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J. Rhodes

William King

James M. Harvey

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THE DESIGN OF ADJUSTABLE STORAGE SHELVES

by

JAMES RHODES[1], WILLIAM KING[2] and JAMES M HARVEY[3]

1 INTRODUCTION

1.1 General introduction

In this paper the results of a research programme on adjustable storage shelving are detailed. The programme was part of a more general European research project on storage racking design. The work was carried out to (i) obtain a design method for calculating the strength of shelves, and (ii) set up a procedure to evaluate the stiffness of connections between shelves and compression members.

In addition to concentrated and distributed load tests and connection stiffness tests, two large scale strain investigations were carried out to show the stress distributions set up in shelves under load. To ensure generality, five different commercial brands of shelf systems were examined.

Within these five types there were numerous variations obtainable, e.g. different connections (clips, bolts, corner plates), reinforcements of different types, and a wide variety of shelf aspect ratios (length to width ratios). The range tested thus offered a very large variety of different conditions to be examined.

1.2 Initial tests on three bay shelving system

The initial exploratory tests were carried out on a commercial three bay shelving system as shown diagrammatically in Fig 1. Corner plates were provided on the top and bottom shelves of both end bays to maintain overall stability of the system and all other shelves were supported on proprietory adjustable shelf clips.

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1 - Senior Lecturer, 2 - Lecturer, 3 - Professor and Head of Department, Department of Mechanics of Materials, University of Strathclyde, Glasgow, Scotland.

In this test series, tests were carried out on individual shelves in the system at different positions on the bays. Under test, a single shelf was loaded uniformly until failure occurred. After failure the collapsed shelf was replaced by another and the succeeding test was carried out on a shelf in a different location on the system.

Loading was applied using canvas bags containing lead shot, each bag measuring approximately 17 cm x 23 cm. It was found that for these tests, and for all subsequent shelf tests, the dimensions of the bags were such that a very good approximation to a uniformly distributed loading could be obtained, regardless of the shelf dimensions. A large stock of loading bags were made up, each carrying a measured quantity of shot to weigh 10 kg, 5 kg, 2 kg or 1 kg. For smaller load increments, bags of sand were made up to give ½ kg loads. Loading was carried out using first a layer of 10 kg bags and then progressively reducing the bag weight for subsequent layers. A routine method of placing the loading bags was also developed to ensure that the loading was more or less uniform even when a layer was only partially completed.

A total of 14 tests were carried out in this series. The results showed that in general the position of the shelf on the system had negligible effect on its failure load, although on average shelves in the central bay were able to withstand a very slightly greater load than shelves on the outer bays. It was also observed that shelves on the end bays tended to fail more dramatically than those on the centre bay, and often broke the support clips on failure.

On the whole, however, it was concluded that shelves could be designed simply on the basis of shelf dimensions, support conditions, etc., without any regard being paid to its position on the shelving system. Subsequent tests on individual shelves could now be carried out in the knowledge that the results of this type of test were applicable directly to practical situations.

1.3 Main test series on individual shelves

In this test series individual shelves were tested to destruction in custom made rigs, built from material supplied by the relevant manufacturers so that the correct fittings and connections could be employed in each case.

Loading was applied via bags of lead shot as in the initial test series.

A total of 125 tests to failure were carried out, in addition to the 14 initial tests, thus giving 139 tests on which to base recommendations.

The following categories of shelf types and support were examined -

1 Plain shelves supported by bolts or clips, Fig 2a
2 Shelves supported by corner plates, Fig 2b
3 Shelves with one or two reinforcing beams, Fig 2c
4 Multiply reinforces shelves, Fig 2d

In all tests the failure loads were noted. In a number of tests measurements of shelf central deflections were taken as loading progressed. Because of the large deformations occurring in the shelves during test, it was not possible to obtain an accurate assessment of central deflection by direct measurement from the shelves. The method used was to lightly fix a metal bar across the mid-span of the shelf under consideration as shown in Fig. 3 and measure the vertical displacement of both ends of the bar using dial gauges. Figure 3 shows a view of a shelf under load.

1.4 Strain investigations

Large scale strain gauge tests were carried out on two shelves; one shelf of width equal to its length and the other of width equal to one third of its length. On the former, 52 strain gauges were attached and on the latter 40 gauges were used. The layout of the gauges is as shown in Fig 4. The gauges were covered by a sheet of polythene during loading for protection and the tests were carried out using loading bags as in the other tests, with readings taken after each layer of bags was applied. The tests were stopped before the maximum recorded strain approached yield, so that the shelves could be re-tested under different support conditions. Various support conditions were tested in this way for comparison purposes.

1.5 Concentrated load tests

This test series was set up to investigate the behaviour and strength of shelves under loading concentrated on one edge only to simulate the worst kind of loading likely to be applied either by extremely eccentric packing, or by accidental loading. The loading was applied through a 12 cm square pad placed on one one edge of the shelf at mid-span as shown in Fig 5. Eighteen tests were carried out on the different types of shelf under various support conditions. Readings of failure load were noted for each test, and measurements of deflections of both loaded and unloaded edge were also noted.

1.6 Procedure to obtain connection stiffness

In the development of a routine procedure to evaluate the rotational stiffness of shelf to upright connections, a number of different approaches were tried. It was found that consistent results for connection strength and stiffness could be obtained by an arrangement of the general type shown in Fig 6. With this type of arrangement a continuous member was fixed to an upright at approximately mid-span. Loading was applied to one end of the member and the deflections of the other end were measured relative to the supporting connection. Using the readings obtained the moment-rotation behaviour could be examined.

Two main types of set-up using this form of arrangement were examined. Firstly, a single beam member, where loads and rotations of a single corner plate were examined, was investigated. The results were compared with tests on a double beam set-up. Various tests were carried out on different corner plate configurations, different bolt torques, and different moment arms for both types of set-up.

In conjunction with these tests, additional shelf tests were carried out to ascertain the applicability of the results derived to the analysis of shelves with corner plates.

2 GENERAL DESIGN PHILOSOPHY

2.1 Method of evaluating shelf behaviour

In the analysis of shelf behaviour, it is postulated that the 'effective width' approach can be used to adequately describe the flexural strength and stiffness of the shelves under test. This is shown diagrammatically in Fig 7 for a shelf, (where effective widths along each edge are assumed to exist). Under load the ineffective centre may be considered to be removed for the purposes of calculating strength and stiffness.

Since the width/thickness ratios encountered in dealing with shelves (up to 1,000) are very much greater than those encountered in most cold-formed steel design codes, then it was decided that a close examination of the effective widths of shelves at failure would be required. Such examinations have been carried out in the past [3, 4] and it has been seen that if effective widths are derived from strength tests a very large scatter of results is observed due to the high sensitivity of the derived effective widths to small changes in collapse load of the members under test. With this in mind it was decided that the 'ineffective width' would be a more useful quantity to derive from the experimental failure loads since, because of the high width/thickness ratios these are proportionately less sensitive to change in collapse loads.

The required expression relating experimental failure load and ineffective width is derived as follows (the symbols being defined in Appendix 2).

On the assumption that failure occurs when the compressive stress reaches yield, and that any effects of yield on the tension side can be ignored, then for the full shelf the failure moment, M_F, is:

$$M_F = \sigma_Y Z_F \quad \text{where} \quad Z_F = \left[I_o - \frac{(Ay)^2}{A_F} \right] \frac{A_F}{Ay}$$

and for the effective shelf the reduced failure moment, M_R, is:

$$M_R = \sigma_Y Z_R \quad \text{where} \quad Z_R = \left[I_o - \frac{(Ay)^2}{A_R} \right] \frac{A_R}{Ay}$$

Therefore

$$\frac{M_R}{M_F} = \frac{Z_R}{Z_F} = \frac{\left[I_o - \frac{(Ay)^2}{A_R}\right]}{\left[I_o - \frac{(Ay)^2}{A_F}\right]} \frac{A_R}{A_F} = \frac{\frac{I_o A_R}{(Ay)^2} - 1}{\frac{I_o A_F}{(Ay)^2} - 1}$$

Also

$$A_R = A_F - t^2\left(\frac{b}{t} - \frac{b_e}{t}\right)$$

Therefore

$$\frac{M_R}{M_F} = \frac{\frac{I_o A_F}{(Ay)^2} - 1 - \frac{I_o t^2}{(Ay)^2}\left(\frac{b}{t} - \frac{b_e}{t}\right)}{\frac{I_o A_F}{(Ay)^2} - 1}$$

This reduces to

$$\frac{M_R}{M_F} = 1 - \frac{I_o t^2}{AyZ_F}\left(\frac{b}{t} - \frac{b_e}{t}\right)$$

Also $$\frac{M_R}{M_F} = \frac{W_A}{W_F}$$

Therefore, rearranging the above expression gives the 'ineffective width' as

$$\left(\frac{b}{t} - \frac{b_e}{t}\right) = \left(1 - \frac{W_A}{W_F}\right) \frac{AyZ_F}{I_o t^2}$$

Using this expression together with the shelf dimensions and failure loads, the required relationship can be obtained graphically.

2.2 Effects of different connection methods

In cases where single bolt connections or clips were used to support the shelf on each corner, it can be assumed that the shelves behaved as simply supported beams, in which case $M_R = \frac{W\ell}{8}$. If gusset plates, or corner plates are used, however, the simple support condition does not hold since a partial clamping effect is obtained. The degree of fixity is dependent on the strength and stiffness of the corner plate connections.

Considering the shelf as a beam loaded uniformly and with restraining moments M_R, proportional to the rotation θ of the ends as shown in Fig 8 provides a method of evaluating the carrying capacity of shelves with corner plates. If $M_R = k\theta$ it can be shown using simple beam theory that

$$M_R = \frac{\bar{W}\ell}{12(\frac{2EI_R}{k\ell} + 1)}$$

where $\bar{W}$ is the total load on the restrained shelf, ℓ is the shelf length and the other symbols are as defined in section 2.1.

The corresponding maximum moment at the shelf mid span is

$$M_C = \frac{\bar{W}\ell}{8} \left[1 - \frac{2}{3(\frac{2EI_R}{k\ell} + 1)} \right]$$

In this case there are three values of moment which could possibly cause failure. These are -

1. The central moment $M_C = \sigma_Y Z_R$
2. The end moment $M_R = \sigma_Y Z_R$
3. The end moment $M_R = C_f$, where C_f is the failure moment of the corner plate supports, obtained from corner plate tests.

These conditions can be written in terms of $\bar{W}$, i.e.

(a) $$\bar{W} = \frac{W_R}{\left[1 - \frac{2}{3 \frac{2EI_R}{k\ell} + 1)} \right]}$$

(b) $$\bar{W} = \frac{3}{2} W_R (\frac{2EI_R}{k\ell} + 1)$$

(c) $$\bar{W} = \frac{12C_f}{\ell} (\frac{2EI_R}{k\ell} + 1)$$

where W_R is the calculated failure load based on the reduced section for a simply supported shelf.

2.3 Effects of reinforcements

For shelves with reinforcements the following simple method of analysis was employed. If the reinforcements, or stiffeners, are not rigidly connected to the shelf along their whole length, i.e. not welded, then it can be assumed that they behave independently. However, the deflections of shelf and stiffeners under load have the same value so that at any given deflection value δ the load on the shelf is

$$W_{SHELF} = \frac{384}{5} \frac{EI}{\ell^3} \delta$$

and that on each stiffener is

$$W_{STIFFENER} = \frac{384}{5} \frac{EI_{ST}}{\ell^3} \delta$$

where I_{ST} is the stiffener second moment of area. The total load carried by the shelf and stiffeners is therefore

$$W_{TOTAL} = \frac{384}{5} \frac{E}{\ell^3} (\Sigma I) \delta$$

where ΣI denotes the sum of the second moments of area of shelf and stiffeners, reduced of course to take account of local buckling. For the shelf the reduced I value, I_R, is as obtained from the shelf tests and is discussed in section 3. For the stiffeners, for simplicity the method used in BS 449 addendum No.1 [1] was used to compute the reduced I values.

Failure is assumed to occur, as previously, when the maximum compressive stress on the shelf reaches yield. Therefore the total load at failure is given by

$$W_{TOTAL} = W_R \times (\frac{\Sigma I}{I_R})$$

3 TEST RESULTS AND ANALYSIS

3.1 Consistency of dimensions and properties for the shelves under test

All shelves tested in this project had their cross-sectional dimensions measured at a number of positions along the shelf. For each batch of shelves tensile tests were made on at least two specimens cut from shelves in the batch. It was found that in general the dimensions of the shelves did not vary by very much from the nominally stated values. There were, however, quite wide variations in the material thicknesses of some types of shelves tested, especially between different batches of the same shelves.

The tensile test results showed that a variation of about 12% - 14% in the yield stresses were obtained for all types of shelves tested. Different characteristic stress-strain curves were exhibited by the specimens from different shelf types. Three types had a sharply defined yield point and the other two had relatively smooth stress-strain curves with poorly defined yield points. For these cases the 0.2% proof stress was taken as the yield stress in calculations.

The average values of material thickness and material yield stress for each type of shelf investigated were used in the relevant calculations.

3.2 Strength tests on shelves with clip or bolt supports

Width to thickness ratios of the shelves tested varied from just over 200 to almost 1,000. In Fig 9 the quantity $\frac{b}{(\frac{b}{t} - \frac{b_e}{t})}$ obtained on the basis of experimental results as outlined in section 2, is plotted against shelf width/thickness ratios. As is evident from the graph, all five types of shelf tested have effective widths at failure of between 20 and 100 times their material thickness.

Also shown on the graphs is a line corresponding to $b_e = 40t$ which is in generally good agreement with the test results and furnishes a very simple method of evaluating shelf strength. That is, design the shelf as a beam and only consider 40t of the shelf width to be effective.

Also shown on the graph is a line corresponding to the effective widths calculated using the AISI specification [2] (with appropriate conversion factors for SI units). This also shows fair agreement with the experimental results, although on average it is slightly non-conservative. On this basis it would appear that for simplicity and conservatism a value of 40t is preferable for the effective width.

It was observed that all shelves with perforations near the edges failed at a perforation, whereas perforations far from the edges produced no adverse effects. As the experimental values of effective width were to some extent reduced by the perforations, it is recommended that for shelves with perforations near the edges the design effective width be reduced from 40t as shown in Fig 10. It is suggested that the net section containing a perforation and extending over 20t from each edge is used in obtaining the section properties of the shelf.

Figure 11 shows the ratio of ultimate loads obtained experimentally to those calculated on this basis (i.e. $b_e = 40t$ with appropriate reductions for shelves with perforations near the edges). It can be seen that the calculations give a reasonable estimate of the load carrying capacity of the shelves although there is quite a large degree of scatter in the experimental results, due partly to variations in material thickness and yield strength.

3.3 Load-deflection behaviour of shelves with clip or bolt supports

Fig 12 shows load deflection paths for one particular type of shelf. As can be seen, very similar behaviour is exhibited for all shelves regardless of the shelf width. This reinforces the notion of the shelves having an effective width independent of their real width. It is rather surprising, however, that in most cases the use of the effective width obtained from the ultimate load tests overestimates the flexural stiffness. The experimental stiffnesses indicate an effective width of between zero and 40t for stiffness calculations. The conclusion that may be taken from this is that the effective width approach, although giving a reasonable estimate of shelf strength, does not give an entirely accurate picture of the mechanics of shelf behaviour, since the stiffness is somewhat underestimated. Nevertheless it can be postulated that a fair estimate of the deflections of all shelves tested could be obtained by assuming that, for deflection purposes, the effective width of the shelf is taken as 20t.

3.4 Tests on shelves with corner plate supports

Twenty-six tests were carried out on shelves with corner plate supports. It was found that the use of this type of support invariably increased both strength and stiffness of the shelf under examination. When ultimate loads of these shelves were compared with those for the same shelves with clip at bolt support the average increase in load carrying capacity was of the order of 40%.

Fig 13 shows a comparison of load-central deflection curves for shelves with corner plates and shelves with clip supports. On this figure the scatter bands obtained from 8 tests on clip supported shelves and 4 tests on corner plate supported shelves are shown. Here it can be seen that the stiffnesses of the shelves are approximately doubled using the corner plates in preference to clips.

It is therefore evident that the use of corner plate supports imposes a restraining effect on the ends of the shelves and induces a condition of partial fixity at the ends. The stiffness and strength of corner plates is examined in section 3.8.

3.5 Tests on reinforced shelves

Nineteen tests were carried out on shelves reinforced by one or more stiffeners. For most part the stiffeners were connected loosely to the shelves by crimping, but in some designs spot-welded reinforcements were used.

The load carrying capacity of the shelves were computed using the sum of the second moments of area for shelf, and stiffeners, as outlined in section 2. Fig 14 shows comparison of the loads calculated in this way with those obtained experimentally. Included also in this figure are the results for unreinforced shelves of the same type. As is seen there is reasonable agreement between calculated carrying capacities and actual carrying capacity. It can therefore be assumed that the simple method of calculation used is adequate for design purposes.

Only shelves with one or two reinforcements were accounted for in Fig 14. For shelves with 3 or more reinforcements the experimental results were rather surprising, and indicated that the addition of more stiffeners did not produce a proportionate increase in strength. This problem requires a more detailed analysis and so, while the results have been noted, no method of approach to multi-stiffened shelves is suggested here.

3.6 Strain investigations

The strains recorded from these tests were converted to stresses using the stress-strain relationships for linear elastic materials. Typical membrane stress distributions across the mid-lines of the shelves with bolted connections are shown in Fig 15. The load magnitudes under which these stresses were obtained were 230 kg and 160 kg for the square and rectangular shelves respectively.

From a complete examination of the various support conditions (bolts, clips and corner plates) it was found that the distributions of membrane or average stress show the following points.

1. The stresses vary from compression at the edges to tension at the centre. The net load carried by the shelf top can be deduced from the stress distribution, and this is very small, indicating very low effectiveness. The stress distributions indicate that in addition to beam action the loads induce tensile membrane stresses due to plate action in the shelf, and this accounts for the low values of effective width obtained in the tests.

2. The peak membrane stresses occur at the plate edges and are of the same magnitude for bolt and clip supports. Corner plate supports reduce the peak membrane stresses.

3.7 Concentrated load tests

From the tests carried out in this series, it was found that the total concentrated load carried by the shelves at failure varied from 0.25 to 0.4 times the failure loads which were calculated for the corresponding uniformly loaded shelves. The average ratio of concentrated load to uniformly distributed load at failure was 0.32.

This indicates that the effective width method can give a fair approximation to the failure loads in this case, as follows. Consider the effective shelf of Fig 6 once more. Under a uniformly distributed load the maximum moment is $\frac{W\ell}{8}$ and both effective sides of the shelf resist this moment. Now if a concentrated load W_C is applied at the centre of one side and torsional stiffness of the ends is neglected the maximum moment is $\frac{W_C\ell}{4}$ and only one side of the shelf resists this moment. Therefore with twice the maximum moment and half the resistance, it follows that at failure $W_C = \frac{W}{4}$, i.e. the shelf can resist 0.25 of the calculated uniformly distributed load if this is applied at the centre of one edge.

The assumptions made in this simple analysis, i.e. neglect of torsional stiffness of the shelf ends and assumption of a concentrated load rather than a patch load, make for conservatism so that the factor 0.25

should underestimate the actual failure load of shelves under this type of loading. The experimental results show that this is indeed the case but are close enough to validate the simple approach used.

3.8 Corner plate stiffness tests

From the tests the following findings were noted:

1. The moment arm used in applying the loading had no effect on the measured failure loads or connection stiffnesses.

2. The bolt torque applied had only a very slight effect on connection strength, with strength increasing marginally for increased bolt torque.

3. The connection stiffness excluding frictional slip (i.e. the stiffness obtained from the unloading lines) was completely independent of bolt torque and depended only on corner plate geometry and dimensions and lengths of uprights.

4. The rate at which slip occurred during connection stiffness tests was dependent on the bolt torque applied, with greater torque requiring greater applied moment to produce slip. At loads near collapse of the corner plates, however, the complete slip capability of the connections appeared to have been taken up regardless of bolt torque so that the total stiffness including slip was not very dependent on bolt torque if measurement was made just before failure.

Fig 16 shows this behaviour for corner plates of one type with three different bolt torques. Although the curves are quite different midway through loading, they converge as the failure load is approached. The stiffness inclusive of slip is taken as the ratio of the moment just before failure to the rotation of the connection caused by that moment.

Fig 17 shows typical moment rotation curves for two similar connections with unloading and reloading at different stages, and a third connection which was tested to failure without unloading. Points which are illustrated by this figure are - 1) Unloading and reloading does not alter the characteristic moment-rotation curve, as upon reloading the curve assumes a continuation of its initial slope and the ultimate moment and rotation values are not affected, 2) the unloading lines are almost perfectly linear and elastic unloading takes place, 3) the slope of the unloading line is independent of the stage at which unloading takes place and gives the stiffness of the connection excluding frictional slip.

From the results, it is suggested that the connection stiffness which should be used in estimation of shelf strength is that which includes friction effects. This is obtained by dividing the moment just before failure by the corresponding rotation.

To assess the validity of this hypothesis, failure loads were calculated for shelves with corner plate supports using the method described in section 2.2 and the connection stiffnesses evaluated from the tests.

The ratios of experimental failure loads to calculated failure loads are shown in Fig 18. As can be seen the loads calculated on the basis of section 2.2 adequately predict the failure loads of shelves with corner plate supports, although there is some scatter in the results, even for identical shelves. The moment which initiated failure in all cases was calculated to be that at the shelf mid-span.

4 RECOMMENDATIONS AND CONCLUSIONS

From the results of the tests, bearing in mind the variations in material thickness and properties, it can be concluded that the simple criteria discussed afford simple procedures for analysing the behaviour of storage shelves. The recommendations for design analysis are summarised as follows:

1. Shelves which are supported by bolts or clips may be considered, for design purposes, to act as beams with reduced effective width. The effective width of shelf which should be used in design is 40 times the thickness of the shelf material, 20 times the thickness adjacent to each edge. If perforations are present in the shelf then the effective width should be reduced by considering the nett section taken through the perforations for the purpose of evaluating section properties. Note that for shelves of square or nearly square planform the possibility of failure due to bending across the shelf width must also be investigated.

2. The flexural stiffness of these shelves is slightly overestimated by assuming an effective width of 40t. Although there are some differences between different designs of shelf, a reasonable estimate of flexural stiffness can be obtained if the effective width used for deflection calculations is taken as 20t.

3. If corner plate supports are used the strength and stiffness of the shelves are increased. The increase in strength can be evaluated with engineering accuracy using the procedure outlined in section 2.2.

4. For shelves with one or two reinforcing beams the total load carried by shelf plus reinforcements can be evaluated adequately by multiplying the calculated failure load for the shelf alone by $\Sigma I/I_R$ where ΣI is the sum of second moments of area of shelf and stiffeners and I_R is the second moment of area of shelf alone. (All I values suitably modified to take account of local buckling).

5. Under the worst possible vertical concentrated load conditions, i.e. a load concentrated on one side of the shelf at mid-span, the shelf will carry approximately one third of its calculated uniformly distributed load.

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APPENDIX 1 REFERENCES

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2 AISI Specification for the design of cold-formed steel structural members 1968

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APPENDIX 2 NOTATION

A_F	cross-sectional area of full shelf
A_R	cross-sectional area of effective shelf
A_Y	first moment of area of edges (about axis through compression flange)
b	full shelf width
b_e	effective shelf width
C_f	failure moment of corner plate supports
I_o	second moment of area of edges (about axis through compression flange)
I_R	reduced second moment of area of shelf about its neutral axis
k	proportionality constant
	shelf length
M_C	maximum moment on shelf at centre span
M_F	failure moment of full shelf
M_R	failure moment of effective shelf
t	material thickness
W	uniformly distributed load

W_A	actual failure load
W_C	concentrated load
W_F	failure load calculated on basis of fully effective shelf
$\bar{W}$	total load on restrained shelf
Z_F	section modulus of complete shelf (compression side)
Z_R	section modulus of effective shelf (compression side)
δ	deflection
σ_Y	yield stress
θ	rotation

Conversion factors

1 mm = 0.0394 inches

1 kg = 2.205 lb

1 MN/m^2 = 145 lb/in^2

1 Nm = 8.85 lb.inches

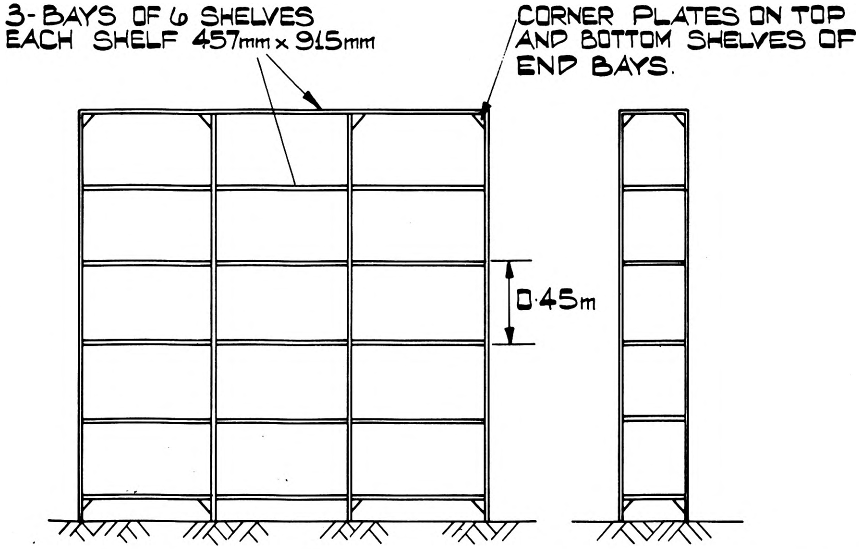


FIG 1. THREE BAY SYSTEM USED FOR INITIAL TESTS

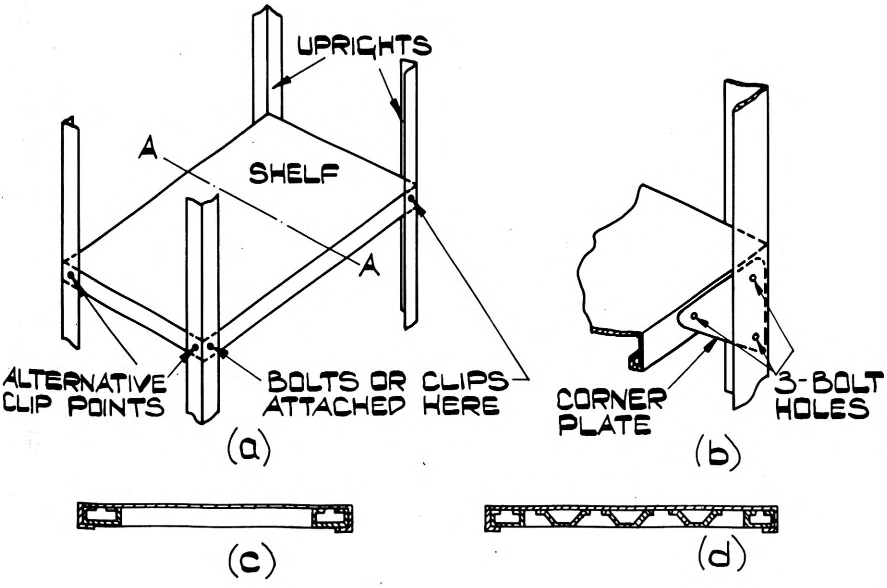


FIG 2. SHELF AND SHELF SUPPORT DETAILS

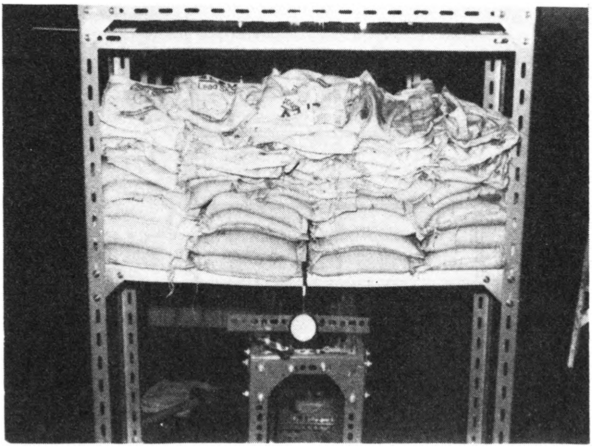


FIG 3 MEASURING DEFLECTIONS UNDER LOAD

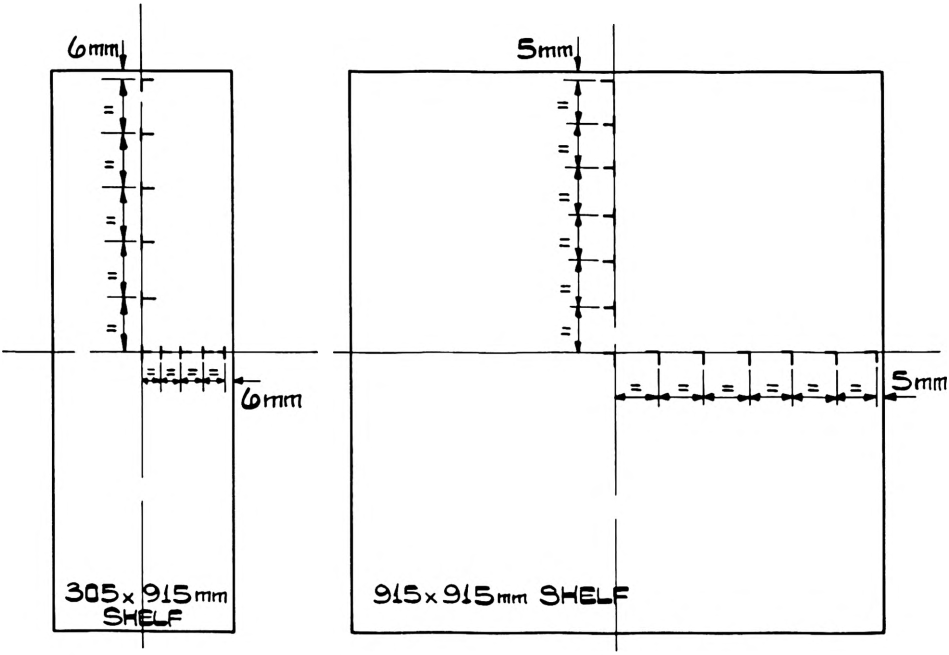


FIG 4 LAYOUT OF STRAIN GAUGES ON SHELVES

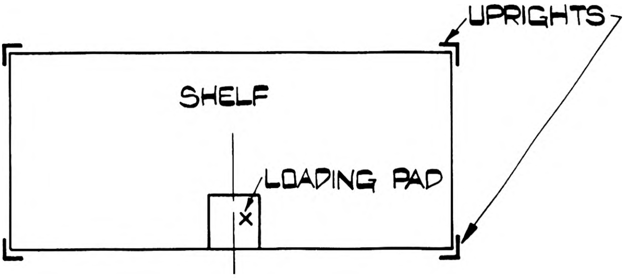


FIG 5. PLAN VIEW OF SET-UP FOR CONCENTRATED LOAD TESTS

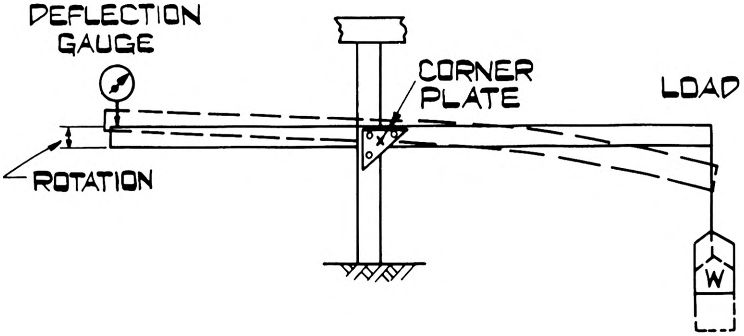


FIG 6 GENERAL ARRANGEMENT TO MEASURE CORNER PLATE STRENGTH AND STIFFNESS

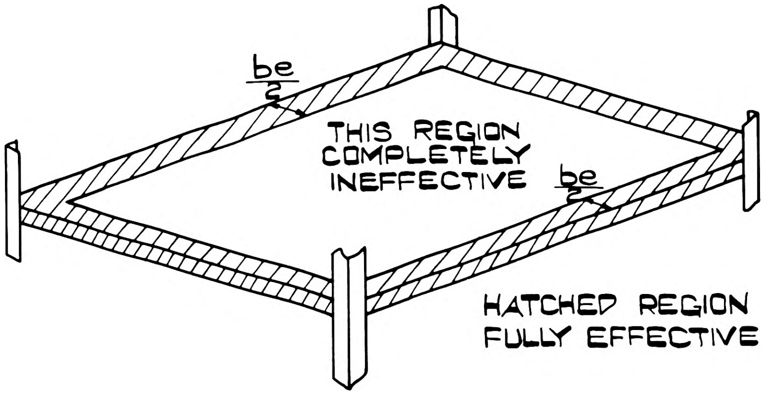


FIG 7 DIAGRAMMATIC ILLUSTRATION OF EFFECTIVE SHELF WIDTH

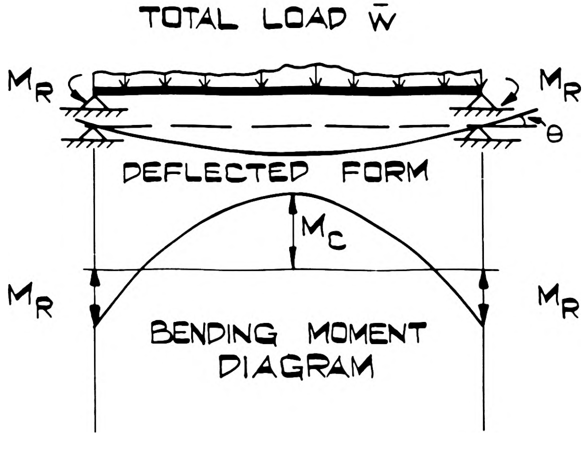


FIG 8 LOADS, DEFLECTIONS AND MOMENTS FOR CORNER PLATE SUPPORTED SHELF

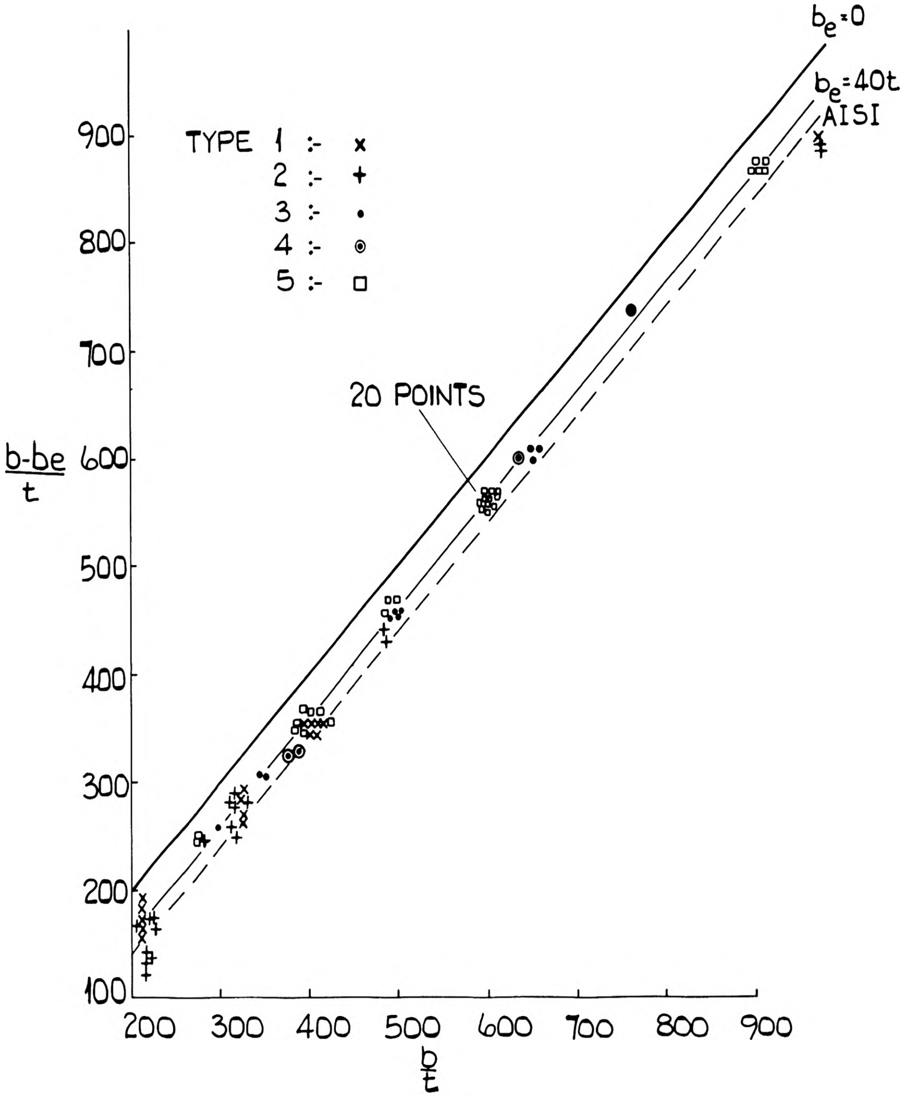


FIG 9 $\left(\frac{b-be}{t}\right)$ AGAINST $\left(\frac{b}{t}\right)$ FROM EXPERIMENTS ON SHELVES WITH CLIP OR BOLT SUPPORTS

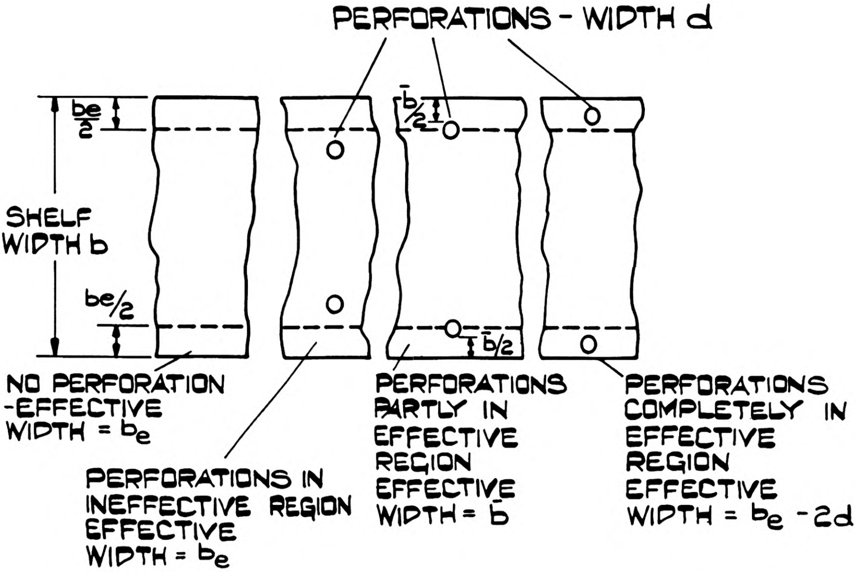


FIG 10 EFFECTS OF PERFORATIONS ON EFFECTIVE WIDTH

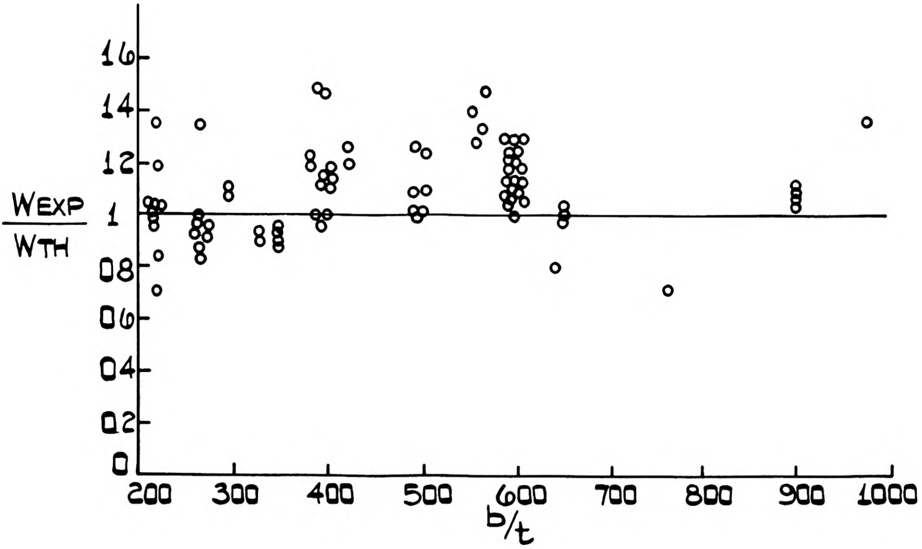


FIG 11 COMPARISON OF EXPERIMENTAL AND CALCULATED FAILURE LOADS

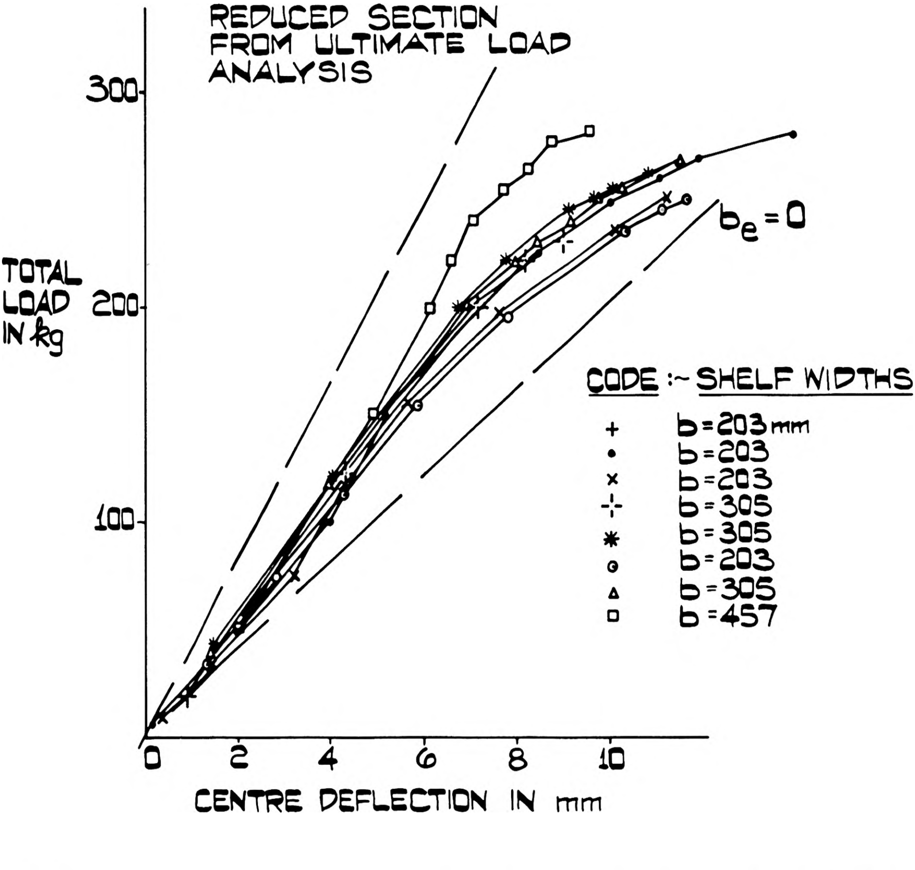


FIG 12 LOAD DEFLECTION CURVES FOR SHELVES OF TYPE 2

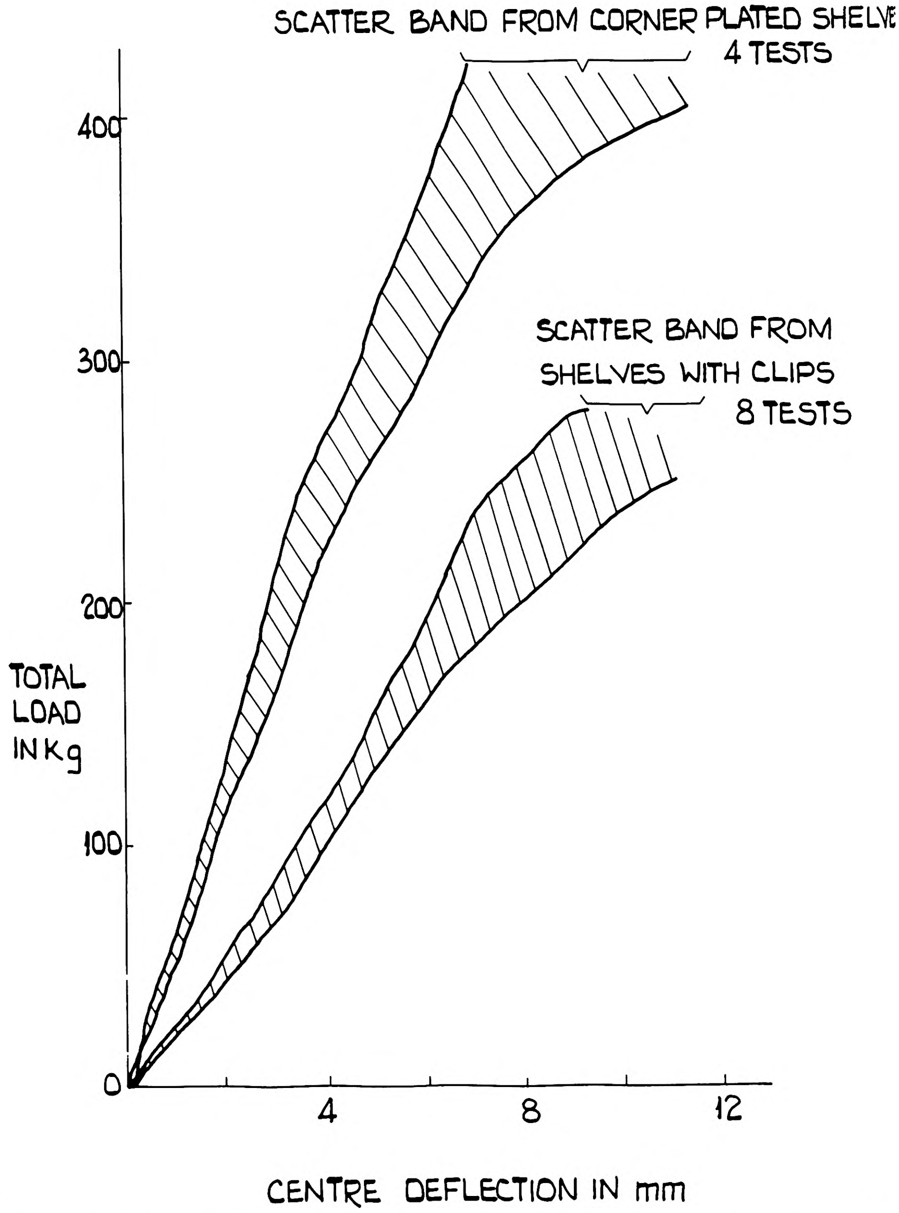


FIG 13 COMPARISON OF LOAD-DEFLECTION CURVES FOR SHELVES WITH CLIP SUPPORTS AND CORNER PLATE SUPPORTS

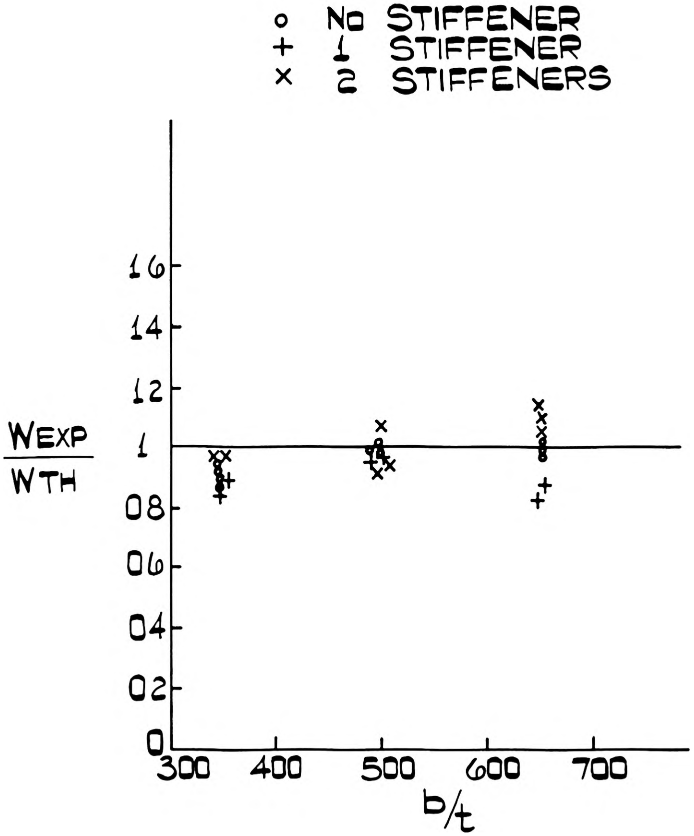
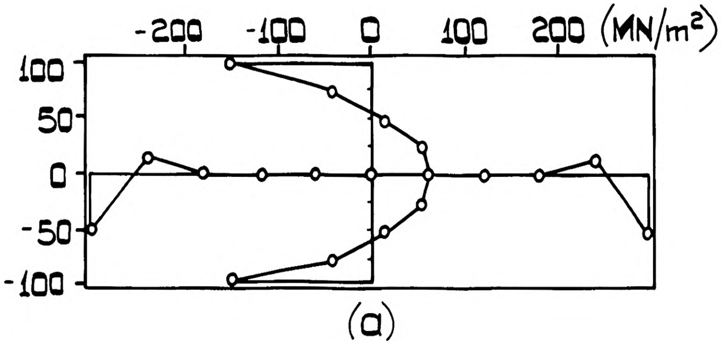


FIG 14 COMPARISON OF EXPERIMENTAL AND CALCULATED FAILURE LOADS FOR REINFORCED SHELVES



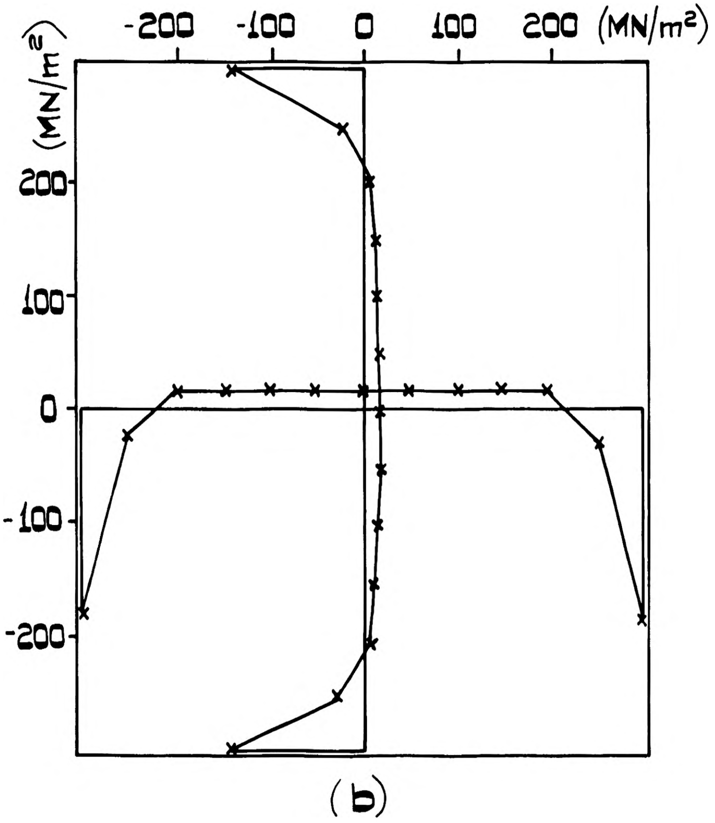


FIG 15 MEMBRANE STRESS DISTRIBUTION-FIXED SUPPORT(BOLTS); (a) 915mm x 305mm SHELF (b) 915mm x 915mm SHELF

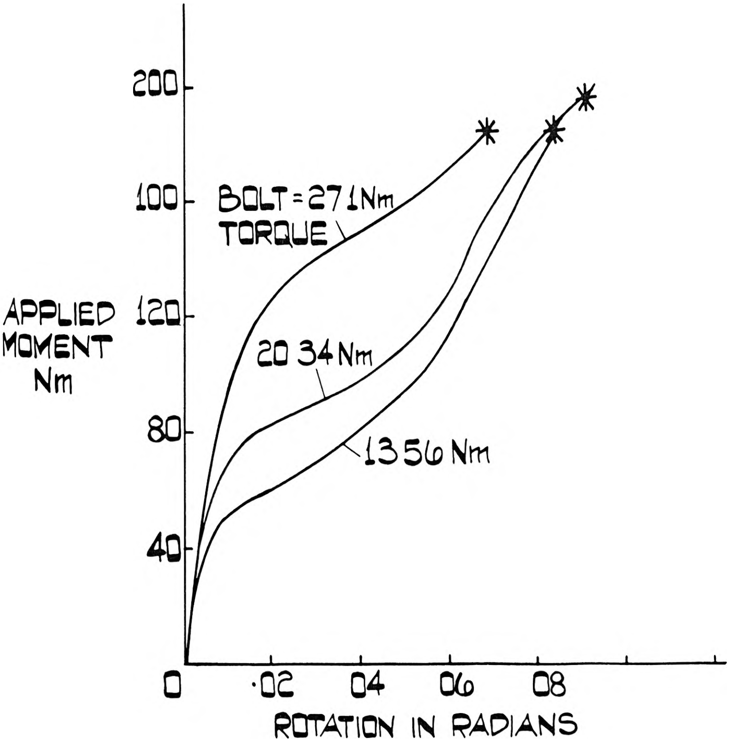


FIG 16 MOMENT-ROTATION CURVES FOR CORNER PLATES

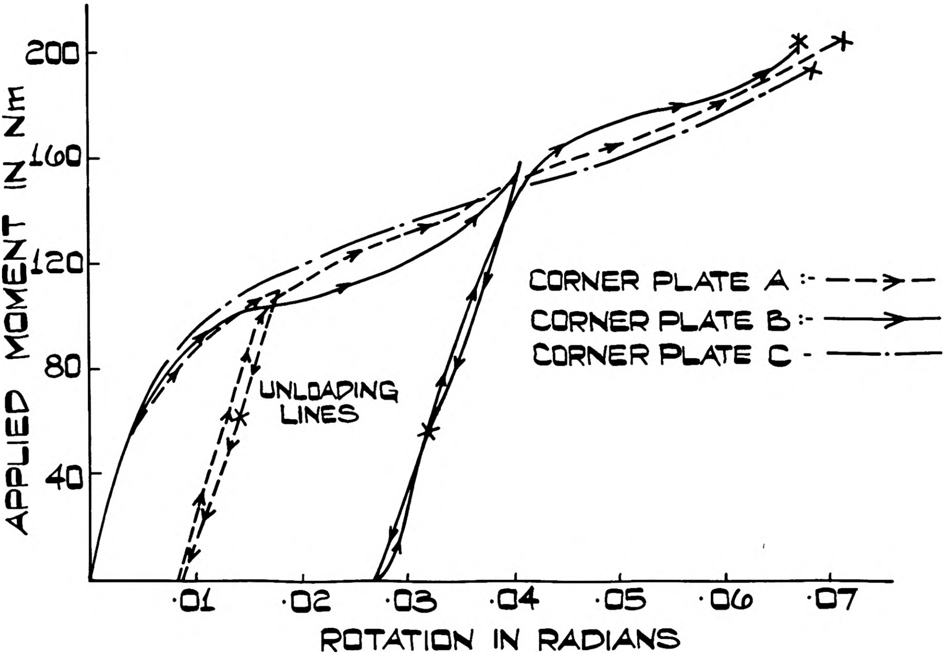


FIG 17 MOMENT ROTATION CURVES SHOWING UNLOADING AND RELOADING

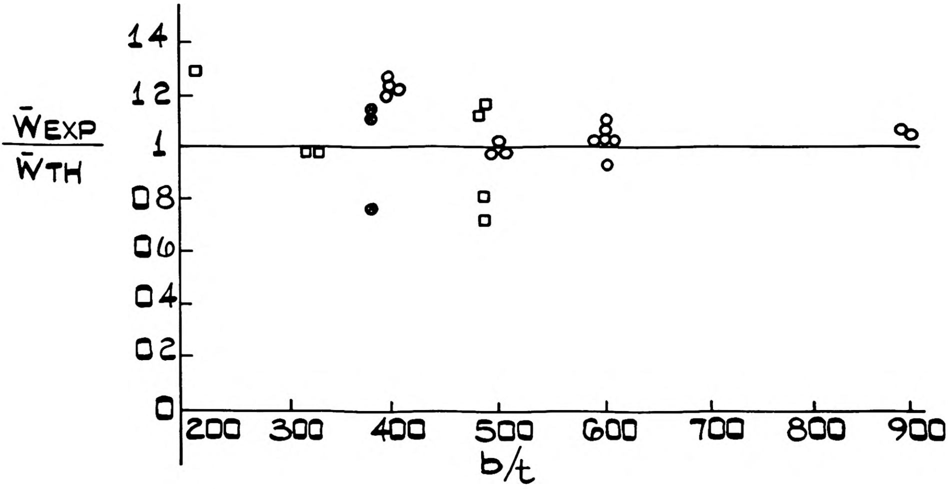


FIG 18 COMPARISON OF EXPERIMENTAL AND CALCULATED FAILURE LOADS FOR CORNER PLATE SUPPORTED SHELVES