bracing Units
11 and 12	proposed	2400 mm	182 Bracing Units	76 Bracing Units
13 and 14	current P21	2400 mm	122 Bracing Units	51 Bracing Units

The panels were rated in accordance with P21 recommendations. Identical pairs were grouped and the results averaged.

Tabulated results in kN, Plywood Panels						
Panel	+ 8 mm	+ 40 mm		- 8 mm	- 40 mm	
		1st	4th		1st	4th
7 and 8	1.9	4.9	4.3	2.1	5.0	4.4
9 and 10	2.3	5.1	4.4	2.3	5.4	4.4
11 and 12	8.7	16.3	11.8	9.5	16.5	11.7
13 and 14	6.2	13.2	10.3	5.9	13.6	11.3

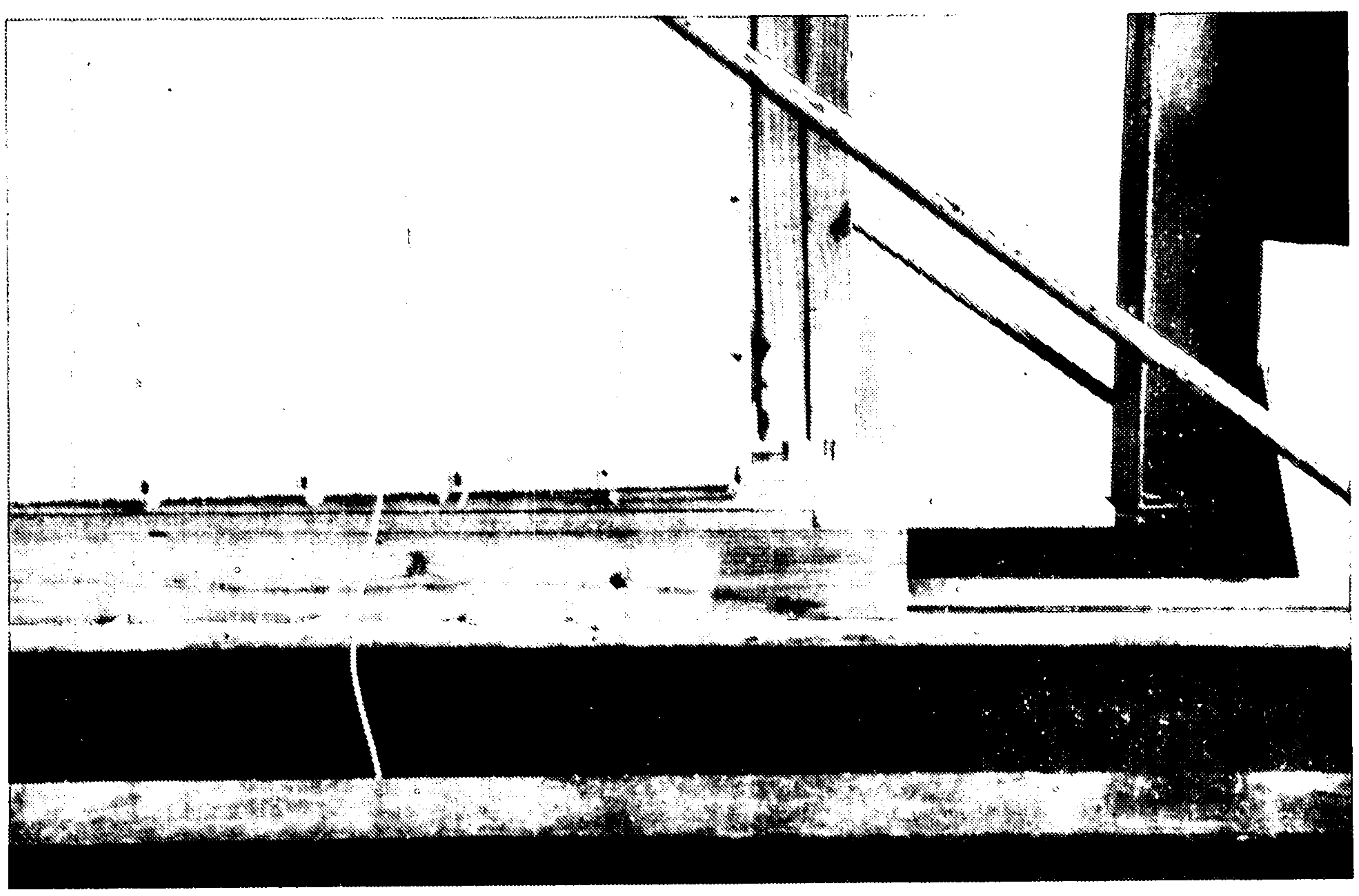

Figure 7: Local fixing failure of plaster board panels

Observations

Seven of the eight plywood lined panels achieved the 40 mm displacement required by the test regime without failure occurring. Test Panel 14 failed before completion of the first 40 mm cycle. At a top plate deflection of 33 mm the nails fixing the building strap pulled out of the stud at one panel end. On completion of the test regime, all plywood panels were subjected to a top plate displacement of up to 60

60 mm (the stroke limit of the equipment). Panels 7 and 12 failed in a similar manner to Panel 14 at a top plate displacement of 50 mm. All other panels, although severely distressed, did not fail during the extended test. None of the tension straps fractured.

Base slip of the bottom plate was negligible in all cases.

DISCUSSION

General

Panels with the additional studs detail lifted severely with the entire panel often "riding" on the nails fixing the bottom plate to the foundation member at the end of a test. In comparison, the proposed restraint detail reduced uplift to approximately one third.

Plaster Board Panels

When a panel is tested at predetermined deflection limits, applying more restraint means less panel rotation and more load is carried by the individual fasteners fixing the sheet material to the framing timber. For the comparatively lower strength plaster board this resulted in earlier failure of the material around these fixings. This mode was particularly apparent along the top and bottom plates where separation of the framing timbers is likely to occur (Figure 7). It is also noted that, when the sheets are fixed in a vertical orientation, the weak cut edges are along these plates. Coincidentally, the ratings for all plaster board panels, with the exception of Panel 1, were similar to each other regardless of the degree of restraint. The ratings, however, were derived from different deflection limits.

Plywood Panels

For the purpose of comparative data on both types of end restraint the predictable behaviour of panels clad with plywood proved particularly useful. Comparison was not obscured by asymmetrical performance or early panel failure as was the case for the plaster board panels. The load-displacement graphs for the tests on the plywood panels are appended. The results obtained for duplicate specimens with the same end restraint were consistently similar and are displayed in one set of graphs. Uplift was plotted against the main deflection to illustrate the performance comparison between both types of restraint.

A higher degree of restraint resulted in greater stiffness and improvéd bracing This effect was most apparent for the longer panels. Using the current restraint with additional studs, the rating per metre increased by 21 per cent when the panel length was increased from 900 mm to 2400 mm. With the proposed detail this figure was 52 per cent. Using a test method developed in the UK and for a similar increase in panel length, Robertson and Griffiths (1981) found an increase of about 100 per cent in rating for 8 mm plywood panels held down using nails at 300 mm centres through the bottom plate.

Although the current P21 paper acknowledges the effect of panel length and states that "the wall length shall be the length for which the performance rating is sought", few panels are tested over a wide range of lengths. Further research into the effect of panel length when tested to P21 specification is suggested.

CONCLUSIONS

The restraint using three nails in shear and the ductility of its performance is believed to more closely represent the effect of boundary conditions on bracing panels in service. This contrasts with the detail using additional studs and end fixity provided by extra nails in withdrawal, where a brittle failure mode is apparent resulting in excessive lifting of the test panel, a characteristic not expected in practice.

For the diagonally braced panels with a plaster board lining the more effective restraint resulted in improved stiffness which was offset by earlier fixing failures. The effects compensated, resulting in similar ratings for both types of restraint.

For the plywood sheathed panels the proposed restraint enhanced panel stiffness and resulted in increased panel ratings calculated in accordance with Technical Paper P21.

From a practical point of view, application of the new restraint proved more efficient. The hardware is easy to install and reusable. The absence of the extra studs required in the alternative detail is both cost efficient and reduces the panel weight which makes handling easier.

RECOMMENDATION

It is recommended that the proposed end restraint be incorporated in the P21 test procedure. Improved modelling of the vertical end restraint which occurs in practice will give more realistic bracing ratings.

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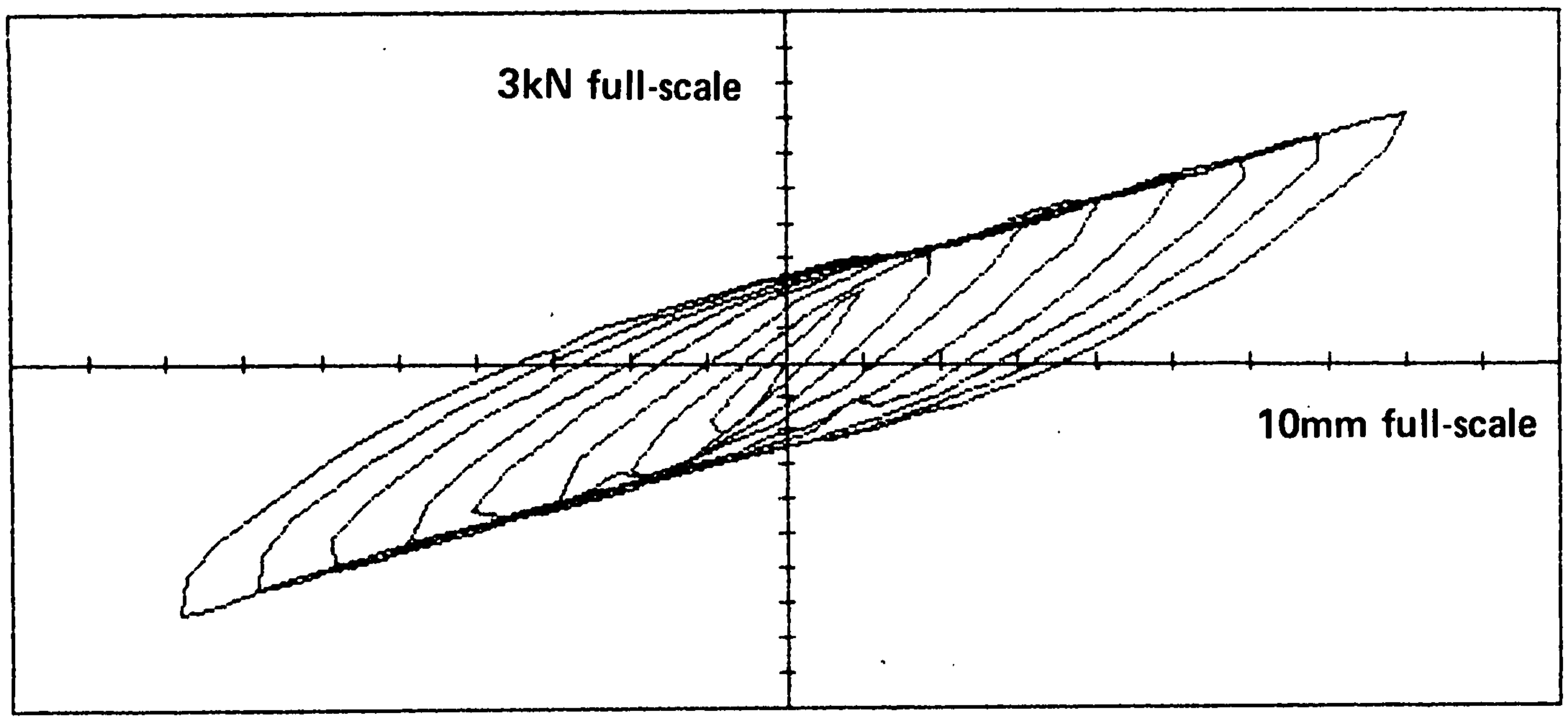
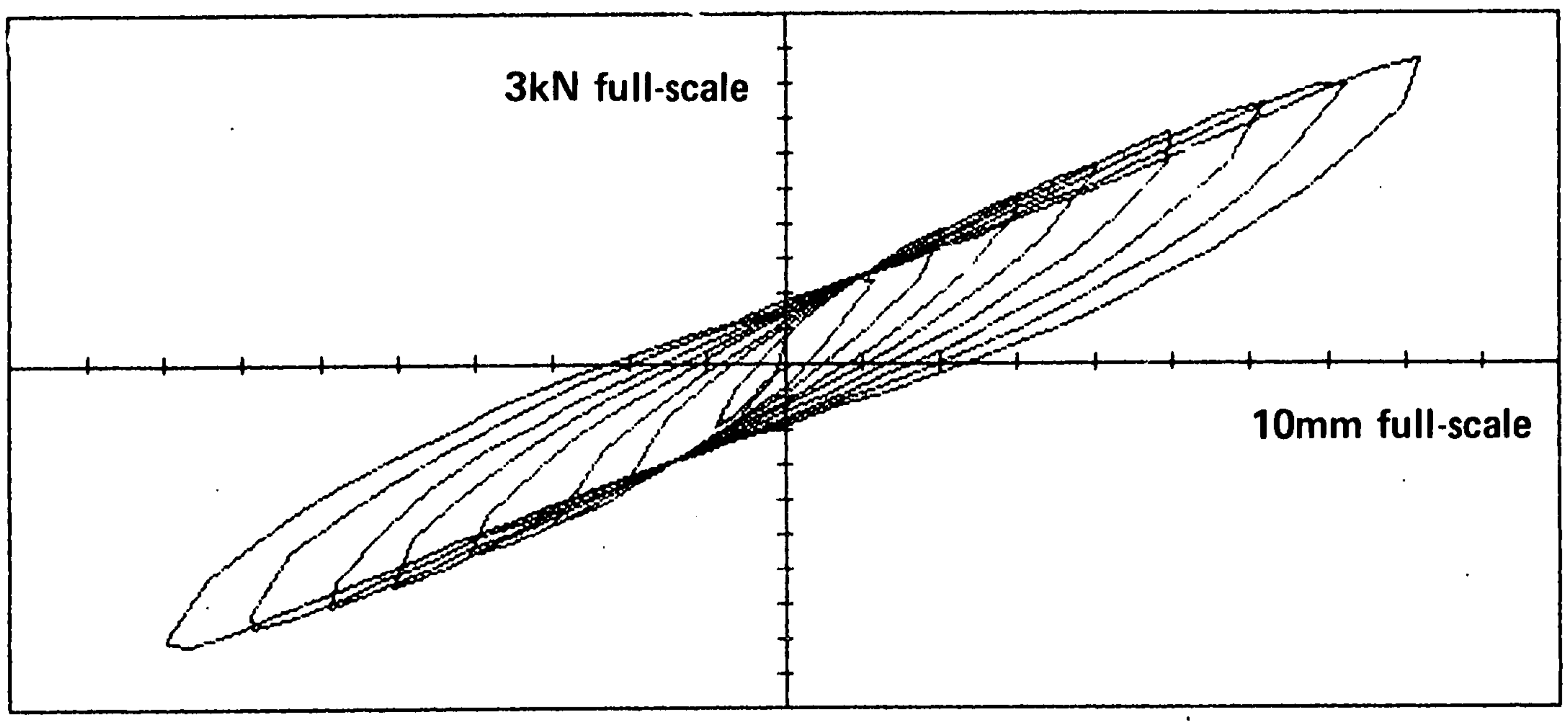
APPENDIX

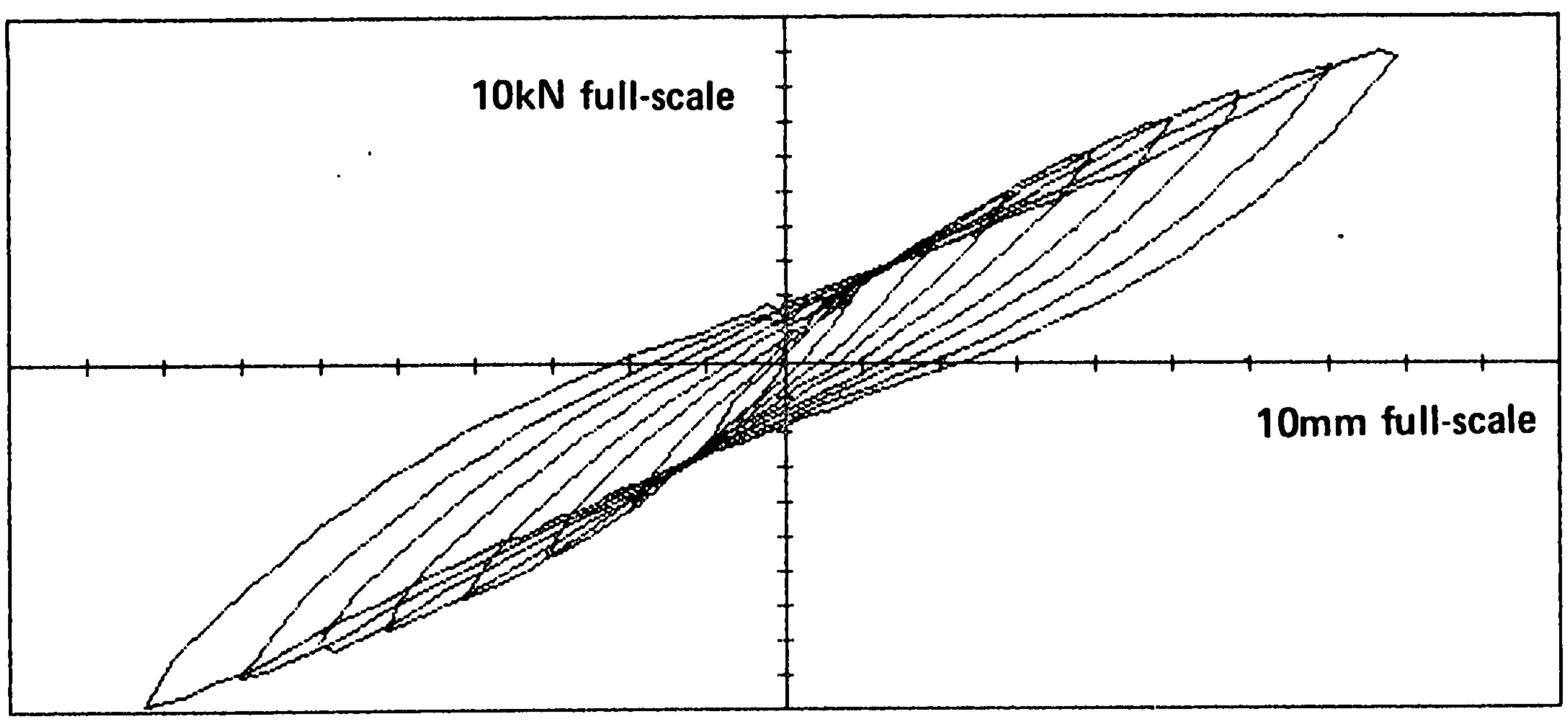
Test Loads and Displacements for the Plywood Panels



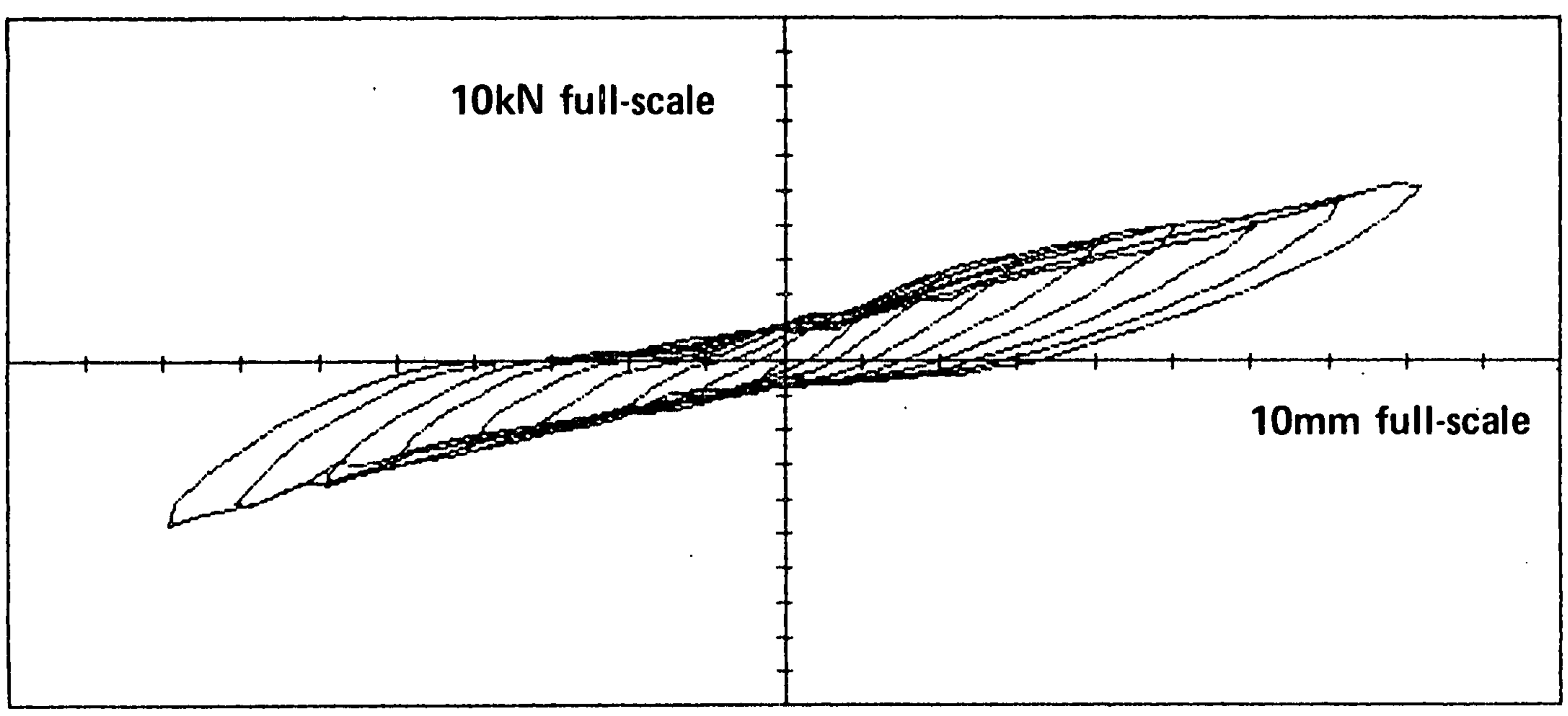
Panels 7 & 8



Panels 9 & 10

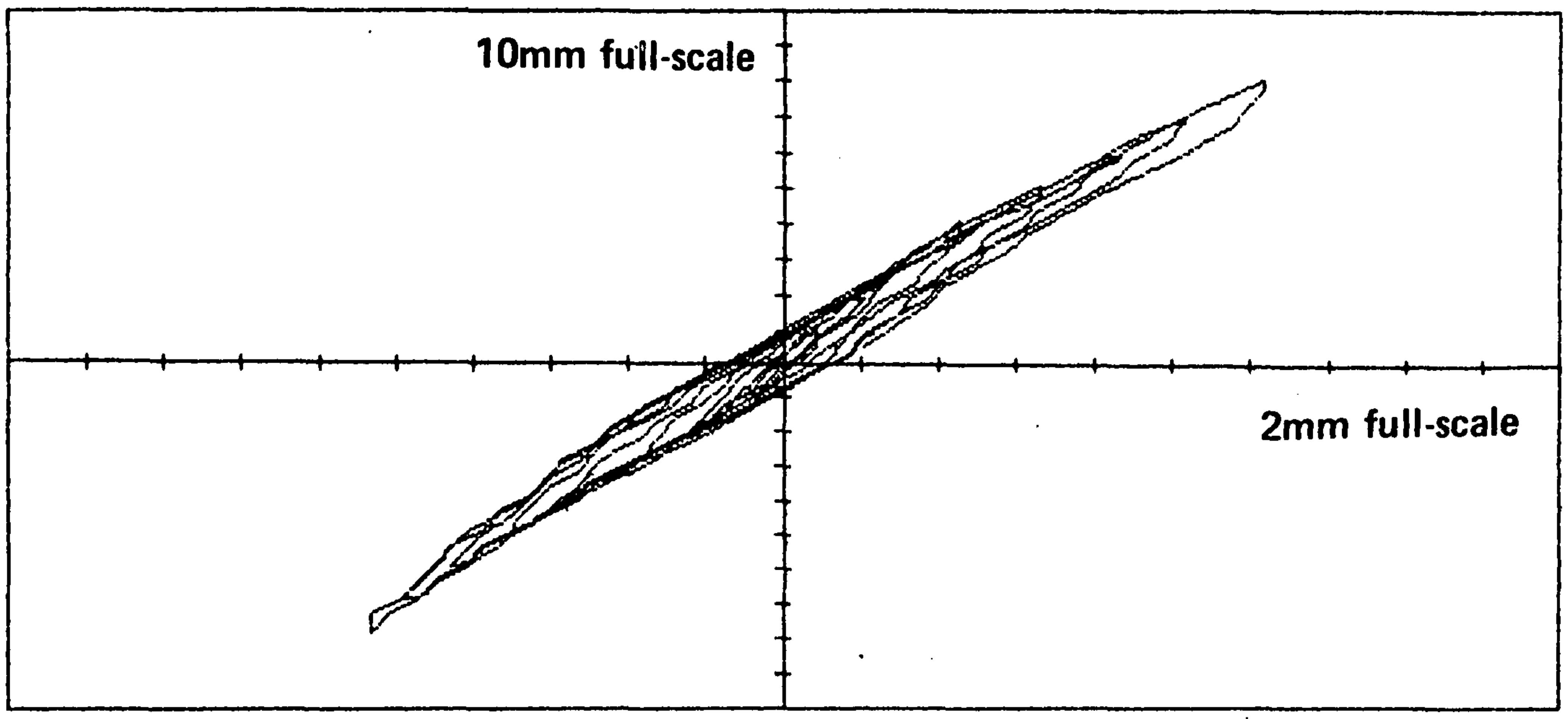


Panels 11 & 12

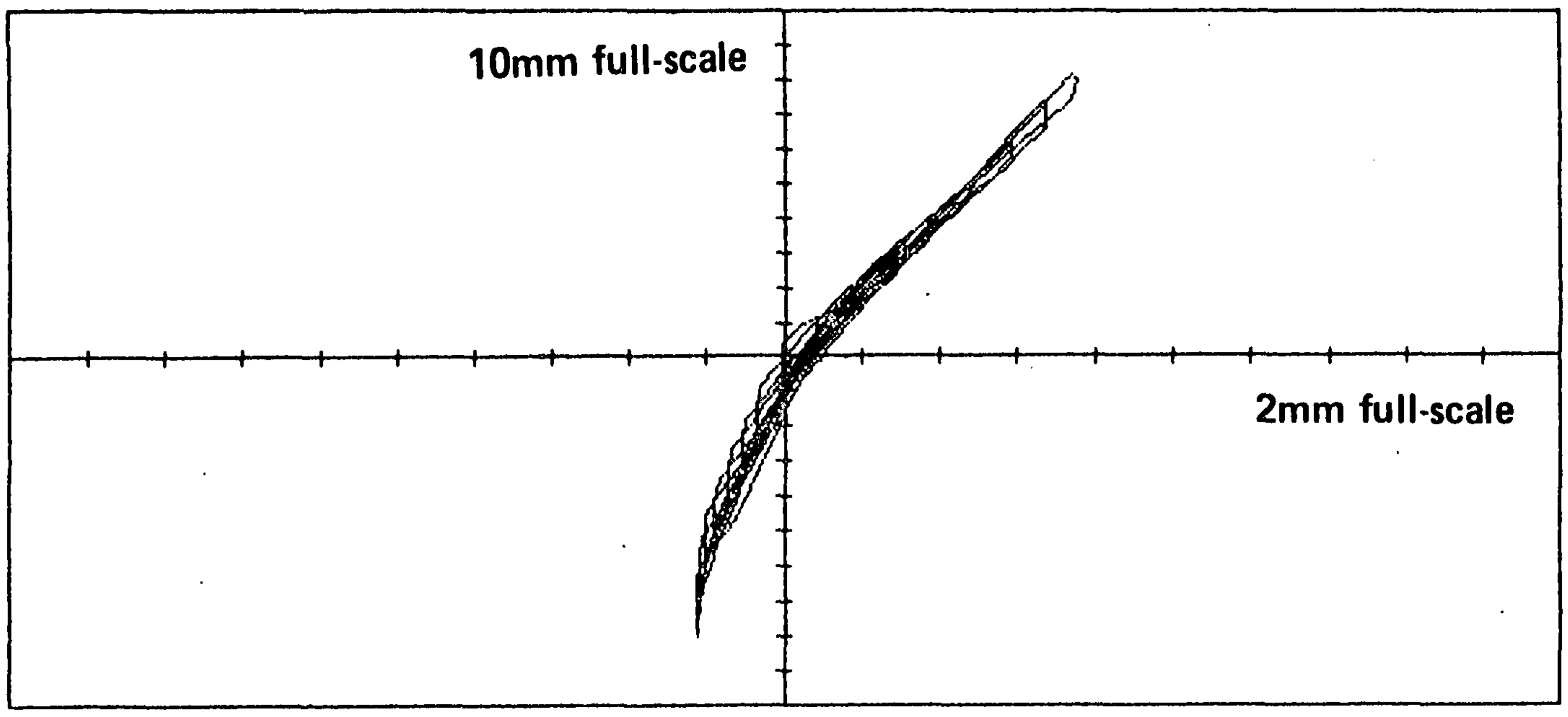


Panels 13 & 14

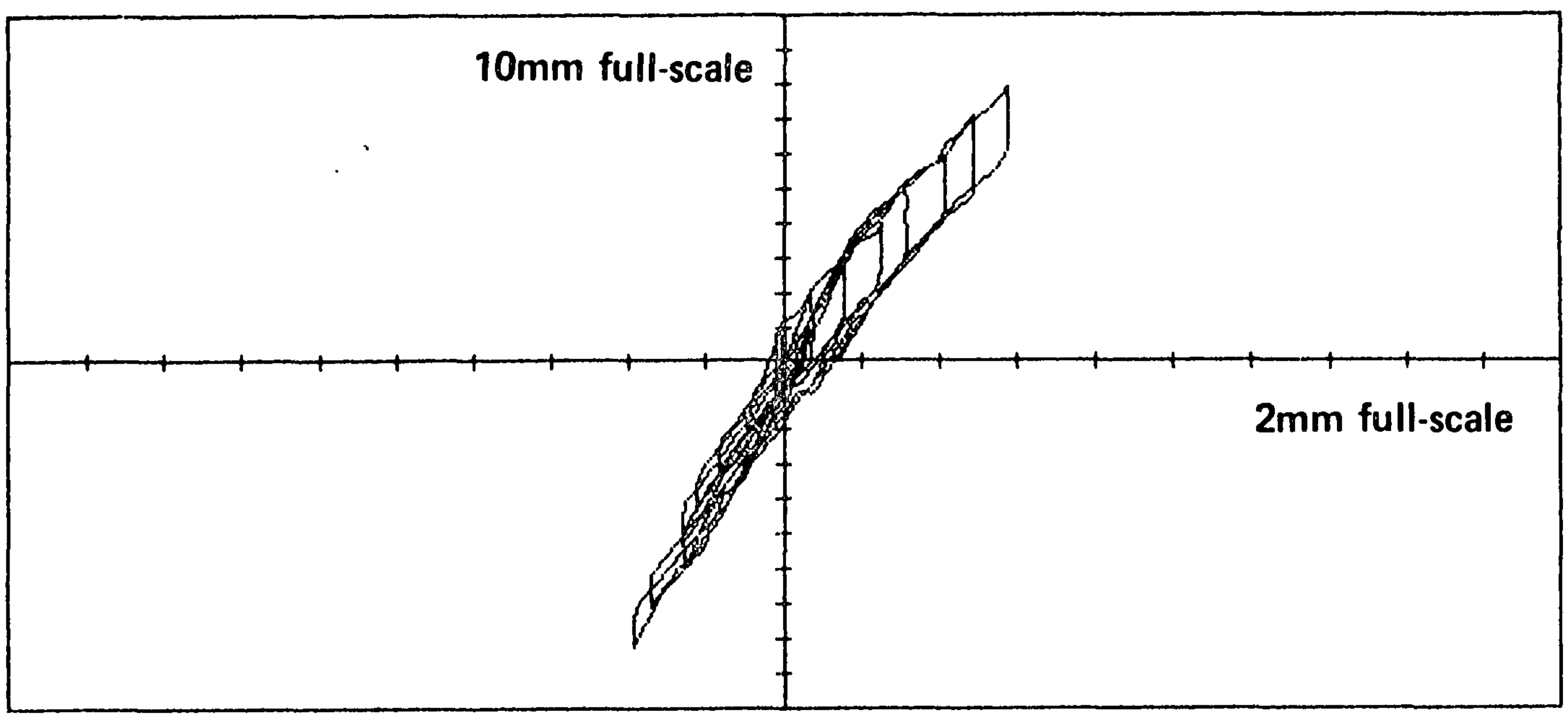
Load versus main deflection
at 8mm cycles



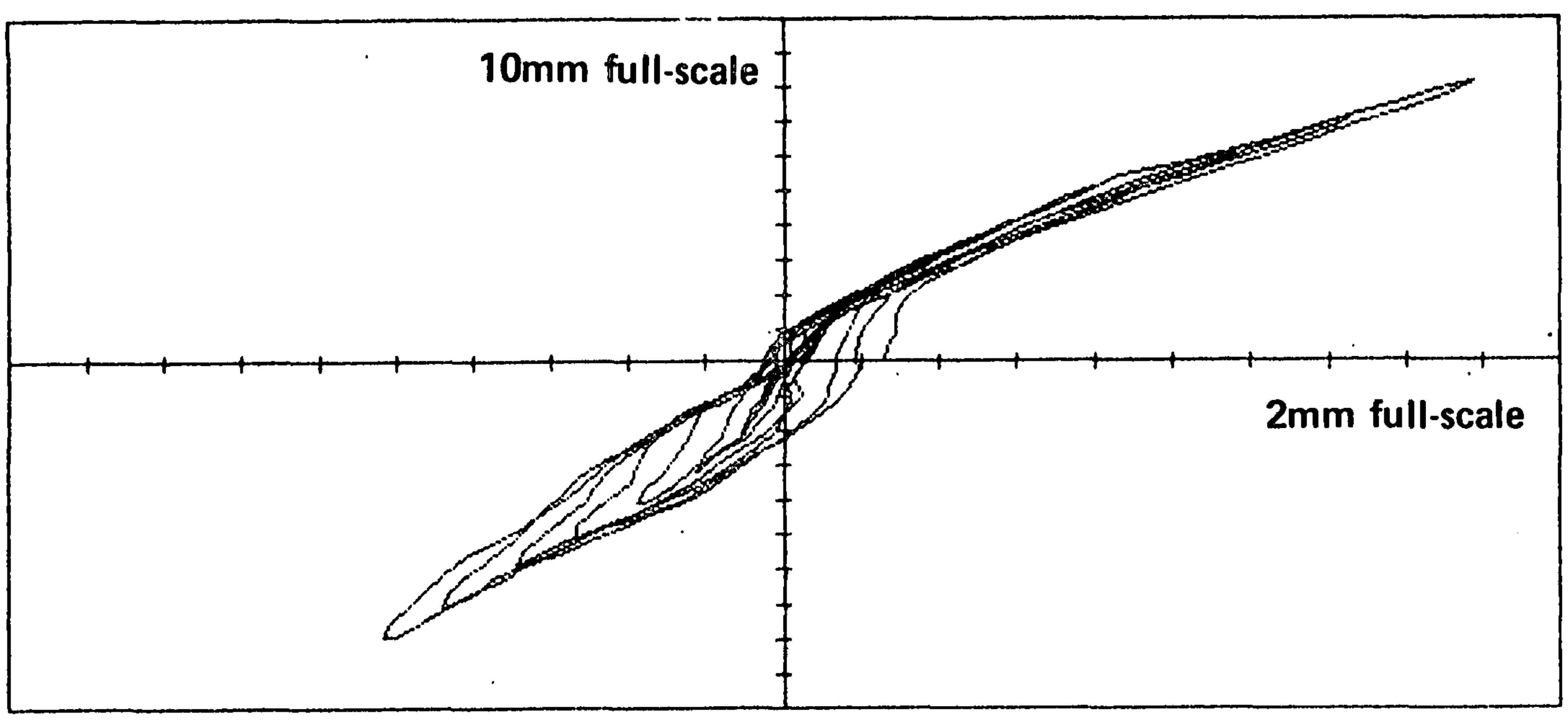
Panels 7 & 8



Panels 9 & 10

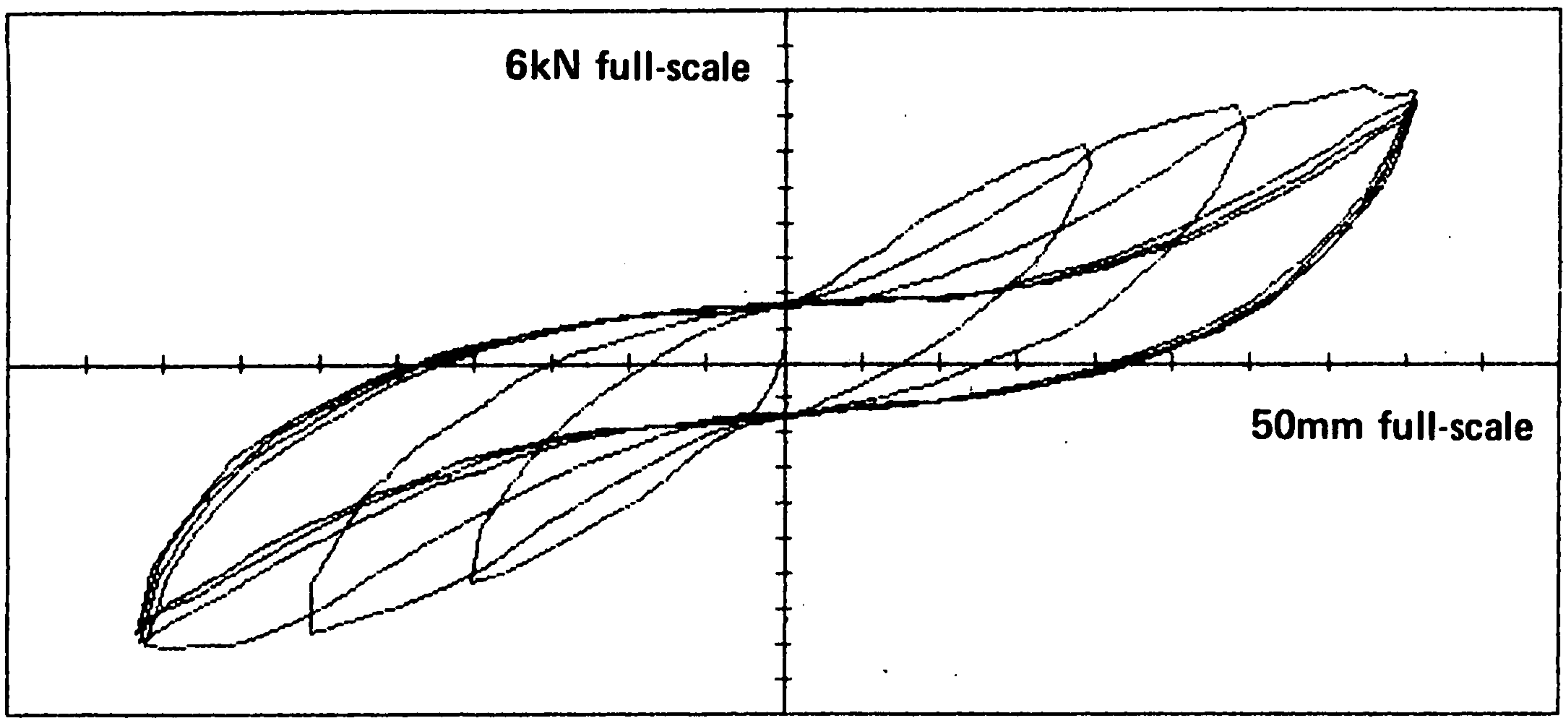


Panels 11 & 12

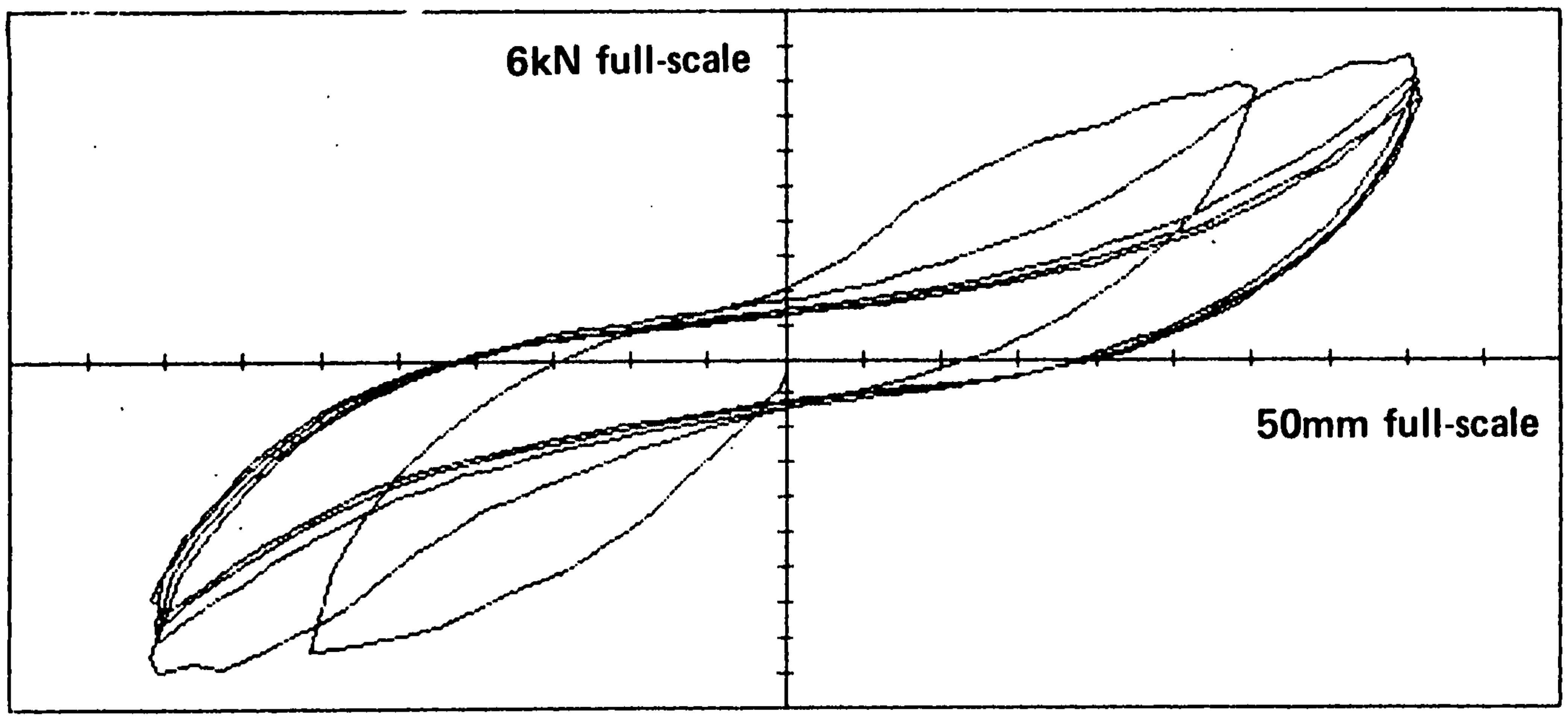


Panels 13 & 14

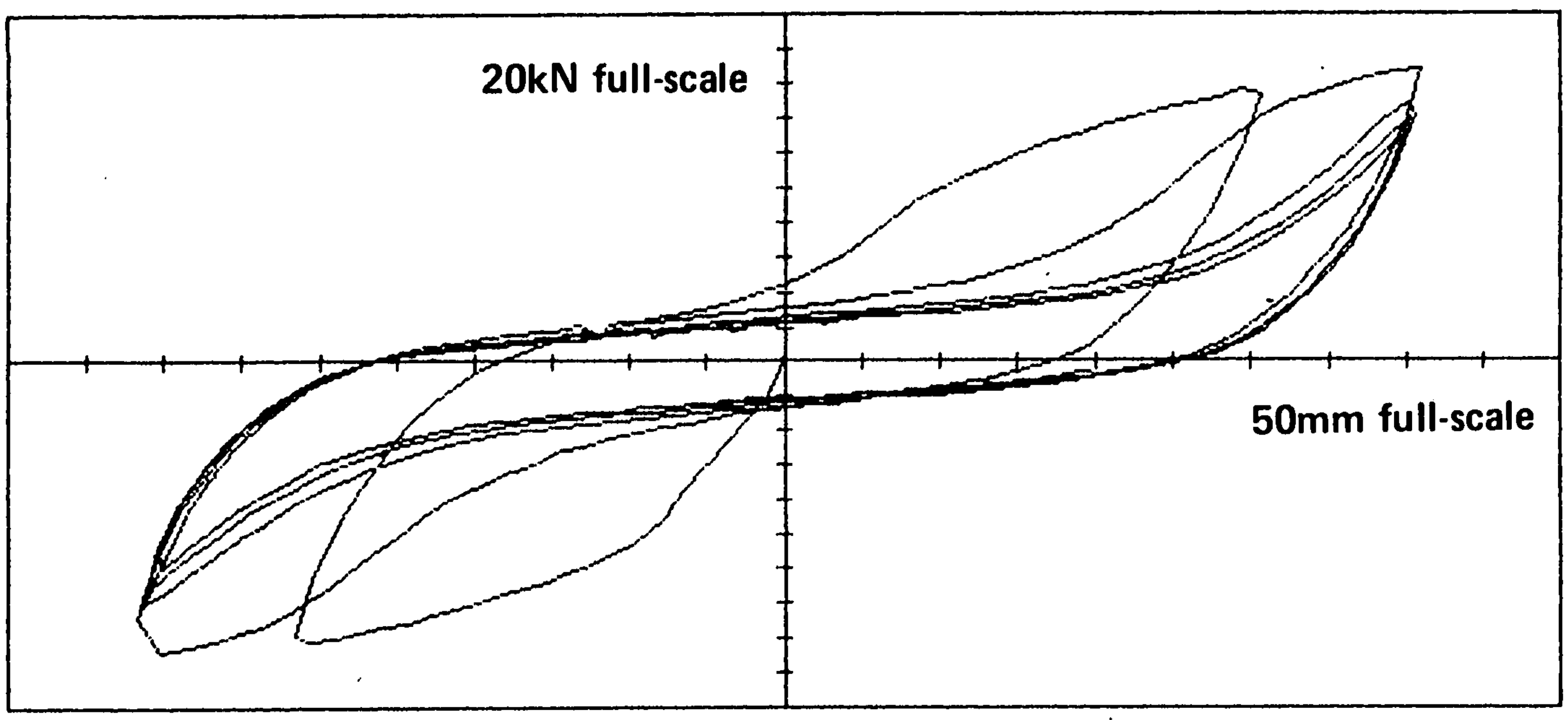
Uplift versus main deflection
at 8mm cycles



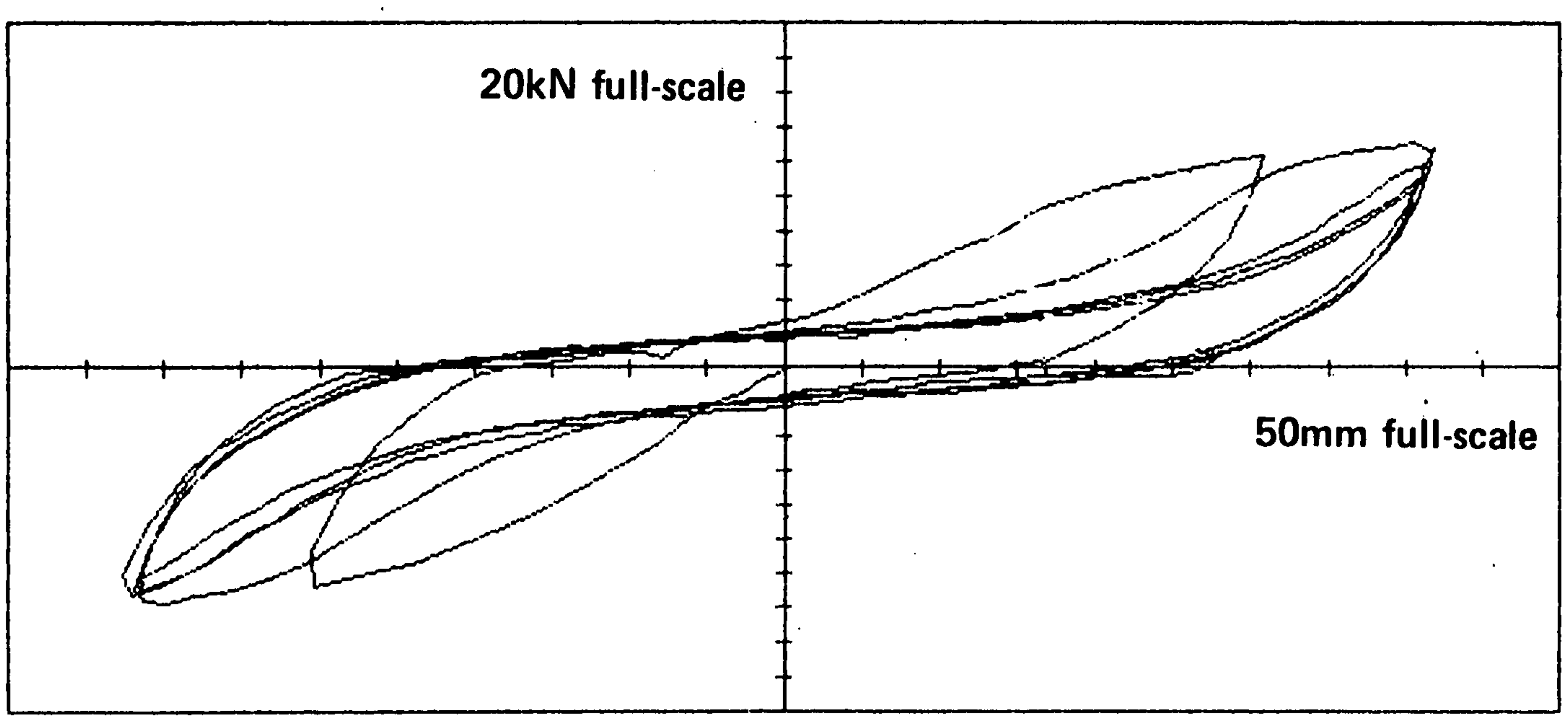
Panels 7 & 8



Panels 9 & 10

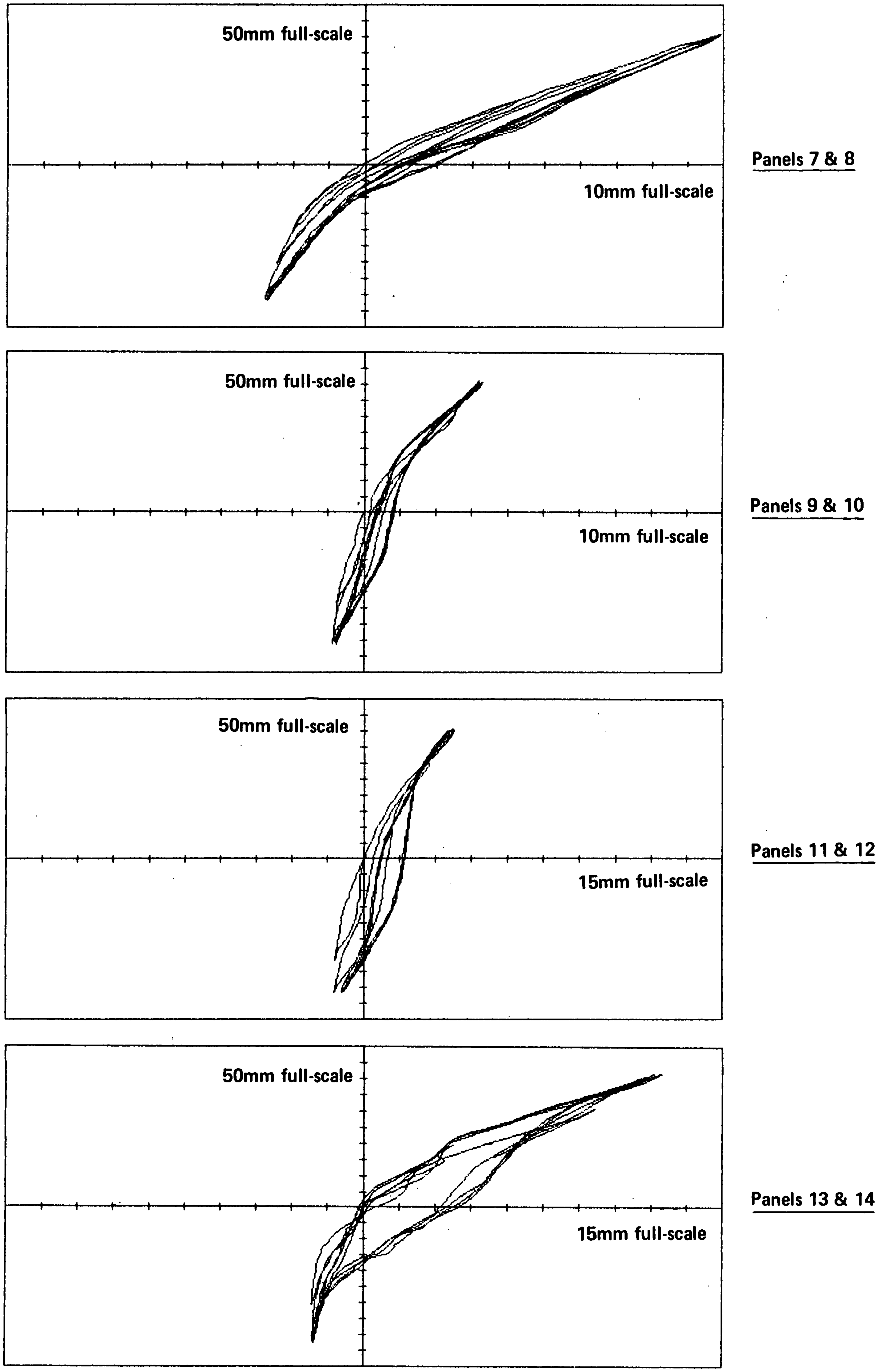


Panels 11 & 12



Panels 13 & 14

Load versus main deflection
at 40mm cycles



Uplift versus main deflection
at 40mm cycles

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