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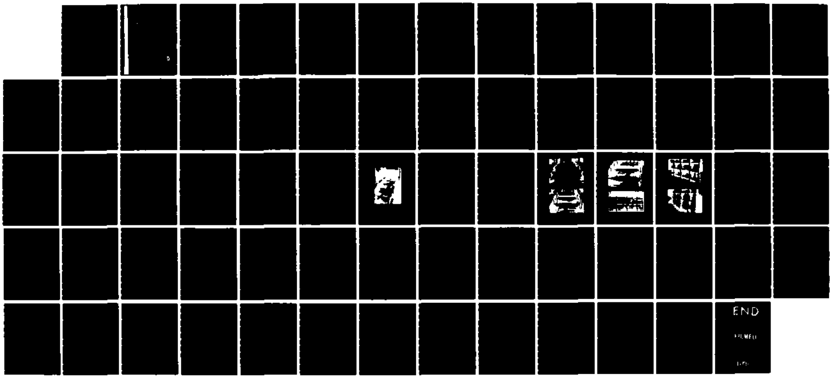

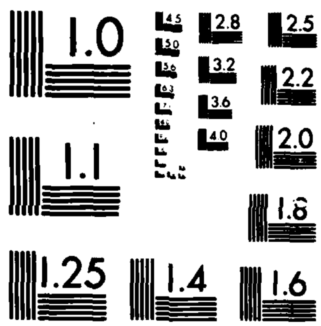

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INTERFRAME BUCKLING OF ALUMINIUM ALLOY STIFFENED PLATING (U)

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INTERFRAME BUCKLING OF ALUMINIUM ALLOY STIFFENED PLATING (UL)

BY

J D CLARKE AND J W SWAN

Summary (UL):

Compression tests on five stiffened N8 aluminium alloy plates covering typical full scale warship scantlings are described. The panels were manufactured using normal shipyard production methods to ensure typical initial distortion and residual stresses.

Maximum loads and post-buckling load/deflection results are compared with theoretical predictions using the ARE computer program N106C.

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INTERFRAME BUCKLING OF ALUMINIUM ALLOY STIFFENED PLATING

INTRODUCTION

1. Although the only recent major use of aluminium alloys in British warship hulls has been the superstructure of the Type 21 frigates, they have potential applications for advanced naval vessels eg SWATHs, hydrofoils and Surface Effect Ships. For this reason it was considered that a series of measurements and tests should be conducted to raise our understanding of the factors affecting the buckling of stiffened aluminium plating nearer to our current understanding of steel structures.

2. Four panels 3.7 m x 2.7 m with different plate and stiffener sizes were ordered from Yarrow Shipbuilders Ltd. Normal ship-building practice was requested for welding to ensure typical imperfections. During construction extensive measurements to obtain in-built residual stresses were taken by ARE and after manufacture the panels were surveyed to obtain plate and stiffener distortion (1)*. Each panel was then cut into two and end and side supports were welded on to give eight compression test specimens each having three longitudinals and two full frame spaces. Compression tests have now been carried out on five of these and the results are presented here and compared with theoretical estimates.

3. The tests were similar to those previously reported for stiffened steel structures (2) except that the sides of the specimens were supported only at the frames so that the failure mode was interframe buckling, and secondly the applied loading was displacement controlled so that the post-buckling behaviour could be monitored. A secondary objective of the tests was to check the theoretical estimates of post-buckling behaviour calculated by the ARE program N106C (3).

4. In parallel with these tests theoretical and experimental work was carried out on the development of weld induced residual stresses and distortion at Cambridge University (4) and on plate buckling at Imperial College (5) and Cambridge University (6,7).

EXPERIMENTAL DETAILS AND PROCEDURE

Details of Test Grillages

5. The stiffened panels from which the test grillages were taken were fabricated in N8 (5083) aluminium alloy. The first three panels had identical longitudinal stiffeners (38 x 76 mm x 1.65 kg/m T bars) with nominal plate thicknesses of 5, 8 and 12 mm. The fourth panel had 8 mm thick plating with 78 x 8 mm flat bar longitudinal stiffeners. In all cases the transverse frames were 64 x 127 mm x 3.85 kg/m T bars at a spacing of 1000mm.

*( ) References on Page 12

6. The panels were divided into two test grillages, each with dimensions as shown in Figure 1. This subdivision resulted in each grillage containing two different plates joined by a longitudinal butt weld offset from the centreline. The ends of the grillages were reinforced with doubler plates to avoid local failures and steel beams were used to distribute the load from the four jacks at one end and the six load cells at the other. The width of the plating along the outer edges was chosen to have an elastic buckling stress with one edge simply supported equal to that for a full width panel simply supported on both edges. Under elastic interframe buckling the grillage can therefore be considered to represent the combined behaviour of three longitudinal stiffener/plate sections. In the absence of buckling, ie for uniform elastic or plastic stresses the total cross sectional area represents approximately 2.75 stiffener/plate combinations. An estimated allowance for this difference has been made below when comparing measurements with theoretical predictions. The error in this estimate is thought to be small, but can be checked later using three dimensional elasto-plastic finite element analysis if considered necessary.

7. Average grillage dimensions and material properties are summarised in Table 1, and Table 2 gives plate slenderness parameters and upper limits to the failure loads based on plate buckling with no allowance for stiffener deformations.

<u>Yield Stress Measurements</u>

8. Tensile stress/strain measurements were made on at least six specimens from each plate and group of stiffeners. In order to establish the effect of strain rate and hold time a number of these were tested according to the recommendations of the DOE-TRRL Panel for Testing Procedures for Steel Models (8), ie at a strain rate of 300 $\mu\epsilon$/min with a hold of 2 mins at a strain of 0.005. Since it was found that testing at 3000 $\mu\epsilon$/min gave very similar results most of the testing was carried out at this rate. The average reduction in 0.2% proof stress at 300 $\mu\epsilon$/min below that at 3000 $\mu\epsilon$/min was 2%. There were further load reductions during the 2 min hold of 2.0% at a strain of 0.005 and 2.6% at 0.01.

9. Attempts were made to measure the compressive yield but these were not satisfactory because of buckling effects. Cambridge University (6) have developed a technique using small coupons with PTFE anti-buckling supports. They report compressive values for N8 aluminium alloy but there are no corresponding tensile values. In steel, comparisons (8) have given static yield values 3% higher in compression but the CP118 minimum specified proof stresses for N8 aluminium alloy are 5.6% lower in compression. In the absence of any other information it has been assumed in the theoretical analysis reported below that there is no significant difference in the yield behaviour in compression, but a total reduction of 4% has been allowed for hold time effects. This reduction has not been included in the values given in Table 1 or in the stress/strain curves for the stiffeners shown in Figures 2 to 4. It can be seen from the proof stress values in Table 1 that the variation from plate to plate is much greater than the hold time

correction. Within each plate the results are fairly consistent but results for the stiffeners showed a large scatter as can be seen from Figures 2 to 4. In fact the average proof stress of 87 MN/m^2 for the flat bar stiffener is below the minimum specification value of 125 MN/m^2 for N8 alloy (9).

Residual Stress and Distortion Measurements

10. Full details of the measurements on the original panels are given in (1). Residual stresses were determined from accurate distance measurements between indents on the plate surface before and after welding. Average and maximum values are given in Table 1. The stiffeners all exhibited a combination of direct and bending stress but there was no systematic correlation between the magnitude of the bending stress and the stiffener distortion.

11. Plate deformations are given in Table 1 and stiffener distortions in Table 3. The stiffener distortions were measured using three different methods. The original panels were surveyed with a displacement transducer mounted on a bar, and measurements were also made using a swept laser beam as a reference plane as reported in (1). As a further check some measurements were also made after the test grillages had been manufactured using the laser deflection method described in (10). All three sets of values, where available, are listed in Table 3. It can be seen that there are quite large differences in the results although they show similar trends. The initial measurements were all made on the plate side and some of the variation could be due to local distortions in the plate surface caused by welding. The laser measurements on the final grillages were made on both the plate side and on the stiffener flanges. The results again show the same trends with differences of typically 0.5 mm between measurements on either side. An exceptionally large difference was recorded for stiffener 6 of grillage 4A which also has the largest distortion measured on either side. In this case there may have been a significant difference in the weld gap during fabrication.

12. Table 3 also gives the values assumed in the theoretical analysis. Any apparently inconsistent values have been eliminated before taking averages.

Loading Rig and Instrumentation

13. The test frame is illustrated in Figure 5. The grillages were loaded by four 500 kN Dartec servohydraulic jacks operated in displacement mode. These incorporate load cells, but as a check on the longitudinal loading at the supports the load was also measured at the reaction end using six load cells. The supports at the frame ends were double bottle screws connected to bars which enabled the top and bottom connections to slide longitudinally under load. The upper supports can be seen in Figure 6, similar supports were attached underneath.

14. For grillage 3A theoretical estimates of the failure load (Figure 30) suggested that this might exceed the 2000 kN available, and two 250 kN pressure controlled jacks were added to

the rig for this test. When the load on the servohydraulic jacks reached 600 kN these jacks were switched in. Although the failure load did not exceed 2000 kN they were useful as it was found that the pump pressure was low and the servohydraulic jacks could only provide a total load of 1680 kN.

15. The strain in the plating and longitudinals was monitored using foil resistance strain gauges distributed as shown in Figure 7. These were recorded via a Peekel strain gauge logger for subsequent computer analysis. Plate and stiffener deflections were monitored by ARE deflection transducers arranged as shown in Figure 8. These were supported on a Dexion datum frame which has been removed in Figure 6 but can be seen in Figure 9a. The deflection signals were also recorded by the Peekel logger.

16. An additional measure of plate deflection was obtained from a transducer which was scanned along the centreline of the plate panels on the unwelded side (see track in Figure 8). The output was recorded on an X-Y plotter and subsequently digitised to produce scaled plots.

Test Procedure

17. The height of the test grillages within the rig was adjusted with the bottle screws until the centreline of the jacks and load cells coincided with the calculated position of the neutral axis. The flexure plates were than clamped in position.

18. The load was applied by the four jacks operating together in displacement mode so that the post buckling behaviour could be determined. At a number of points over the load/deflection curve the strains and deflections were logged. The deflection was held for at least three minutes before logging to minimise short term creep effects. At a number of load increments prior to buckling the load was returned to zero and the strains were logged so that stresses could be determined from the elastic relaxation. The plate deflection was scanned at each load point using the transducer mentioned above.

19. At the higher deflections care had to be taken to ensure that the grillage did not move the datum frame, and deflection transducers which were nearing their limiting range were removed or reset. The tests were continued until the overall behaviour could no longer be accurately monitored.

RESULTS

Load/Deflection Behaviour

20. The loading sequence and average deflections for each grillage are given in Tables 4a to 4e. The loads quoted are the average of the values given by the load cells and the jacks. The maximum differences between this average and the jack load were 2.6% at the maximum load and 3.8% at the maximum deflection. The longitudinal deflections quoted are the average values of the

differences between the appropriate four pairs of transducers illustrated in Figure 8. δ_1 is the length change over the frame space nearest to the jacks, δ_2 is the corresponding value for the other frame space, and δ_3 is the change in overall length of the grillage. In each case a contraction is shown as negative. As in general the measuring points did not coincide with the neutral axis a correction has been applied to allow for the effect of rotation of the transverse frames. The method used is described in Appendix A.

21. w_1 and w_2 are average values of the vertical deflections of the three stiffeners in each frame space relative to their ends (positive upwards). The deflections of each stiffener are listed separately in Tables 5a to 5e. The values for stiffeners deflecting downwards are less accurate for large deflections because of the effect of stiffener tripping, which tended to occur near the centre of the frame space, ie near the location of the vertical deflection transducer on the table.

22. The permanent deformation after the final load is illustrated in Figures 9 to 11. In many cases the maximum deflection did not coincide with the location of the deflection transducer so the results have not been presented here. In all cases the tripping only became noticeable in the post-buckling region and did not appear to influence the maximum load.

23. Figure 12 shows the load/deflection curves across both frame spaces for each grillage, and Figures 13 to 17 show the values for each frame space separately. For grillage 3A there was a sudden jump in deflection just past the maximum load and the probable path is shown dotted. In addition to the measurements taken after three minute holds, continuous load/overall grillage contraction plots were taken as an indication of the behaviour of the grillage during the test. For other grillages the load scale was the output from one jack only and the results are not included here. For grillage 3A, which was the last grillage tested, the jack signals were summed to give total load and the trace for the final loading is illustrated in Figure 18. It can be seen that near the maximum load the reduction during the three minute hold is considerable. The dynamic jump does not occur at constant grillage displacement because the frame acts as a spring and there is an additional contraction as the stiffness of the grillage reduces. The stiffness of the frame can be determined from the difference between the jack displacement and the overall grillage displacement. Results from all five tests fall within the band shown in Figure 19. The non-linearity is thought to be partly due to the initial closure of gaps, eg bolt clearances, in the rig. This plot can be used to define the limiting post-buckling stiffness which can be controlled in the frame.

24. It can be seen from Tables 4a and 5a that the stiffeners in grillage 1A did not behave similarly. In one frame space the outer stiffeners deformed vertically in opposite directions producing a considerable amount of twist in the structure. It was decided therefore to test the second grillage fabricated from Yarrows panel 1 as well. This grillage (1B) behaved much more uniformly, but as can be seen from Figure 12 the load/shortening curves were very similar.

Plate Deformation

25. Figures 20 to 23 show the plate deflection traces measured along the centreline of the plate panels on the unwelded side (see Figure 8). It was not possible to obtain a complete trace at some of the higher loads because the deflection transducer was out of range. In some cases therefore the permanent deformation shown corresponds to higher load values than for the deformation shown under load. Tables 4b to 4e give the load levels corresponding to the scan numbers.

26. A large part of the deflection, particularly in the case of grillage 3A which has the thickest plate, is due to the stiffener distortion. It can be seen that the plating generally buckles into three half waves and that the initial deformation, particularly for grillage 1B has a three half wave component.

Plate Stresses

27. The longitudinal stresses derived from the elastic strain relaxation is shown in Figures 24 to 26. Account was taken of transverse strains using a Poisson's ratio of 0.3. In the plate the values are the average of the top and bottom gauges. At the stiffener positions the values were interpolated to give the stress at the centre of the plate.

28. The reason for the low values on one gauge for grillage 3A is not known but could be due to partial failure of the adhesive. The average plate stresses have been derived by integrating these values and are plotted against edge strain as a fraction of yield values in Figure 27. These plots have been used to check the validity of the stress/strain curves assumed in the theoretical analysis discussed below.

COMPARISON WITH THEORETICAL PREDICTIONS

29. A number of calculations have been carried out using the computer program N106C (3) to give an indication of the accuracy of this program in predicting maximum loads and post-buckling behaviour. A single stiffener and associated plating was represented and symmetric behaviour was assumed beyond the mid frame positions. Each half frame length was subdivided into ten elements each with twenty fibres representing the stiffener and one variable width fibre representing the plating. Since measured residual stresses in the stiffeners were low and variable in sign they were ignored in this analysis.

30. Following the recommendation of Dier and Dowling (6) and Moflin and Dwight (6) it was assumed that the non dimensionalised plate behaviour could be represented by that for steel with the same β value $\left(\beta = b/t\sqrt{\frac{\sigma_0}{E}}\right)$. Appropriate curves were therefore selected (via the parameter NEW in N106) which corresponded to a b/t value which for steel would give the same β. This was not possible for grillage 1B since the equivalent b/t in steel (160)

was outside the range of values incorporated in the program. From the residual stress and distortion measurements (1) it appeared that the appropriate curves would be between the "nearly perfect" and "moderate" sets given in (3). Since the effective b/t values did not coincide exactly with the values available calculations were carried out for two NEW values which bracketed the range, ie "nearly perfect", low b/t and "moderate", high b/t. For grillage 1B the best approximation available was to use the b/t = 90 curve for "severe" imperfections. This was slightly above the curve shown in Figure 27. Calculations were also carried out for this grillage using the Faulkner formula (NEW = 3). In each case calculations were made using the average, and maximum vertical stiffener distortions given in Table 3. The average values are probably more representative as there will be an interaction in the buckling behaviour of adjacent stiffeners.

31. Results of the calculations are compared with the measured load/shortening behaviour in Figures 28 to 31. Except in the case of grillage 3A where the calculated load/displacement curve has a sharp peak, the estimates of maximum load bracket the measured values. In each case however the post-buckling load carrying capability is underestimated. One contribution to this difference is the rotational restraint at the ends of the transverse frames provided by the supports. The rotational stiffness of these supports was measured after the tests by applying a known moment and results are given in Figure 32. Over the initial part of the range the plot is linear with a stiffness of 2.0×10^7 Nmm/radian which corresponds to 1.4×10^7 Nmm/radian per stiffener. Figure 33 shows the effect of rotational constraint on the buckling behaviour of grillage 1B (NEW = 31, Average stiffener distortion). The measured value of 1.4×10^7 Nmm/radian gives a significant increase in the post-buckling strength, but a value of approximately 5×10^7 Nmm/radian would be needed to match the observed behaviour. A possible explanation is the effect of the short end frames which are reinforced with doubler plates. These are not represented by the simple two half span model used for these comparisons.

RECOMMENDATIONS FOR FURTHER WORK

32. It is important to establish the reason for the difference in the predicted and measured post-buckling behaviour. Some N106C calculations should therefore be carried out using a four span representation which includes the effect of the stiffer end sections. The effect of residual stresses in the stiffeners should also be investigated to see if these are a possible reason for the over-estimate of the peak load for grillage 3A.

33. There are three remaining test grillages 2B, 3B and 4B. These have welded edge supports but have not been strain gauged. Consideration will be given to testing these with fully rotational frame supports to eliminate this uncertainty in the comparison. Attention will also be given to the accurate measurements of longitudinal displacements, but it should be possible to simplify the instrumentation by omitting the strain measurements and some of the deflection measurements.

CONCLUSIONS

34. One of the most significant facts to emerge from these tests is the variation in yield strength in material which is supposed to satisfy the N8 specification. If aluminium alloy is used in future ships in critical locations where strength is important it will be necessary to have adequate quality control.

35. It appears that in most cases the maximum strength of aluminium alloy structures can be calculated using N106C with the plating behaviour represented by an equivalent steel b/t value giving the same β. It should be noted that the peak load for sharply varying load/deflection curves may be overestimated.

36. The post-buckling strength measured during the test was higher than that predicted by the simple two half frame finite element model used. This was partly due to the rotational restraint at the frame ends but could also be due to the additional rotational restraint at the ends provided by the short sections with doubler plates. It should be noted that since design calculations are usually carried out using the two half frame representation, there will be a similar underestimation of the post-buckling strength for stiffeners close to hard corners where the frame rotation is constrained and in cases where the collapse only occurs over one or two frame spaces.

37. In future tests care should be taken to minimise errors in longitudinal displacements caused by frame rotation.

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38. The authors would like to acknowledge the assistance of many ARE personnel in conducting these tests. In particular Mr Somerville for the procurement of the panels and measurement of imperfections, Mr Penman and Mr Aitcheson for tensile testing, distortion measurements, instrumentation and assistance with the analysis, Mr Hugill for some of the N106 calculations, and Mr Adamson and Mr Duncan for carefully setting up the grillages and their instrumentation in the test frame.

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TABLE 1

AVERAGE GRILLAGE DIMENSIONS, YIELD STRENGTH AND INITIAL IMPERFECTIONS
(Plate A is smaller plate, width 0.41 of total)

Grillage No		PLATE						LONGITUDINAL STIFFENERS					
		Thickness (mm)	0.2% Proof stress (MN/m^2) (1)	σ/t (2)		Compressive residual stress (MN/m^2)		Thickness (mm)		0.2% Proof stress (MN/m^2) (1)	Residual stress (MN/m^2) at top of stiffener		
				Ave	Max	Ave	Max	Web	Table		Ave	Min	Max
1A	Plate A	5.01	274 ± 3										
	Plate B	5.06	288 ± 3										
	Average	5.04	282	0.76	0.86	27	38	4.32	7.90	162 ± 12	-8	-20	+3
1B	Plate A	5.01	274 ± 3										
	Plate B	4.98	257 ± 2										
	Average	4.99	264	1.06	1.94	27	38	4.31	7.90	162 ± 12	-8	-20	+3
2A	Plate A	7.39	157 ± 7										
	Plate B	7.32	166 ± 4										
	Average	7.35	162	0.39	0.52	26	32	4.37	7.97	178 ± 28	+1	-17	+12
3A	Plate A	12.34	189 ± 8										
	Plate B	12.37	189 ± 8										
	Average	12.36	183	0.13	0.22	21	24	4.31	7.90	178 ± 17	-15	-29	+5
4A	Plate A	8.23	157 ± 6										
	Plate B	7.23	164 ± 3										
	Average	7.69	161	0.44	0.52	37	44	9.37	-	87 ± 3	-17	-70	+37

Notes (1) Mean and standard deviation from tensile tests at 3000 με/mm on six specimens. Reductions for compressive loading and hold time are discussed in the text.

(2) Central plate deflection/plate thickness.

TABLE 2

SQUASH LOADS AND UPPER ESTIMATE OF FAILURE LOAD FROM EFFECTIVE WIDTH

Grillage	Area (mm^2) Plate (A_p)	Area (mm^2) Stiffeners (A_s)	Average Yield Stress (MN/m^2) Plate (σ_p)	Average Yield Stress (MN/m^2) Stiffeners (σ_s)	b/t	β (1)	b_e/b (2) $2/\beta - 1/\beta^2$	b_e/b (2) from Ref (6)	Squash Load (kN)	Upper Est. of failure load (kN) (3)	Actual failure load (kN)
1A	6212	1783	282	162	91.2	5.81	0.31	0.34	2041	832	850
1B	6200	1781	264	162	91.4	5.64	0.32	0.34	1925	812	800
2A	9139	1800	162	178	62.0	3.01	0.55	0.48	1801	1135	1070
3A	15326	1781	189	178	37.0	1.93	0.77	0.72	3214	2547	1710
4A	9536	2136	161	87	59.4	2.83	0.58	0.48	1721	1076	760

Notes: (1) $\beta = b/t \sqrt{\sigma_o/E}$ using 0.2% Proof Stress for σ_o and 69400 N/mm^2 for E

(2) Effective width/panel width

(3) From $b_e/b \; A_p \sigma_p + A_s \sigma_s$ using b_e/b from $2/\beta - 1/\beta^2$ (Faulkner formula)

TABLE 3

INTERFRAME GIRDER DISTORTION

Vertical deflection at midframe position with respect to line through frames (mm)
+ve in direction of stiffeners

GRILLAGE	FRAME	LONGL.	PLATE SIDE			TOP OF STIFFENER	AVERAGE	VALUES USED IN CALCULATION	
			(a)	(b)	(c)	(c)		AVE.	MAX.
1A	1-2	1	-	-0.3	-	-0.4	-0.3	+0.7	+1.2
		2	(+0.1)	+1.3	-	+1.2	+1.2		
		3	+1.1	+1.3	-	+1.1	+1.2		
	2-3	1	-	+0.1	-	+0.1	+0.1	-0.4	-0.9
		2	(-0.2)	-1.0	-	-0.9	-0.9		
		3	(+0.1)	-0.5	-	-0.4	-0.4		
1B	1-2	4	+1.1	+1.9	+0.2	+0.5	+0.9	+0.5	+1.1
		5	+0.9	+1.4	+0.7	+1.3	+1.1		
		6	-	-0.1	-1.3	-0.4	-0.6		
	2-3	4	+0.1	-0.2	-0.2	0	-0.1	+0.1	-0.2
		5	+0.7	+0.2	+0.6	+0.4	+0.5		
		6	-	-0.2	-0.2	-0.1	-0.2		
2A	1-2	4	+0.8	+1.3	-	-	+1.0	0.0	-1.3
		5	0	0	-	-	0		
		6	-	-1.3	-	-	-1.3		
	2-3	4	+0.5	+2.1	-	-	+1.3	+0.4	+1.3
		5	0	+0.2	-	-	+0.1		
		6	-	-0.1	-	-	-0.1		
3A	1-2	1	-	-	-1.8	-1.5	-1.6	-0.7	-1.6
		2	-0.6	-0.8	-1.0	-0.7	-0.8		
		3	+0.3	+0.5	-0.1	+0.2	+0.2		
	2-3	1	-	-	-0.8	-0.5	-0.6	-0.2	-0.6
		2	-0.1	-0.2	0	-0.2	-0.1		
		3	-0.3	0	-0.2	+0.6	0.0		

TABLE 3 CONT'D

GRILLAGE	FRAME	LONGL.	PLATE SIDE (a)	PLATE SIDE (b)	PLATE SIDE (c)	TOP OF STIFFENER (c)	AVERAGE	VALUES USED IN CALCULATION AVE.	VALUES USED IN CALCULATION MAX.
4A	1-2	4	+1.7	+2.4	-	+1.1	+1.7	+1.0	+1.7
		5	+0.5	-0.4	-	0	0		
		6	-	-	-	+1.3	+1.3		
	2-3	4	-2.1	-1.9	-2.0	-1.2	-1.7	-2.3	-4.9
		5	-0.1	-0.4	-0.5	-0.2	-0.3		
		6	-	-	-2.8	-7.0	-4.9		

Methods of measurement

(a) From linear deflection transducer after correction for straightness of slide bar.

(b) Measurement from swept laser plane.

(c) Laser deflection transducer.

Values in brackets have not been included in the average since they appear inconsistent.

TABLE 4a

GRILLAGE 1A LOADING SEQUENCE AND AVERAGE DEFLECTIONS

(See RESULTS section in text for definition of δ and w)

SCAN NO.	LOAD (kN)	JACK DEFL. (mm)	LONGL. DEFL. (mm)			VERT. DEFL. (mm)		REMARKS
			δ_1	δ_2	$\delta_1 + \delta_2$	$\bar{w}_1$	$\bar{w}_2$	
1	0	0						
2	91	1.5	-0.2	-0.3	-0.5			
3	0	-						
4	207	3.2	-0.5	-0.5	-1.0			
5	0	-						
6	313	5.1	-0.7	-0.8	-1.5			
7	0	-						
8	427	7.1	-1.0	-1.3	-2.3			
9	0	-						
10	542	9.2	-1.3	-1.6	-2.9	-0.2	+0.1	)
11	0	-						)Large differences
12	0	-						)between vertical
13	648	10.4	-1.9	-1.8	-3.7	+0.1	+0.1	)stiffener deflec-
14	0	-						)tions in each
15	722	12.0	-1.8	-2.2	-4.0	+0.3	+0.2	)frame space
16	0	-						)see Table 5a
17	834	15.0	-2.4	-3.3	-5.7	+0.6	-1.4	)
18	836	18.0	-3.2	-4.4	-7.6	+0.9	-4.0	)
19	762	21.0	-4.2	-5.2	-9.2	*	*	
20	761	21.0						Repeat after moving limiting deflection transducers
21	673	26.0	-5.1	-6.9	-12.0			
22	562	30.5	-7.4	-8.6	-16.0			
23	549	32.4	-7.1	-9.2	-16.3			
24	0	-						

* Transducers out of range

TABLE 4b

GRILLAGE 1B LOADING SEQUENCE AND AVERAGE DEFLECTIONS

SCAN NO.	LOAD (kN)	JACK DEFL. (mm)	LONGL. DEFL. (mm)			VERT. DEFL. (mm)		REMARKS
			δ_1	δ_2	δ_3	$\bar{w}_1$	$\bar{w}_2$	
1	0	0						
2	22	1	-0.1	-0.1	-0.2	0.1	0.1	
3	62	2	-0.2	-0.3	-0.3	0.1	0.1	
4	119	3	-0.3	-0.4	-0.6	0.1	0.2	
5	0	-	0.0	0.0	-0.1	0.0	0.0	
6	172	4	-0.3	-0.6	-1.0	0.2	0.2	
7	0	-	-0.1	0.0	-0.1	0.0	0.0	
8	295	6	-0.7	-0.9	-1.8	0.4	0.3	
9	0	-	0.1	-0.1	-0.1	0.0	0.0	
10	422	8	-1.0	-1.3	-2.8	0.6	0.4	
11	0	-	0.0	-0.1	-0.1	0.0	0.0	
12	543	10	-1.4	-1.6	-3.8	0.9	0.5	
13	0	-	0.0	-0.1	-0.1	0.0	0.0	
14	653	12	-1.8	-2.0	-5.0	1.3	0.5	
15	0	-	-0.1	0.0	-0.3	0.0	-0.1	
16	0	-	-0.2	-0.3	-0.1	0.1	-0.1	Repeat zero on second day of test
17	713	12	-2.2	-2.4	-6.1	1.9	0.3	
18	787	14	-2.7	-2.9	-7.7	3.2	-0.3	
19	0	-	-0.4	-0.2	-1.0	0.8	-0.3	
20	785	16	-4.3	-2.8	-9.6	7.3	-2.7	Max load 800 kN
21	686	19	-6.6	-2.8	-12.6	16.6	-7.1	
22	0	-	-3.8	-0.9	-5.8	10.2	-5.0	
23	586	22	-9.0	-4.4	-16.7	22.9	-13.6	
24	553	25	-10.2	-5.2	-18.8	26.4	-15.0	
25	490	30	-13.1	-5.6	-24.5	34.7	-19.1	
26	0	-	-10.5	-4.7	-18.2	27.0	-14.0	

TABLE 4c

GRILLAGE 2A LOADING SEQUENCE AND AVERAGE DEFLECTIONS

SCAN NO.	LOAD (kN)	JACK DEFL. (mm)	LONGL. DEFL. (mm)			VERT. DEFL. (mm)		REMARKS
			δ_1	δ_2	δ_3	$\bar{w}_1$ (a)	$\bar{w}_2$ (a)	
1	0	0						
2	54	1.2	+0.1	-0.1	-0.3	0.0	0.03	
3	99	1.9	+0.1	-0.1	-0.5	0.02	0.03	
4	202	3.4	-0.1	-0.2	-0.9	0.10	0.09	
5	297	4.5	-0.2	-0.3	-1.3	0.17	0.17	
6	0	-	0.1	-0.3	0.0	-0.02	0.08	
7	0	-	0.1	-0.3	0.0	0.05	0.11	Repeat zero after modifications to plate deflection transducer
8	455	6.1	-0.4	-0.5	-2.0	0.27	0.22	
9	585	7.4	-0.6	-0.7	-2.7	0.40	0.28	
10	741	8.6	-0.8	-0.9	-3.6	0.52	0.38	
11	0	0	-0.4	-0.0	-0.2	0.14	0.14	
12	883	9.5	-1.4	-1.3	-4.9	0.71	0.74	
13	961	11.0	-1.6	-1.7	-5.8	0.99	1.04	
14	0	-	-0.6	-0.4	-1.0	0.34	0.41	
15	1023	12.5	-2.0	-2.0	-7.0	1.30	1.41	
16	1063	14.1	-2.4	-2.6	-8.2	1.73	2.04	
17	0	-	-1.0	-0.6	-1.8	1.00	1.13	
18	1064	15.6	-3.1	-2.8	-9.9	3.16	2.82	
19	1057	18.1	-3.8	-3.8	-12.1	5.20	5.19	
20	0	-	-2.0	-2.3	-4.5	3.42	3.43	
21	1034	20.0	-5.0	-3.7	-14.3	8.78	4.99	
22	1012	22.2	-5.8	-4.1	-16.1	11.1	6.40	
23	985	24.2	-7.1	-4.1	-17.9	15.0	6.12	
24	927	26.2	-8.4	-3.7	-20.0	(23.0) (b)	4.61	
25	836	28.2	-10.3	-3.6	-22.5	(34.0) (b)	1.87	
26	0	-	-9.1	-3.5	-13.4	(25.0) (b)	2.99	

Notes: (a) Large variation between stiffeners - see Table 5c
(b) Estimated value - one or more transducers out of range.

TABLE 4d

GRILLAGE 3A LOADING SEQUENCE AND AVERAGE DEFLECTIONS

SCAN NO	LOAD (kN)	JACK DEFL. (mm)	LONGL. DEFL. (mm) δ_1	δ_2	δ_3	VERT. DEFL. (mm) $\bar{w}_1$	$\bar{w}_2$
1	0	0					
2	198	2.6	0.0	-0.2	-0.6	-0.2	-0.1
3	398	4.6	-0.2	-0.4	-1.0	-0.3	-0.1
4	600	6.4	-0.3	-0.5	-1.6	-0.5	0.0
5	0	-	0.0	0.1	0.0	-0.1	-0.1
6	996	10.5	-0.7	-0.8	-2.8	-0.9	-0.1
7	0	-	0.1	0.0	0.0	-0.1	-0.1
8	1185	11.9	-0.8	-1.0	-3.5	-1.1	-0.1
9	0	-	0.0	-0.1	-0.1	-0.1	-0.1
10	1377	13.1	-1.2	-1.3	-4.3	-1.4	-0.1
11	0	-	-0.1	-0.1	-0.1	-0.1	0.0
12	1574	13.8	-1.2	-1.5	-5.0	-2.0	+0.5
13	0	-	-0.1	-0.2	-0.4	-0.4	0.0
14	0	-	-0.1	-0.2	-0.4	-0.4	+0.1
15	1663	15.7	-1.4	-1.8	-5.4	-2.7	+0.9
16	0	-	-0.2	-0.3	-0.4	-0.9	+0.3
17	0	-	-0.1	-0.3	-0.5	-1.0	+0.3
18	1685	16.2	-1.8	-2.4	-6.3	-12 *	+4.0
19	842	17.4	-8.9	-2.6	-11.0	-32 *	+16.0
20	808	20.2	-12.2	-2.7	-13.8	-35 *	+18.0
21	648	25.0	-12.8	-4.8	-19.3	-80 *	+20.2
22	0	6.7	-8.6	-1.6	-10.4	-53 *	+13.3

* Transducers out of range; values estimated from plate deformation trace and direct measurement after test.

TABLE 4e

GRILLAGE 4A LOADING SEQUENCE AND AVERAGE DEFLECTIONS

SCAN NO	LOAD (kN)	JACK DEFL. (mm)	LONGL. DEFL. (mm)			VERT. DEFL. (mm)	
			δ_1	δ_2	δ_3	$\bar{w}_1$	$\bar{w}_2$
1	0	0					
2	96	1.9	-0.0	-0.1	-0.44	-0.1	+0.1
3	166	3.0	-0.1	-0.2	-0.64	-0.1	+0.2
4	254	4.1	-0.3	-0.2	-0.94	-0.2	+0.3
5	0	-	-0.2	+0.3	+0.19	-0.1	0.0
6	441	6.0	-0.6	-0.4	-1.68	-0.4	+0.5
7	595	7.8	-0.7	-0.7	-2.37	-1.3	-1.0
8	0	-	-0.4	+0.4	-0.12	-0.5	+0.3
9	716	9.3	-1.0	-1.1	-3.08	-2.8	+1.9
10	757	11.4	-1.8	-2.1	-4.89	-13.0	+7.8
11	0	-	-0.5	0.0	-1.29	-9.5	+4.1
12	0	-	-0.6	-0.2	-1.12	-9.1	+4.2
13	572	9.0	-1.4	-1.7	-3.91	-12.6	+6.2
14	659	10.1	-1.6	-1.8	-4.40	-12.4	+6.8
15	0	-	-0.4	0.0	-1.28	-9.6	+4.1
16	723	11.0	-1.8	-2.1	-4.89	-14.5	+7.5
17	619	12.0	-3.0	-3.0	-6.03	-23.2	+13.5
18	577	12.4	-3.2	-2.7	-6.60	*	+15.9
19	535	13.0	-3.7	-3.0	-7.24	*	+19.0
20	488	14.0	-4.2	-3.5	-8.42	*	+22.2
21	426	16.1	-4.9	-4.9	-10.5	*	+27.9
22	386	18.1	-6.3	-6.5	-12.4	*	+30.6
23	0	-	-4.3	-1.0	-7.4	-40 †	+24.1

* Transducers out of range

† Estimated from plate deformation trace

TABLE 5a

GRILLAGE 1A VERTICAL DEFLECTIONS OF STIFFENERS

+ve upwards

SCAN NO.	LOAD (kN)	CHANNEL NO. (SEE FIGURE 8)					
		116	117	119	123	124	126
		Deflection relative to ends (mm)					
10	542	-0.3	-0.2	0.0	0.0	-0.2	+0.3
13	648	+0.3	+0.1	+0.1	+0.1	-0.3	+0.5
15	722	+0.5	+0.3	-0.1	+0.2	-0.3	+0.7
17	834	+1.3	+1.2	-0.9	-1.1	-2.3	+0.8
18	836	+2.2	+2.0	-1.5	-6.5	-6.5	-0.2

TABLE 5b

GRILLAGE 1B VERTICAL DEFLECTIONS OF STIFFENERS

+ve upwards

SCAN NO.	LOAD (kN)	CHANNEL NO. (SEE FIGURE 8)					
		116	117	119	123	124	126
		Deflections relative to ends (mm)					
1	0						
2	22	+0.05	+0.14	+0.03	+0.11	+0.22	+0.06
3	62	+0.08	+0.07	+0.03	+0.23	+0.19	-0.05
4	119	+0.16	+0.06	+0.07	+0.37	+0.31	-0.19
5	0	+0.04	+0.01	+0.06	+0.02	-0.03	-0.01
6	172	+0.35	+0.13	+0.10	+0.47	+0.43	-0.37
7	0	+0.02	0.0	+0.05	+0.02	-0.05	+0.02
8	295	+0.77	+0.30	+0.07	+0.55	+0.65	-0.35
9	0	+0.02	-0.02	+0.04	+0.02	-0.07	-0.01
10	422	+1.16	+0.47	+0.22	+0.61	+0.79	-0.21
11	0	+0.02	-0.03	+0.03	+0.01	-0.08	-0.03
12	543	+1.57	+0.73	+0.38	+0.61	+0.92	-0.13
13	0	+0.03	+0.04	+0.02	+0.03	-0.12	-0.03
14	653	+2.01	+1.22	+0.71	+0.54	+0.93	+0.05
15	0	+0.11	0.0	-0.06	-0.11	-0.19	+0.05
16	0	+0.28	+0.01	-0.10	-0.05	-0.13	-0.12
17	713	+2.83	+1.93	+0.95	+0.18	+0.66	-0.02
18	787	+4.30	+3.39	+1.79	-0.81	+0.13	-0.25
19	0	+1.20	+0.93	+0.32	-1.06	-0.81	+0.85
20	785	+9.69	+7.33	+4.91	-3.17	-2.60	-2.21
21	686	+18.31	+16.70	+14.78	-6.83	-8.10	-6.28
22	0	+11.41	+10.36	+8.98	-5.95	-6.16	-2.75
23	586	+23.77	+23.01	+21.82	-15.73	-13.74	-11.38
24	553	+25.77	+26.62	+26.73	*	*	-14.21
25	490	+32.61	+35.55	+36.08	*	*	-19.13
26	0	+25.40	+28.80	+26.90	-15.50	-13.60	-13.00

* Transducer out of range

TABLE 5c

GRILLAGE 2A VERTICAL DEFLECTIONS OF STIFFENERS

+ve upwards

SCAN NO.	LOAD (kN)	CHANNEL NO. (SEE FIGURE 8) 116	117	119	123	124	126
		Deflections relative to ends (mm)					
1	0						
2	54	-0.01	+0.06	+0.06	+0.06	-0.03	+0.05
3	99	-0.09	+0.05	+0.10	+0.03	+0.05	+0.02
4	202	-0.03	+0.13	+0.20	+0.09	+0.13	+0.05
5	297	+0.05	+0.23	+0.24	+0.14	+0.20	+0.17
6	0	-0.08	+0.13	+0.11	-0.03	+0.20	+0.06
7	0	-0.15	+0.15	+0.14	0.0	+0.25	+0.07
8	455	+0.12	+0.35	+0.34	+0.24	+0.35	+0.07
9	585	+0.22	+0.47	+0.51	+0.34	+0.36	+0.13
10	741	+0.38	+0.54	+0.65	+0.52	+0.37	+0.26
11	0	0.0	+0.21	+0.22	-0.01	+0.33	+0.11
12	883	+0.68	+0.43	+1.02	+0.84	+0.66	+0.73
13	961	+0.95	+0.54	+1.48	+1.24	+0.85	+1.04
14	0	+0.23	+0.29	+0.51	+0.31	+0.56	+0.37
15	1023	+1.23	+0.75	+1.91	+1.82	+1.14	+1.27
16	1063	+1.54	+0.90	+2.74	+2.87	+1.64	+1.60
17	0	+0.82	+0.48	+1.69	+1.51	+1.05	+0.83
18	1064	+2.50	+2.56	+4.43	+4.62	+2.56	+1.28
19	1057	+2.28	+4.90	+8.41	+9.71	+4.62	+1.23
20	0	+1.20	+3.08	+5.98	+6.44	+2.96	+0.88
21	1034	+5.33	+9.23	+11.77	+10.52	+4.35	+0.09
22	1012	+5.51	+12.01	+15.79	+14.19	+5.60	-0.58
23	985	+8.67	+16.55	+19.76	+15.08	+5.09	-1.80
24	927	+15.36	+22.70	*	+13.96	+3.35	-3.49
25	836	+22.43	*	*	+12.26	-0.69	-5.96
26	0	+16.21	*	*	+9.87	+1.31	-2.21

* Transducer out of range

TABLE 5d

GRILLAGE 3A VERTICAL DEFLECTIONS OF STIFFENERS

+ve upwards

SCAN NO.	LOAD (kN)	CHANNEL NO. (SEE FIGURE 8) 116	117	119	123	124	126
		Deflections relative to ends (mm)					
1	0						
2	198	-0.08	-0.33	-0.20	+0.03	-0.21	-0.02
3	398	-0.14	-0.58	-0.33	+0.04	-0.27	+0.03
4	600	-0.20	-0.85	-0.44	+0.07	-0.30	+0.11
5	0	-0.05	-0.08	-0.16	0.0	-0.13	-0.14
6	996	-0.37	-1.56	-0.79	+0.13	-0.57	+0.19
7	0	-0.03	-0.11	-0.14	+0.08	-0.13	-0.15
8	1185	-0.43	-1.97	-1.03	+0.15	-0.72	+0.24
9	0	+0.01	-0.15	-0.24	+0.13	-0.18	-0.17
10	1377	-0.59	-2.39	-1.34	+0.30	-0.51	+0.62
11	0	+0.12	-0.16	-0.21	+0.13	-0.13	-0.09
12	1574	-0.85	-3.33	-1.93	+0.58	-0.35	+1.29
13	0	+0.03	-0.59	-0.59	+0.28	-0.19	+0.05
14	0	+0.08	-0.60	-0.59	+0.28	-0.21	+0.09
15	1663	-1.44	-3.91	-2.85	+0.88	-0.11	+1.96
16	0	-0.28	-1.38	-1.16	+0.49	-0.12	+0.40
17	0	-0.28	-1.51	-1.22	+0.51	-0.18	+0.45
18	1685	-10.33	-2.82	*	+3.08	+2.32	+6.60
19	842	*	-4.74	*	+12.34	+15.65	+19.91
20	808	*	*	*	+13.94	+18.01	+22.06
21	648	*	*	*	+15.19	+20.31	+24.97
22	0	*	*	*	+10.40	+13.57	+15.94

* Transducer out of range

TABLE 5e

GRILLAGE 4A VERTICAL DEFLECTIONS OF STIFFENERS

+ve upwards

SCAN NO.	LOAD (kN)	CHANNEL NO. (SEE FIGURE 8)					
		116	117	119	123	124	126
		Deflections relative to ends (mm)					
1	0						
2	96	-0.11	-0.07	-0.13	+0.15	+0.09	+0.20
3	166	-0.16	-0.14	-0.08	+0.23	+0.12	+0.35
4	254	-0.24	-0.19	-0.20	+0.34	+0.09	+0.44
5	0	+0.05	0.0	-0.20	+0.03	-0.01	+0.05
6	441	-0.61	-0.39	-0.30	+0.59	+0.15	+0.76
7	595	-1.30	-1.13	-1.38	+1.02	+0.42	+1.58
8	0	-0.40	-0.44	-0.87	+0.12	+0.20	+0.47
9	716	-3.00	-2.99	-2.40	+1.72	+1.12	+2.78
10	757	-12.5	-14.3	-12.2	+8.44	+6.15	+8.73
11	0	-10.9	-9.4	-8.2	+4.77	+3.13	+4.26
12	0	-10.8	-9.3	-7.2	+4.79	+3.39	+4.29
13	572	-13.5	-12.0	-10.3	+7.00	+4.85	+6.83
14	659	-13.2	-12.9	-10.9	+7.54	+5.35	+7.56
15	0	-11.1	-9.5	-8.2	+4.91	+3.18	+4.20
16	723	-16.9	-14.6	-12.1	+8.27	+6.06	+8.30
17	619	-24.9	*	-21.5	+16.6	+11.9	+12.1
18	577	*	*	*	+19.0	+14.3	+14.4
19	535	*	*	*	+21.7	+17.6	+17.6
20	488	*	*	*	+25.4	+20.6	+20.6
21	426	*	*	*	+30.5	+26.4	+26.8
22	386	*	*	*	+33.5	+28.9	+29.3
23	0	*	*	*	+27.0	+23.3	+22.0

* Transducer out of range

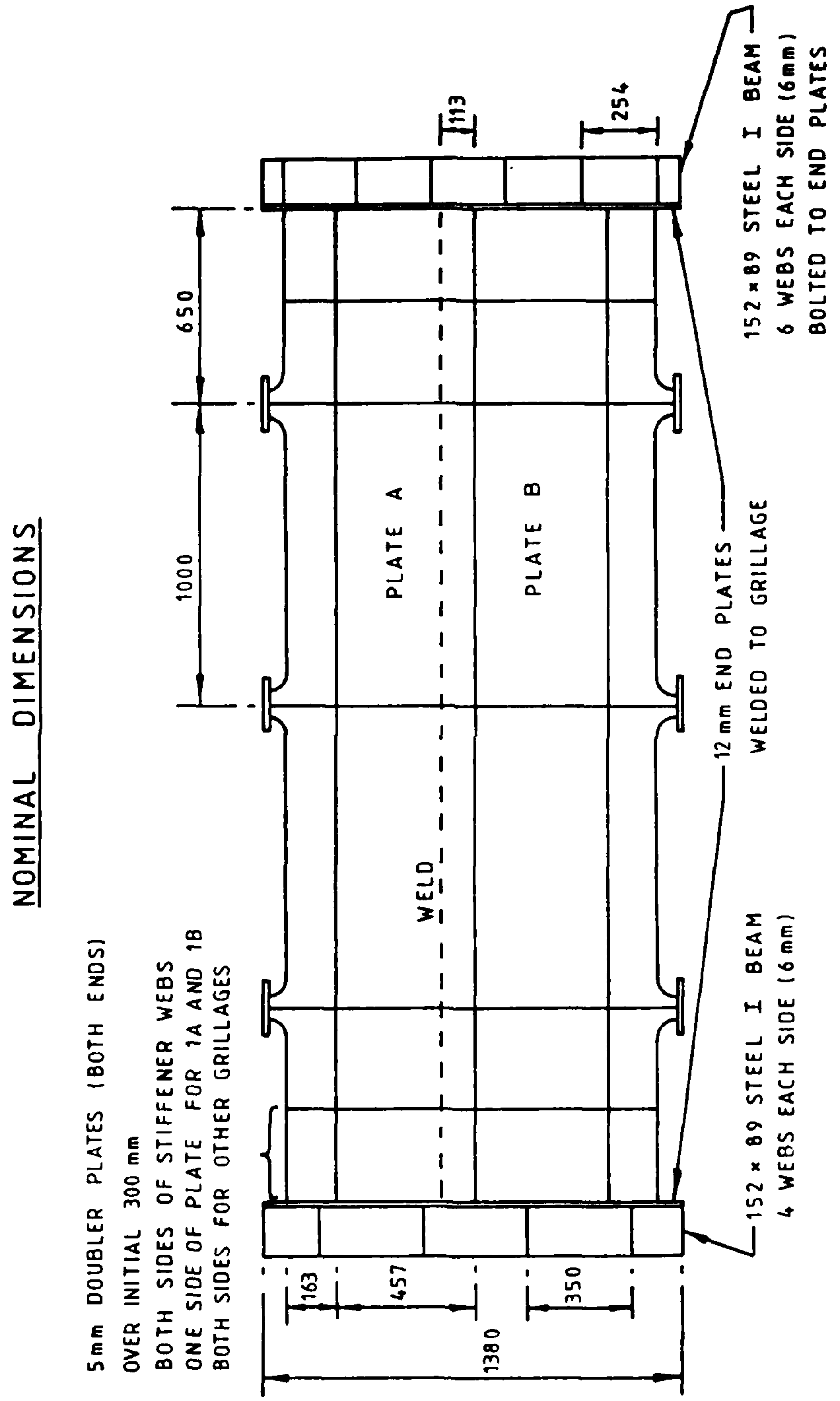

NOMINAL DIMENSIONS
5mm DOUBLER PLATES (BOTH ENDS)
OVER INITIAL 300 mm
BOTH SIDES OF STIFFENER WEBS
ONE SIDE OF PLATE FOR 1A AND 1B
BOTH SIDES FOR OTHER GRILLAGES
PLATE A
PLATE B
WELD
650
1000
113
254
163
457
350
1380
152 × 89 STEEL I BEAM
6 WEBS EACH SIDE (6mm)
BOLTED TO END PLATES
12 mm END PLATES
WELDED TO GRILLAGE
152 × 89 STEEL I BEAM
4 WEBS EACH SIDE (6 mm)

FIGURE 1

STRESS/STRAIN RELATIONSHIP FOR GRILLAGE 1A & 1B STIFFENERS

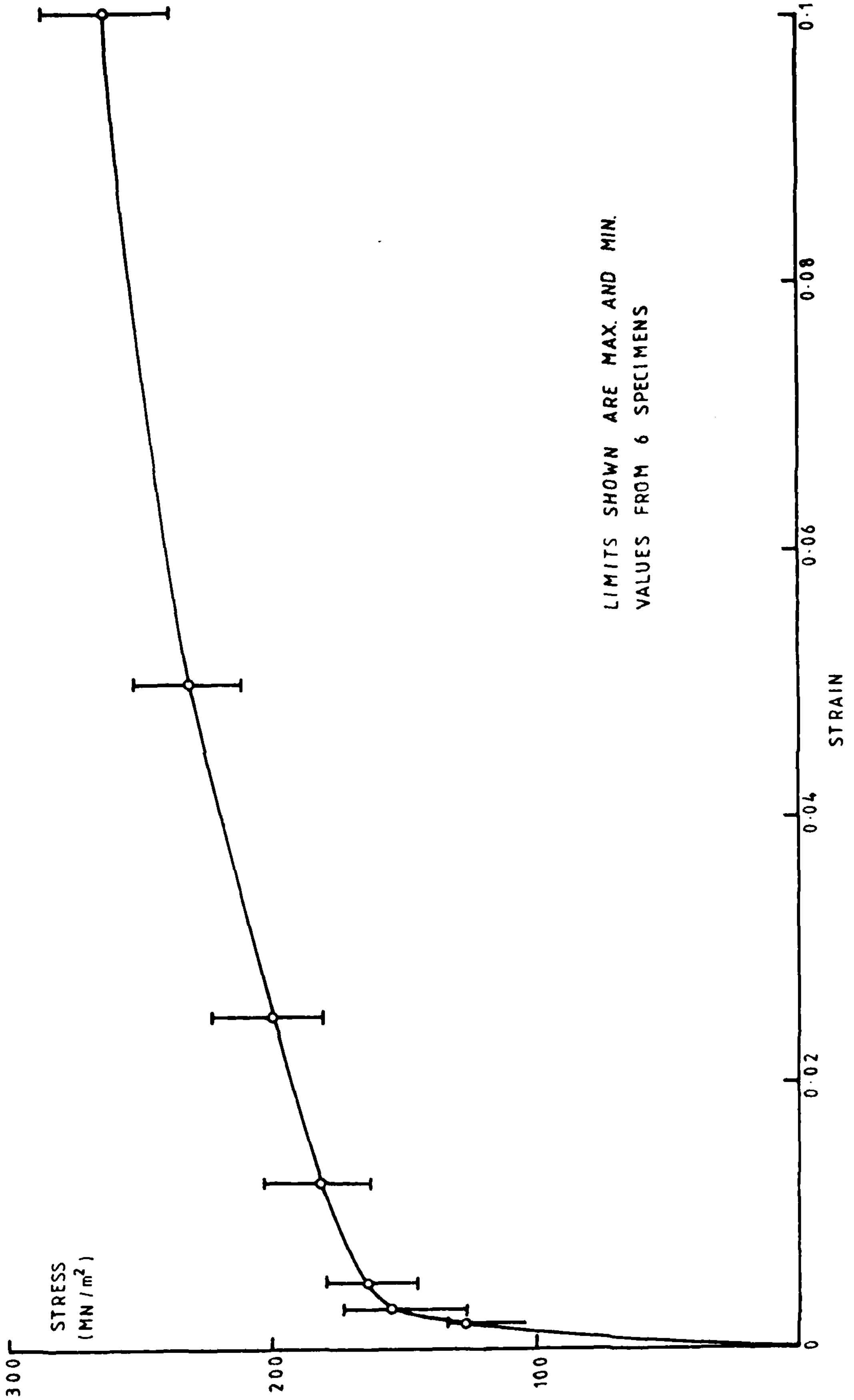


FIGURE 2

AMTE (S) R85104

STRESS / STRAIN RELATIONSHIP FOR GRILLAGE 2A & 3A STIFFENERS

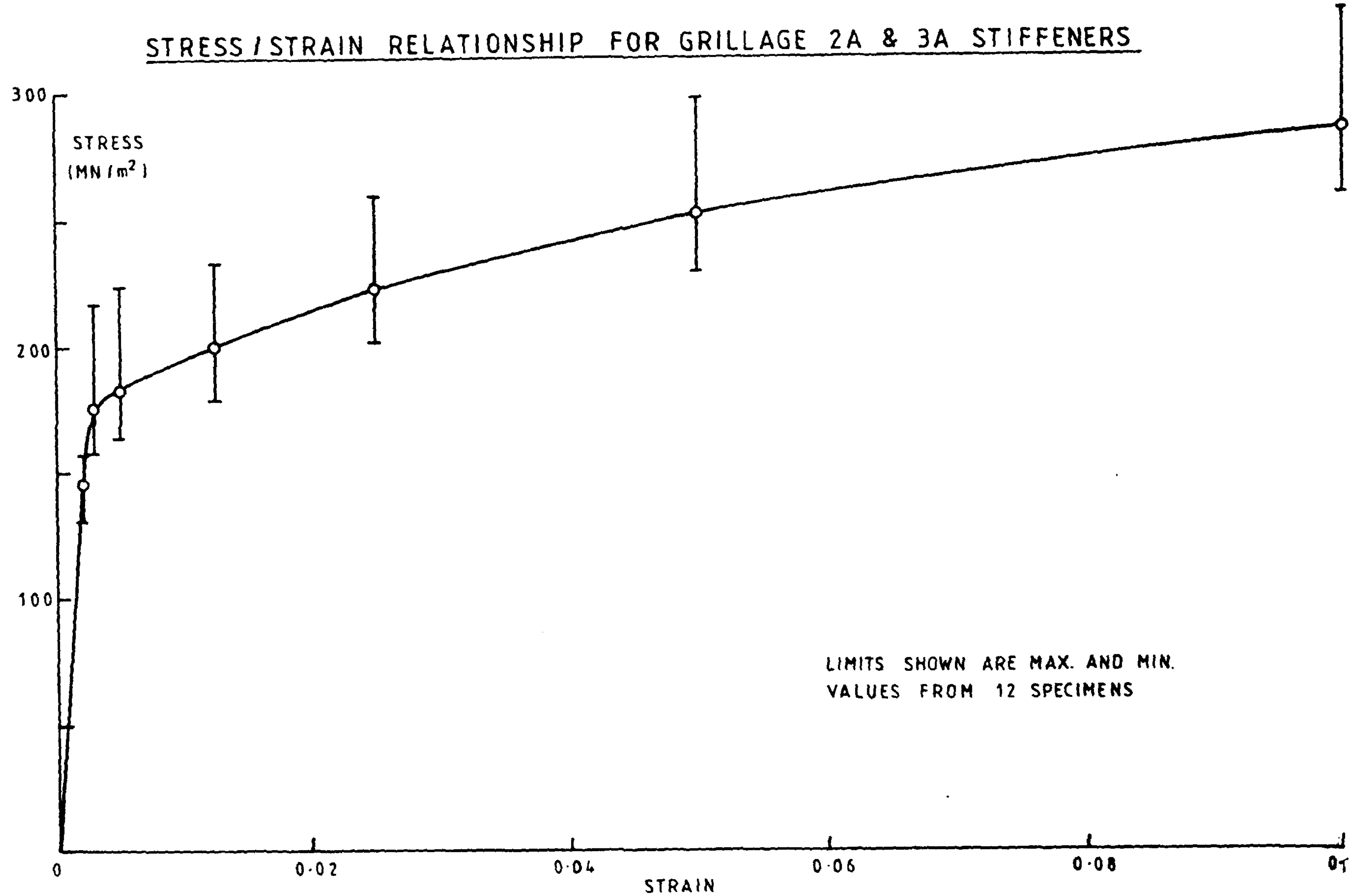


FIGURE 3

STRESS / STRAIN RELATIONSHIP FOR GRILLAGE 4A STIFFENERS

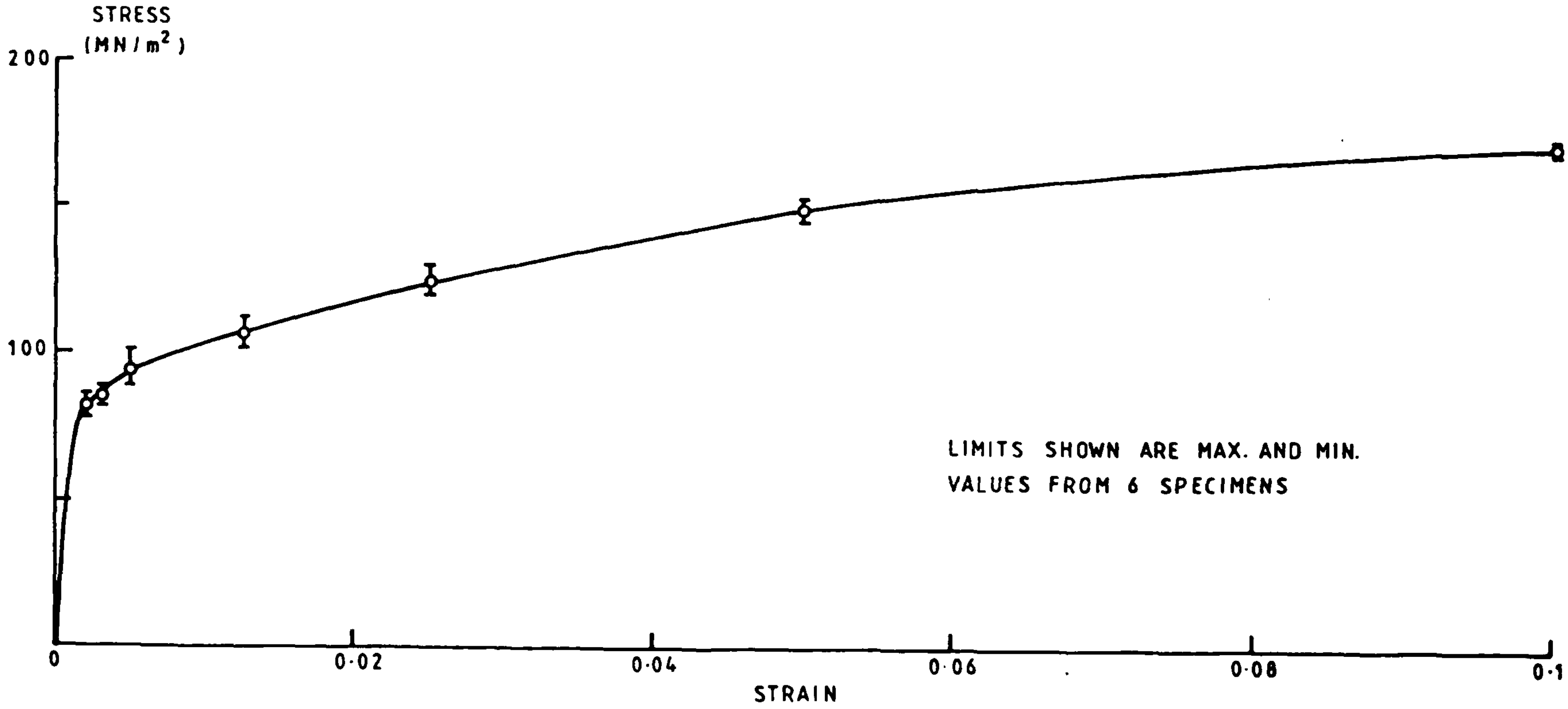


FIGURE 4

UNLIMITED

TEST FRAME - SIDE ELEVATION

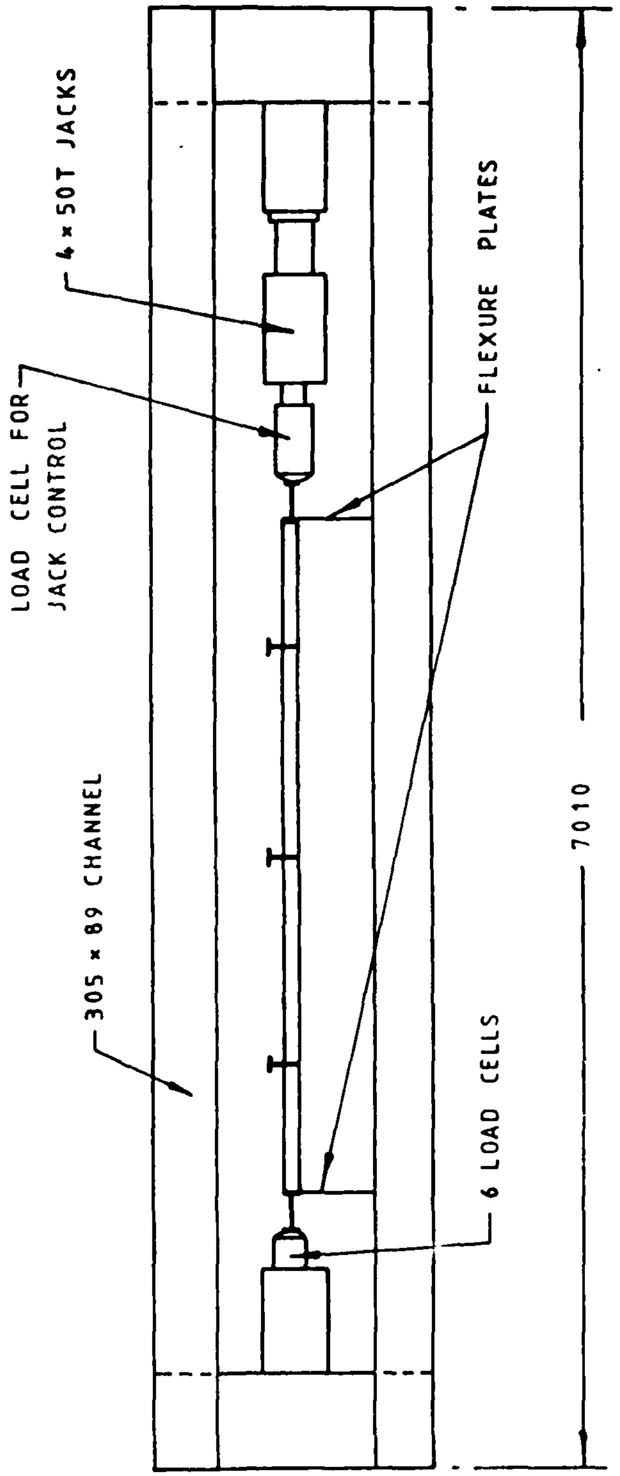


FIGURE 5

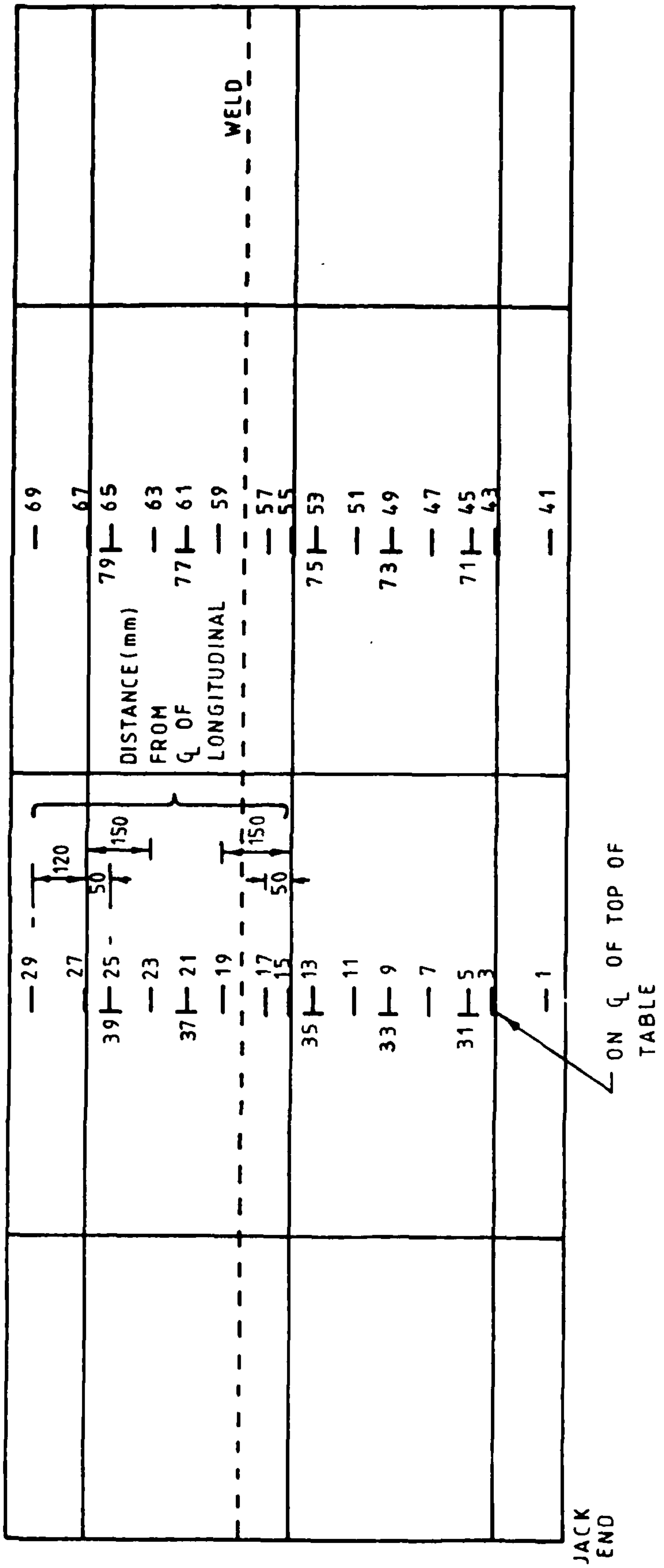
TEST FRAME - AFTER COMPLETION OF GRILLAGE 4A TEST AND REMOVAL OF DATUM FRAME

SL 84/01/03

FIGURE 6

STRAIN GAUGE POSITIONS STIFFENER SIDE

(VIEWED FROM STIFFENER SIDE)



ALL LOCATIONS HAVE A SIMILAR GAUGE ON THE PLATING SIDE
(GAUGE No. INCREMENTED BY ONE)

FIGURE 7

POSITION OF DEFLECTION TRANSDUCERS

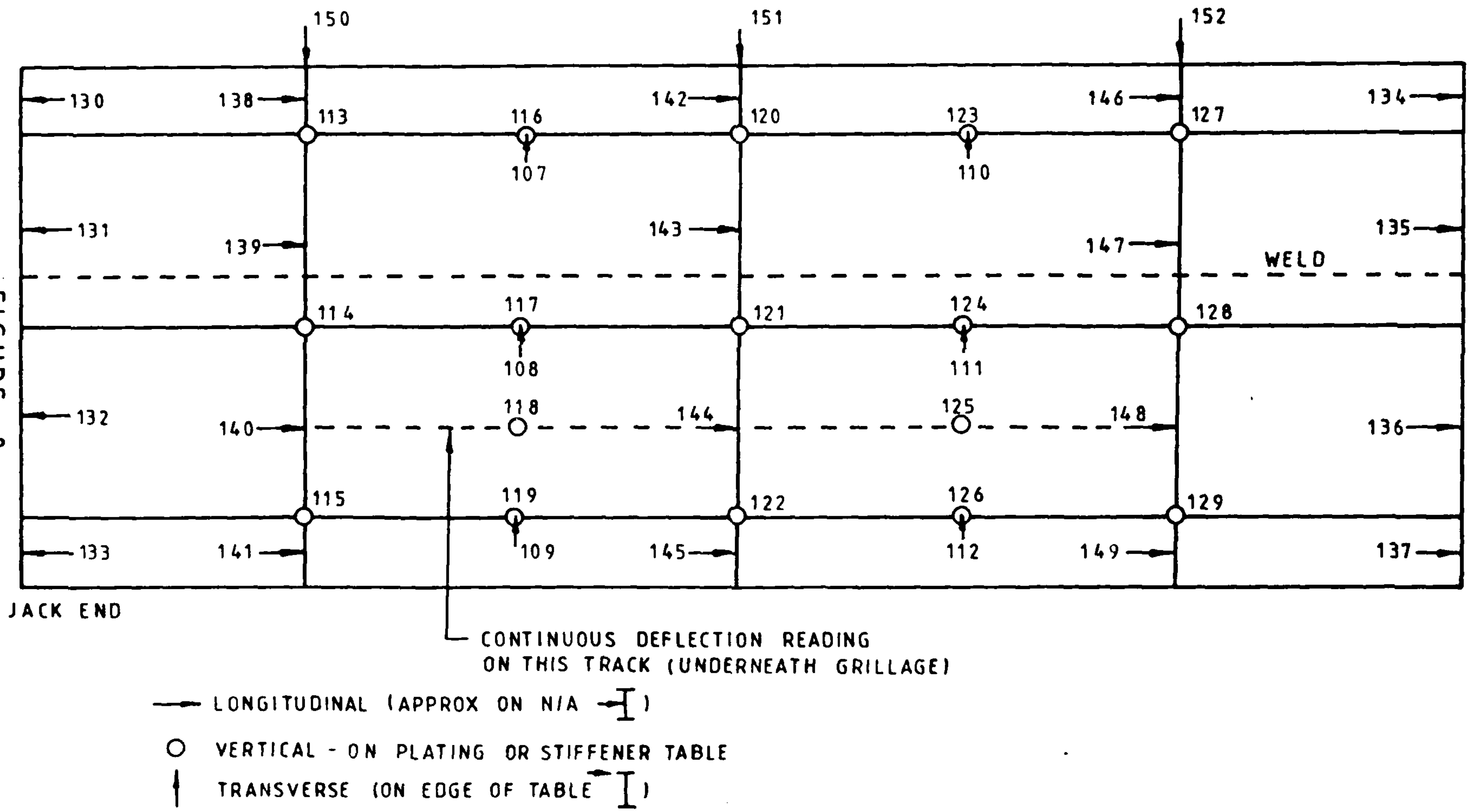
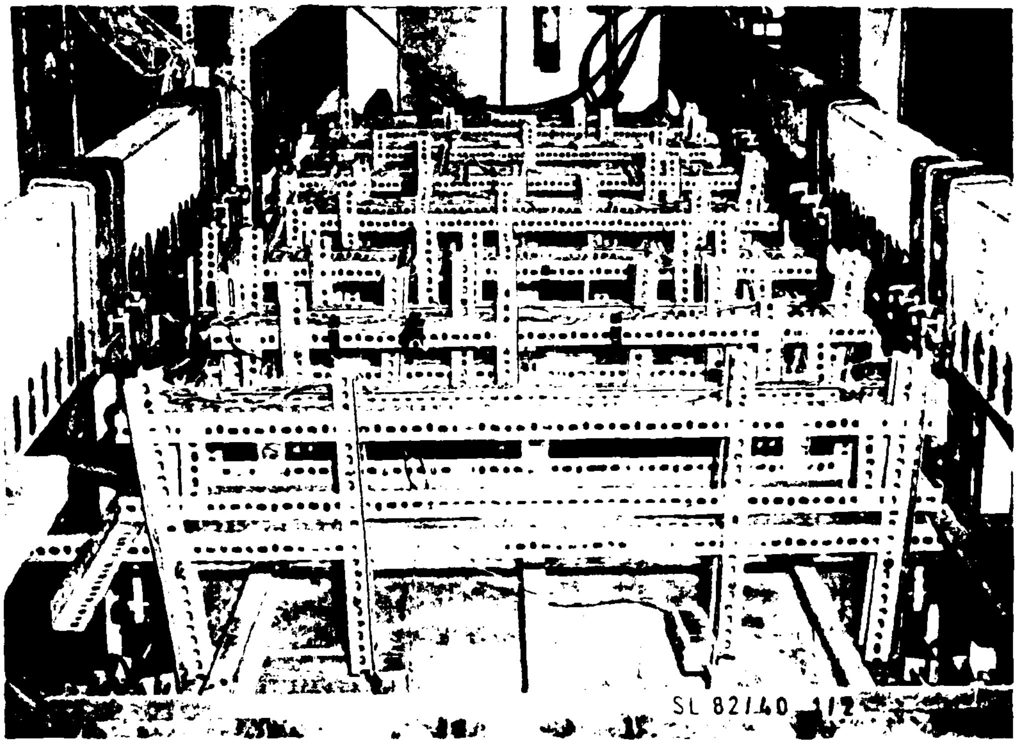


FIGURE 8

a) GRILLAGE 1B SHOWING [illegible] JM FRAME



b) GRILLAGE 1B PERMANENT DEFORMATION AFTER FINAL LOAD

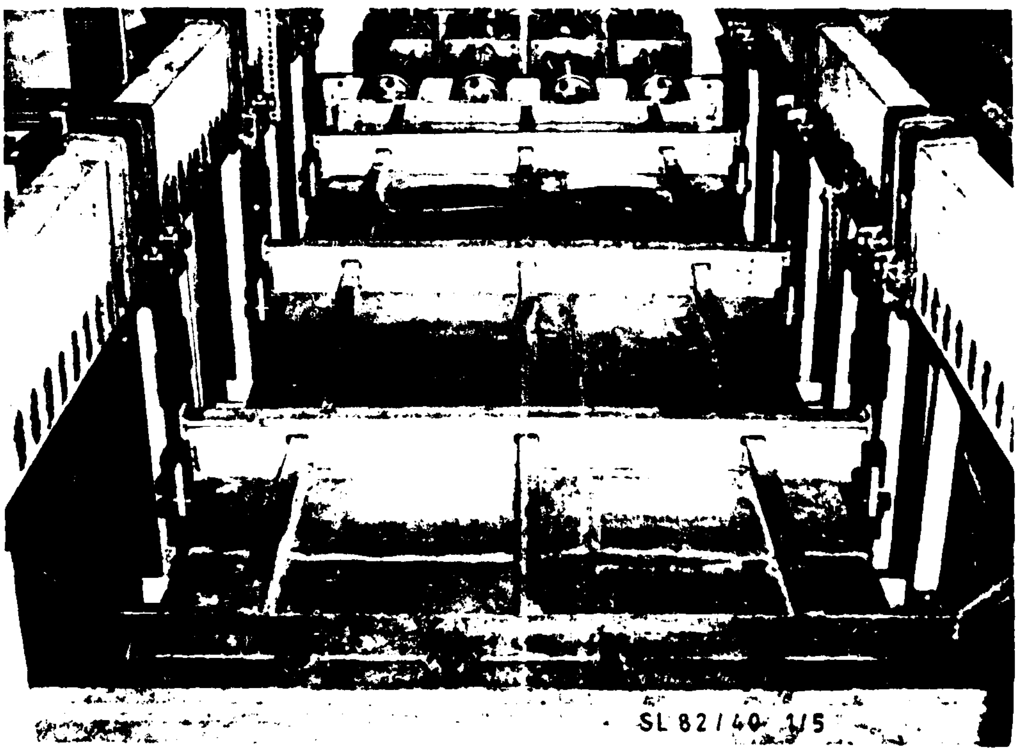
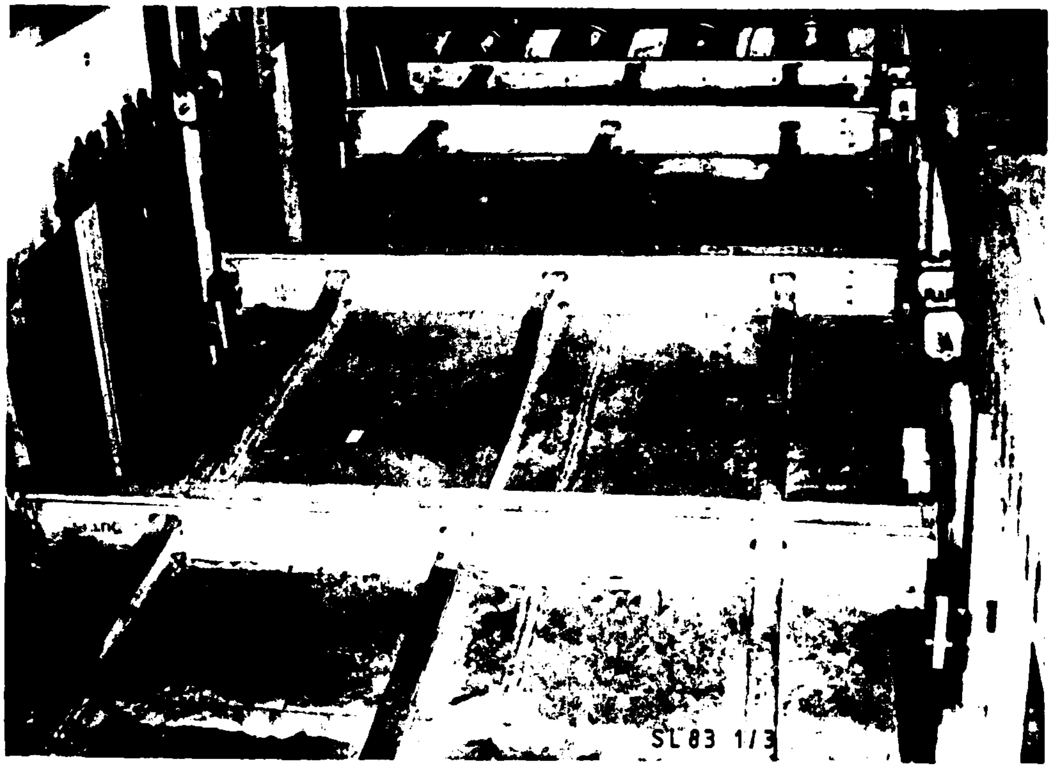


FIGURE 9

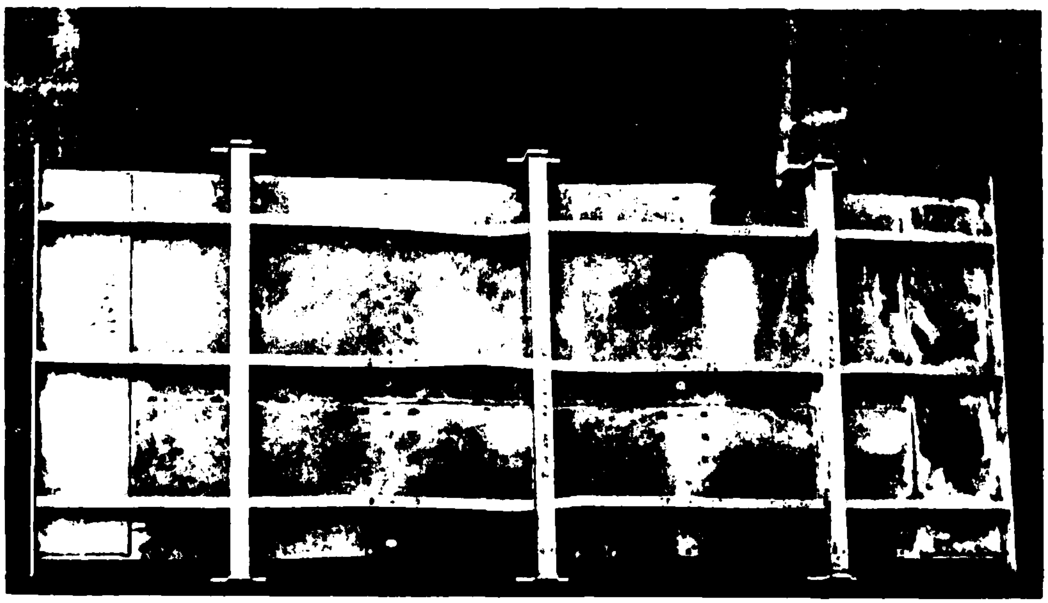
UNLIMITED

GRILLAGE 2A PERMANENT DEFORMATION AFTER FINAL LOAD

a)



b)



SL83 1/9

FIGURE 10

UNLIMITED

AMTE (S) R 85104

a) GRILLAGE 3A PERMANENT DEFORMATION AFTER FINAL LOAD

SL 84/105/3

b) GRILLAGE 4A PERMANENT DEFORMATION AFTER FINAL LOAD

SL 84/32/03

FIGURE 11

UNLIMITED

TOTAL CONTRACTION OF TWO CENTRAL FRAMES

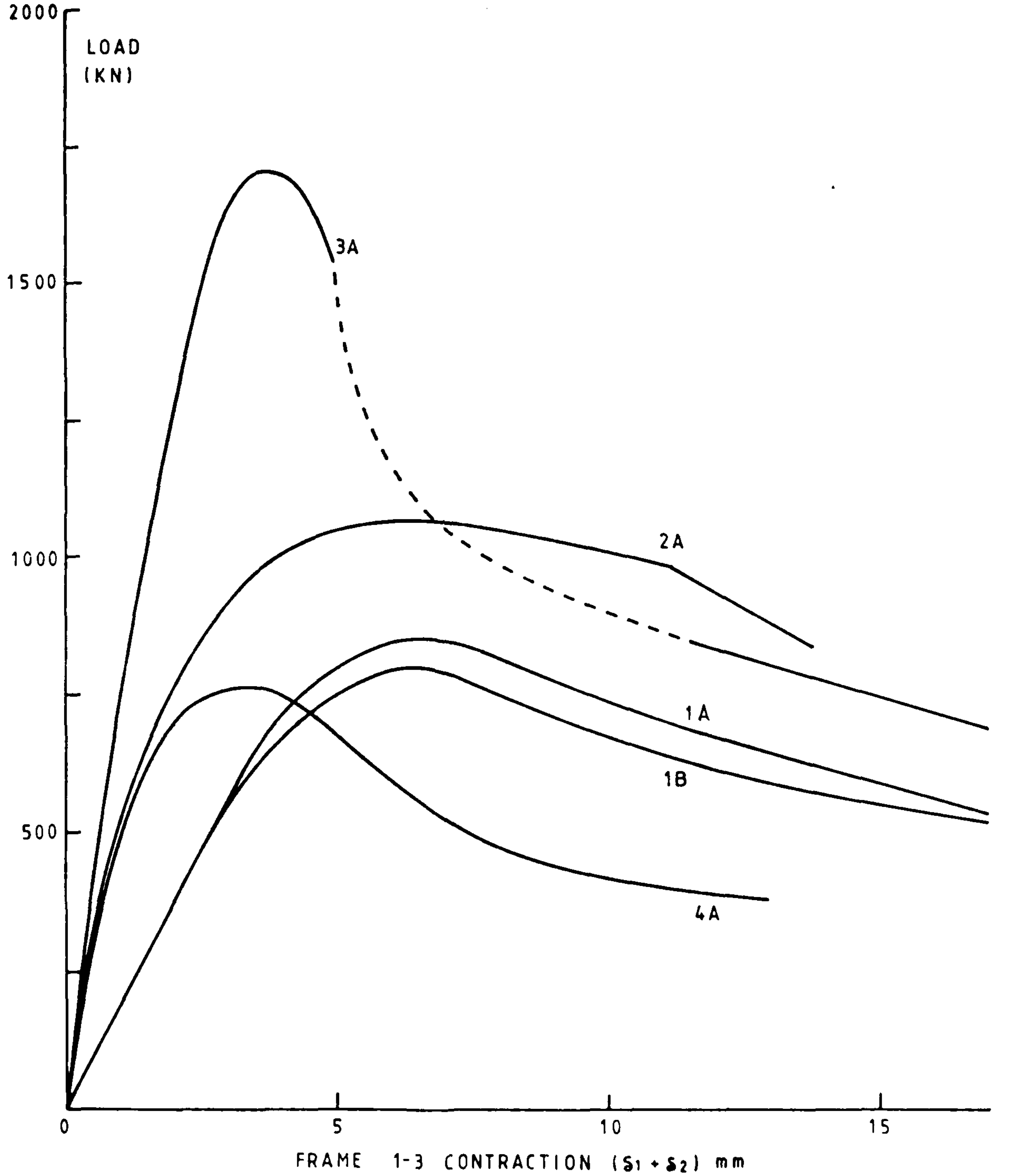


FIGURE 12

GRILLAGE 1A - INTERFRAME CONTRACTION

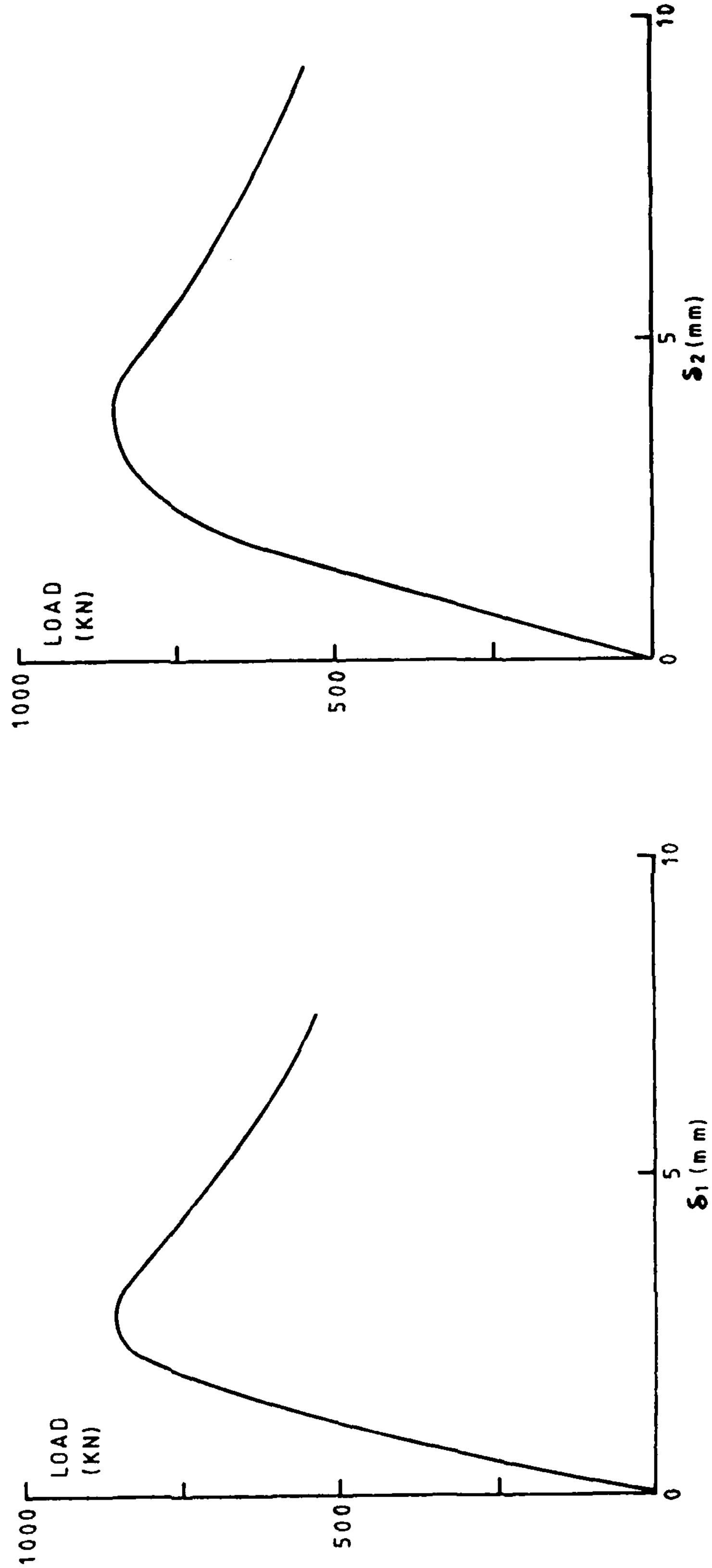


FIGURE 13

GRILLAGE 1B - INTERFRAME CONTRACTION

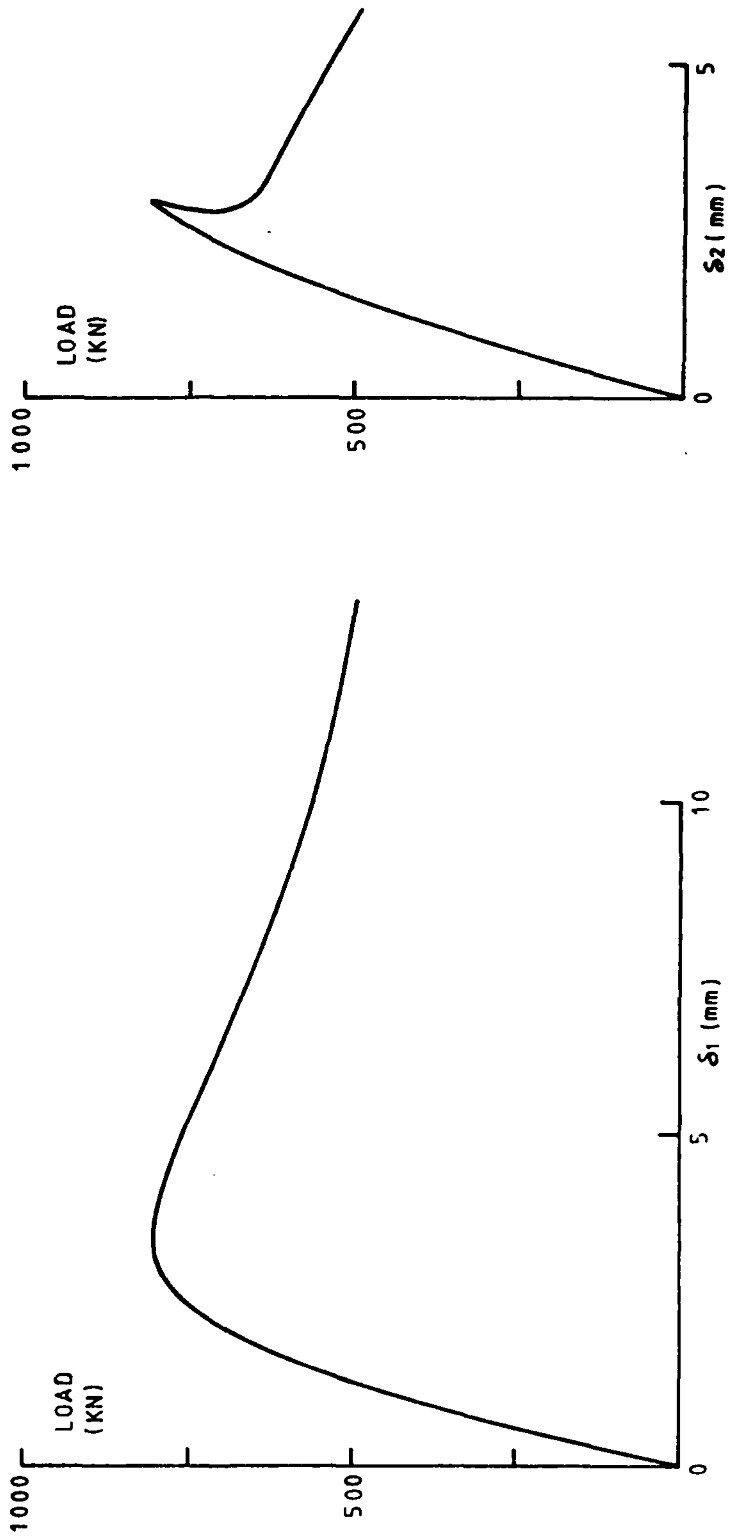


FIGURE 14

GRILLAGE 2A - INTERFRAME CONTRACTION

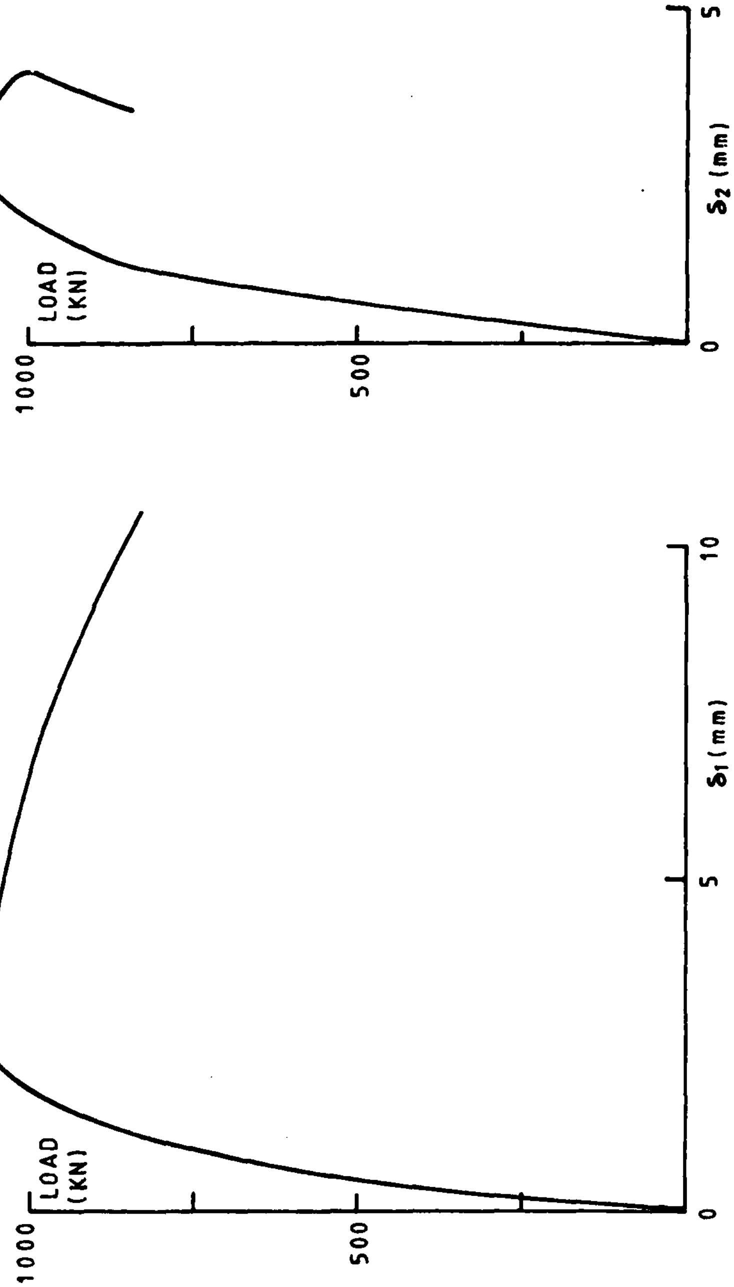


FIGURE 15

GRILLAGE 3A — INTERFRAME DEFLECTION

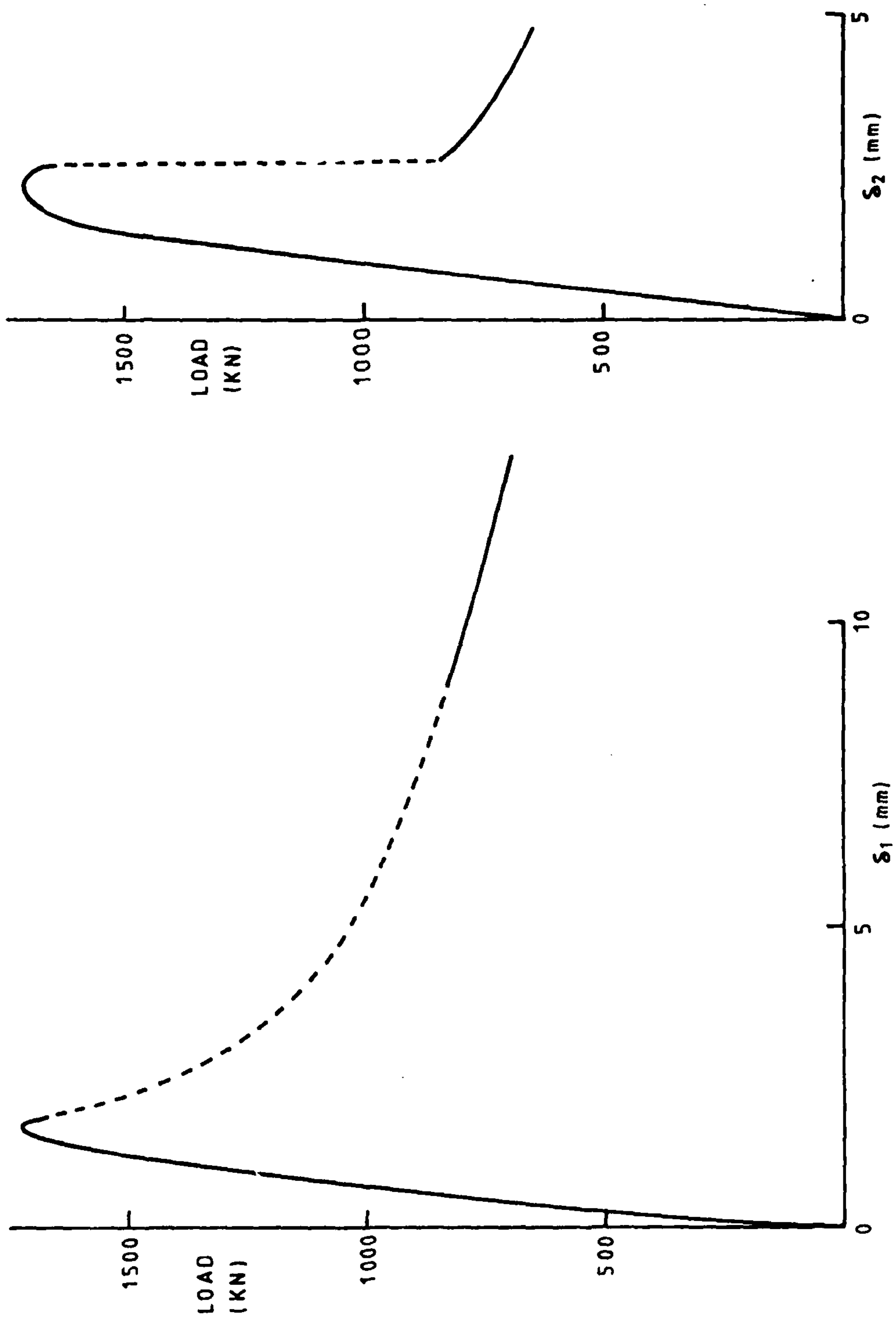


FIGURE 16

GRILLAGE 4A - INTERFRAME DEFLECTIONS

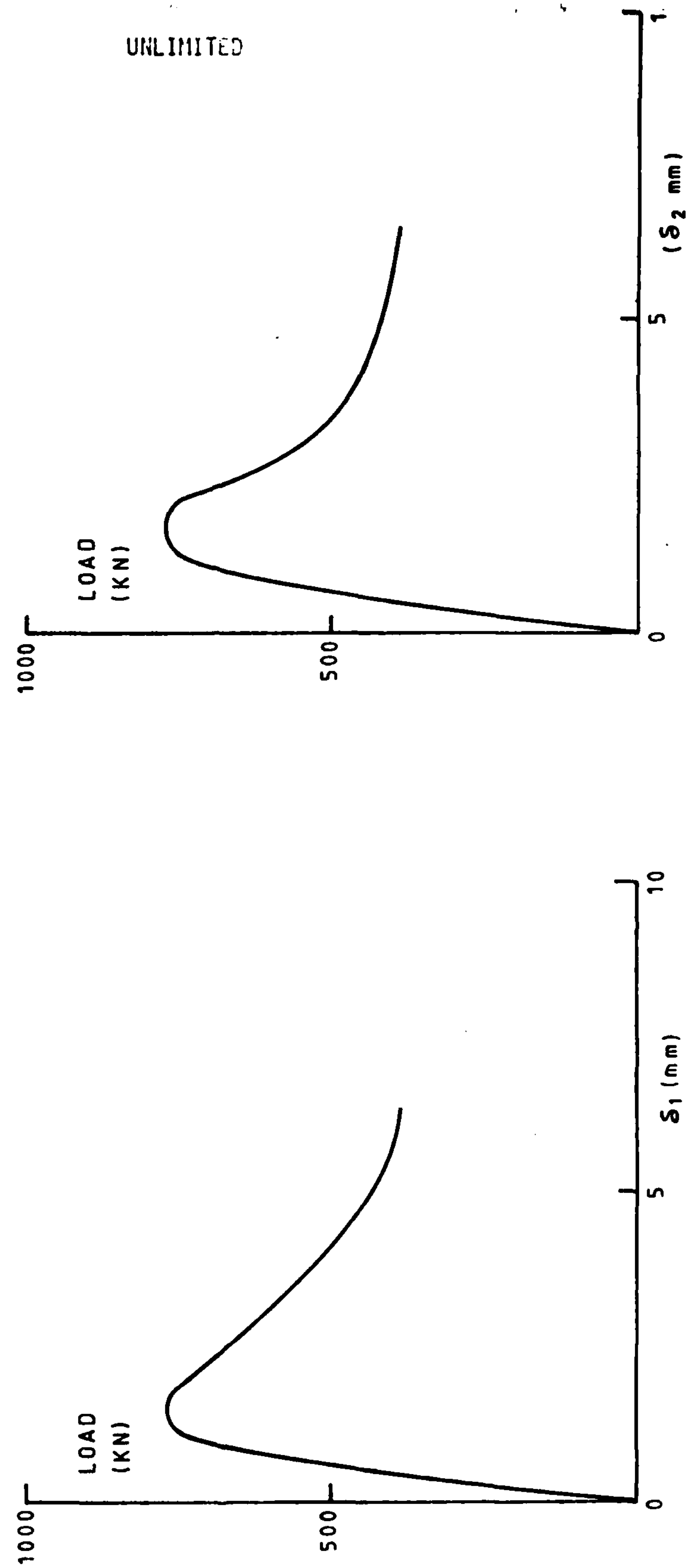


FIGURE 17

GRILLAGE 3A - OVERALL GRILLAGE CONTRACTION

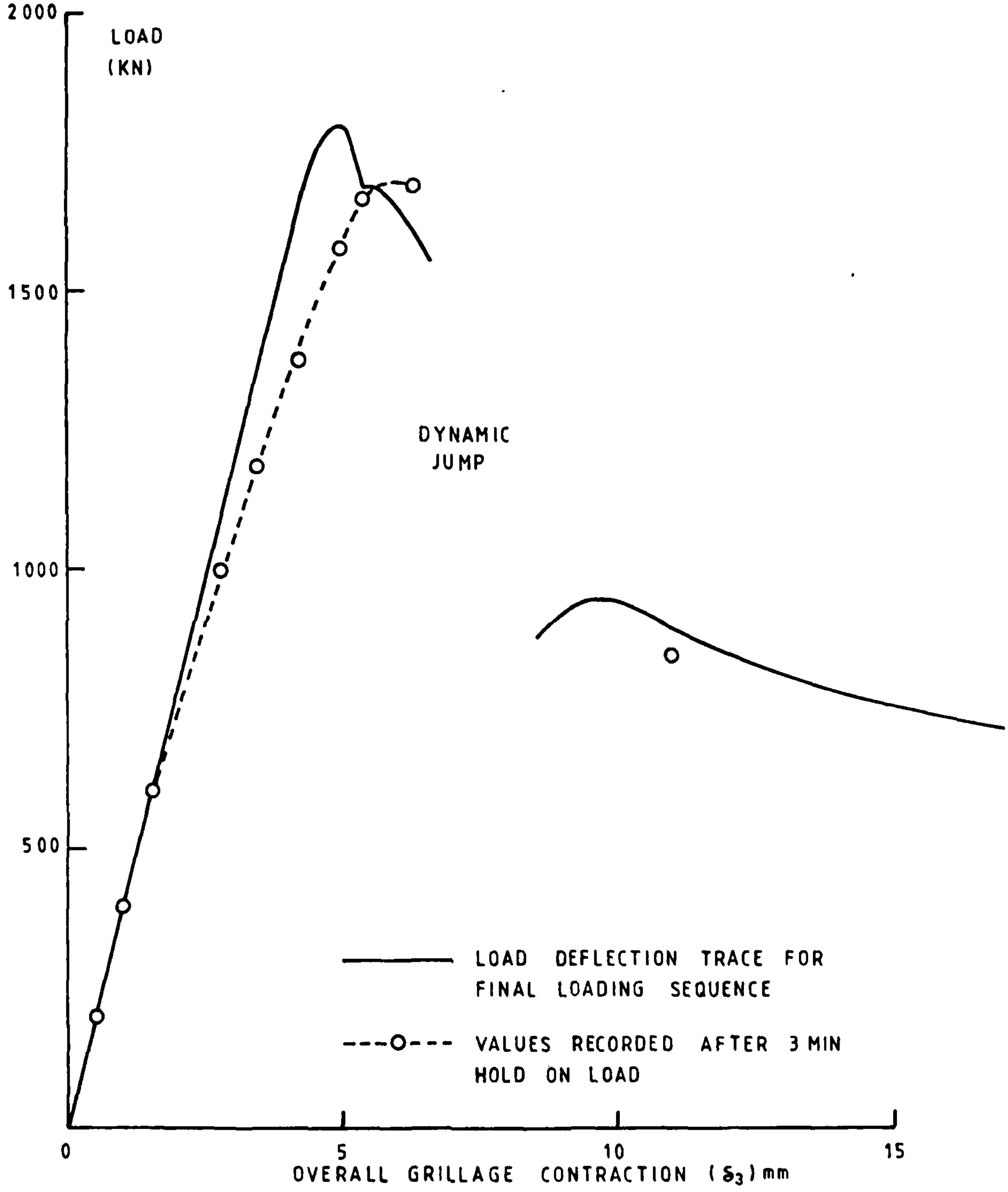


FIGURE 18

STIFFNESS OF FRAME AND JACK SUPPORTS

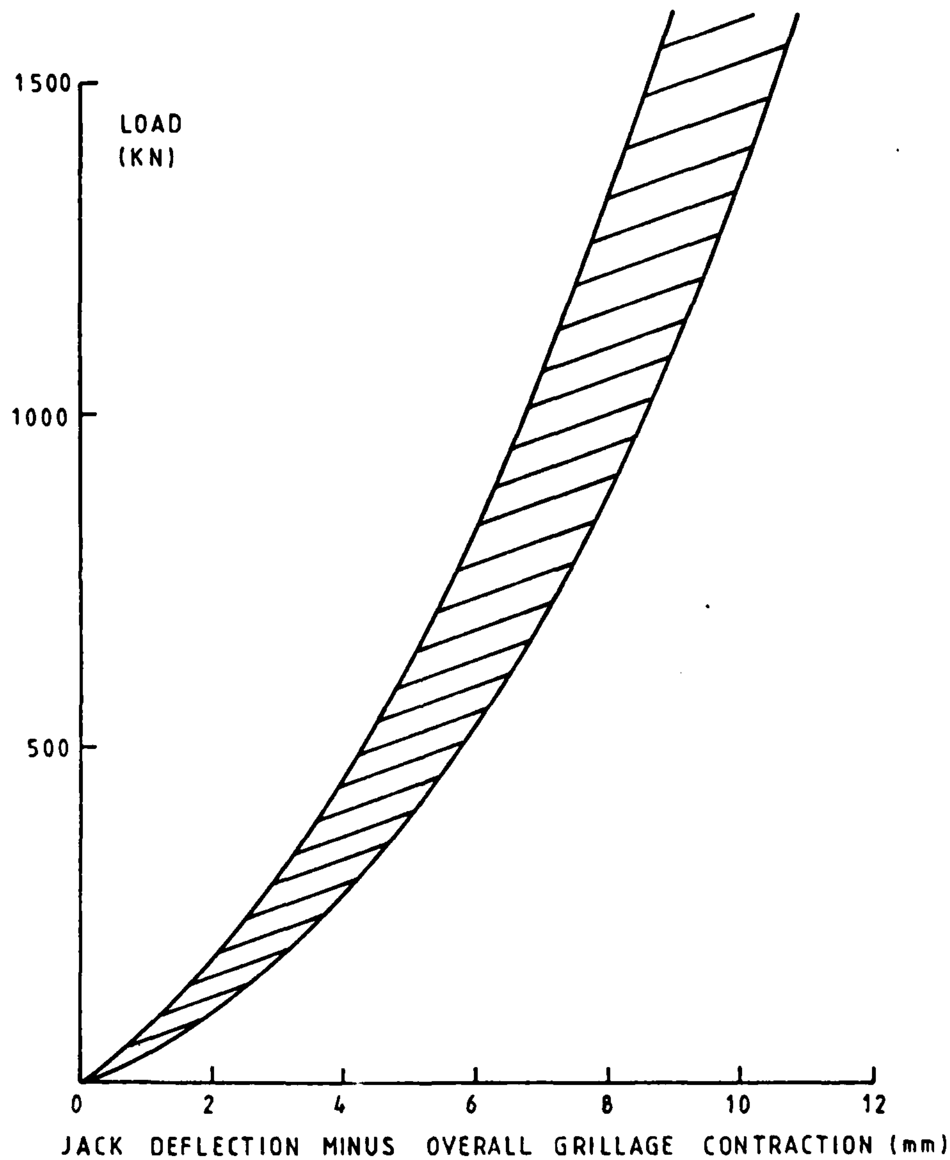


FIGURE 19

GRILLAGE 1B PLATE DEFLECTION
(ALONG CENTRELINE ON UNWELDED SIDE)
(RELATIVE TO PLATE ENDS)

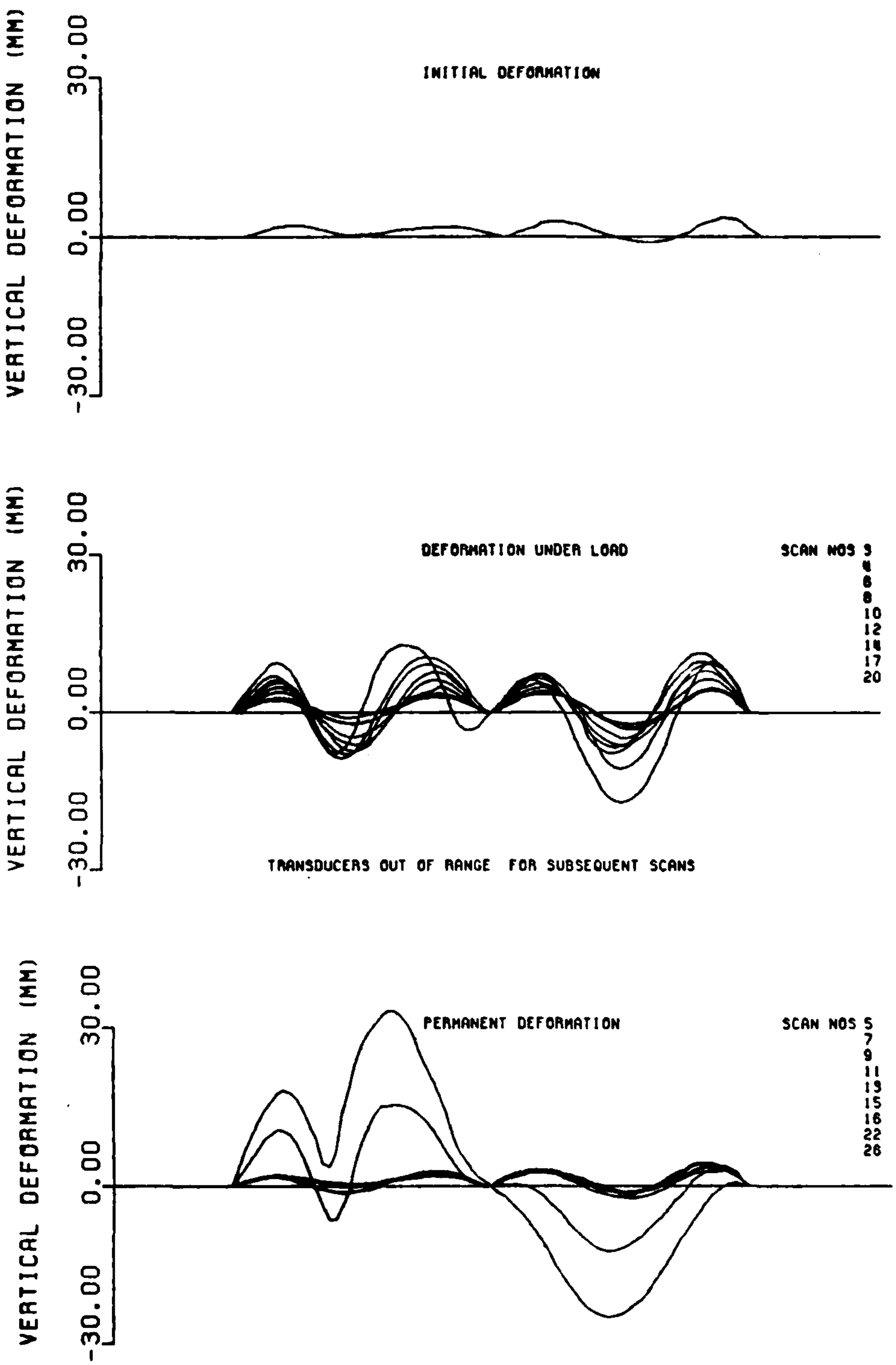


FIGURE 20

GRILLAGE 2A PLATE DEFLECTION
(ALONG CENTRELINE ON UNWELDED SIDE)
(RELATIVE TO PLATE ENDS)

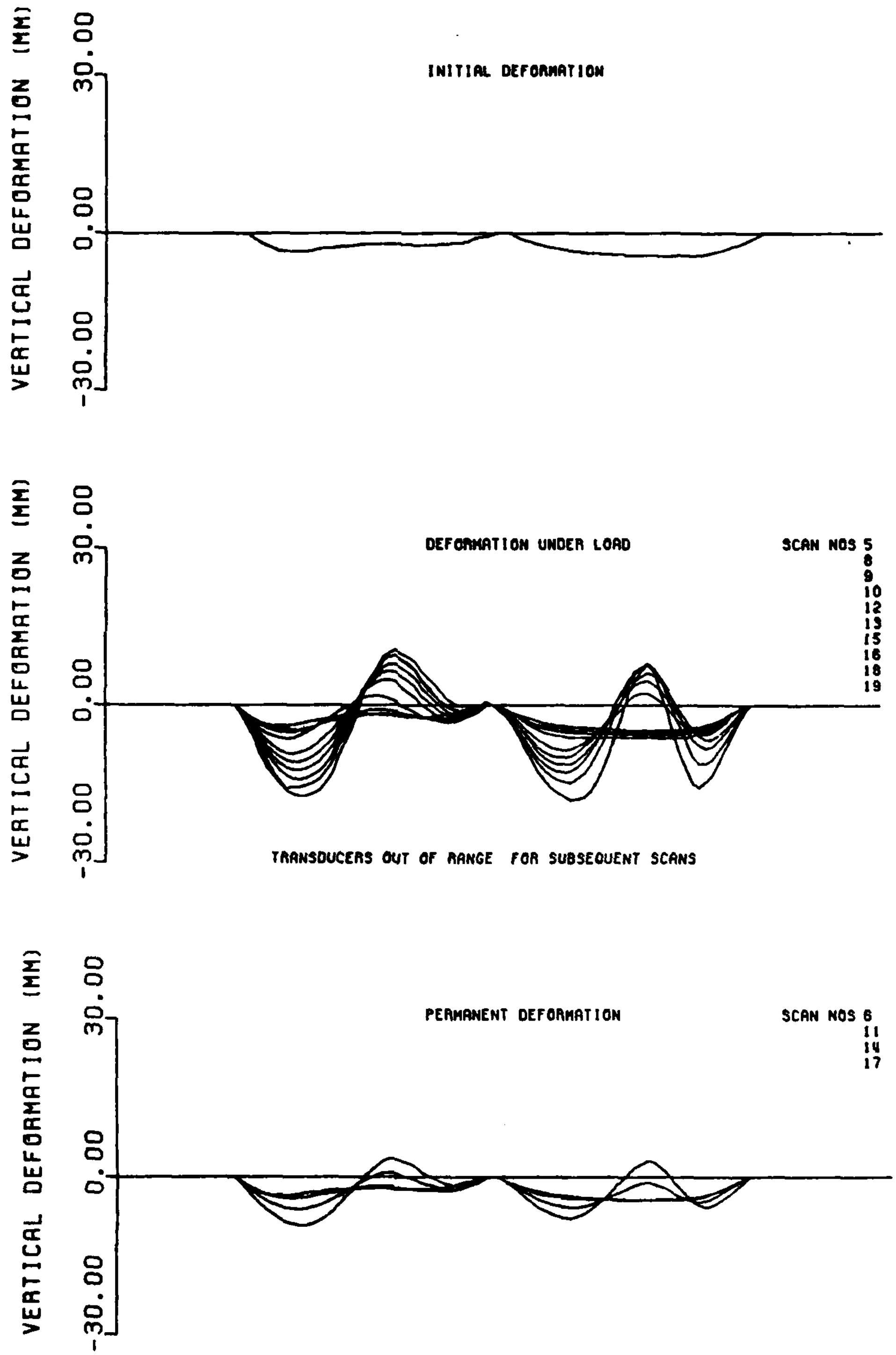


FIGURE 21

GRILLAGE 3A PLATE DEFLECTION
(ALONG CENTRELINE ON UNWELDED SIDE)
(RELATIVE TO PLATE ENDS)

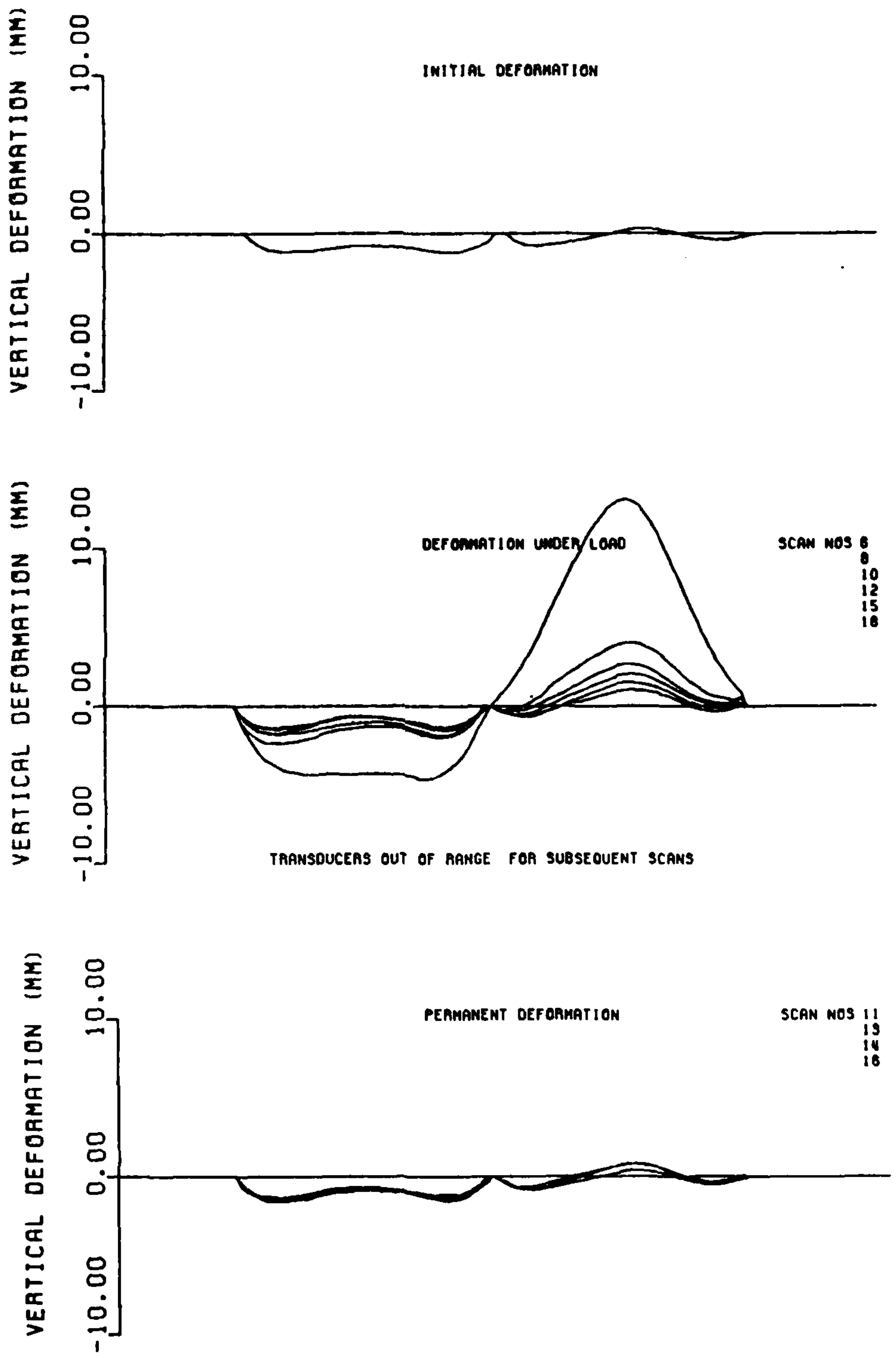


FIGURE 22

UNLIMITED

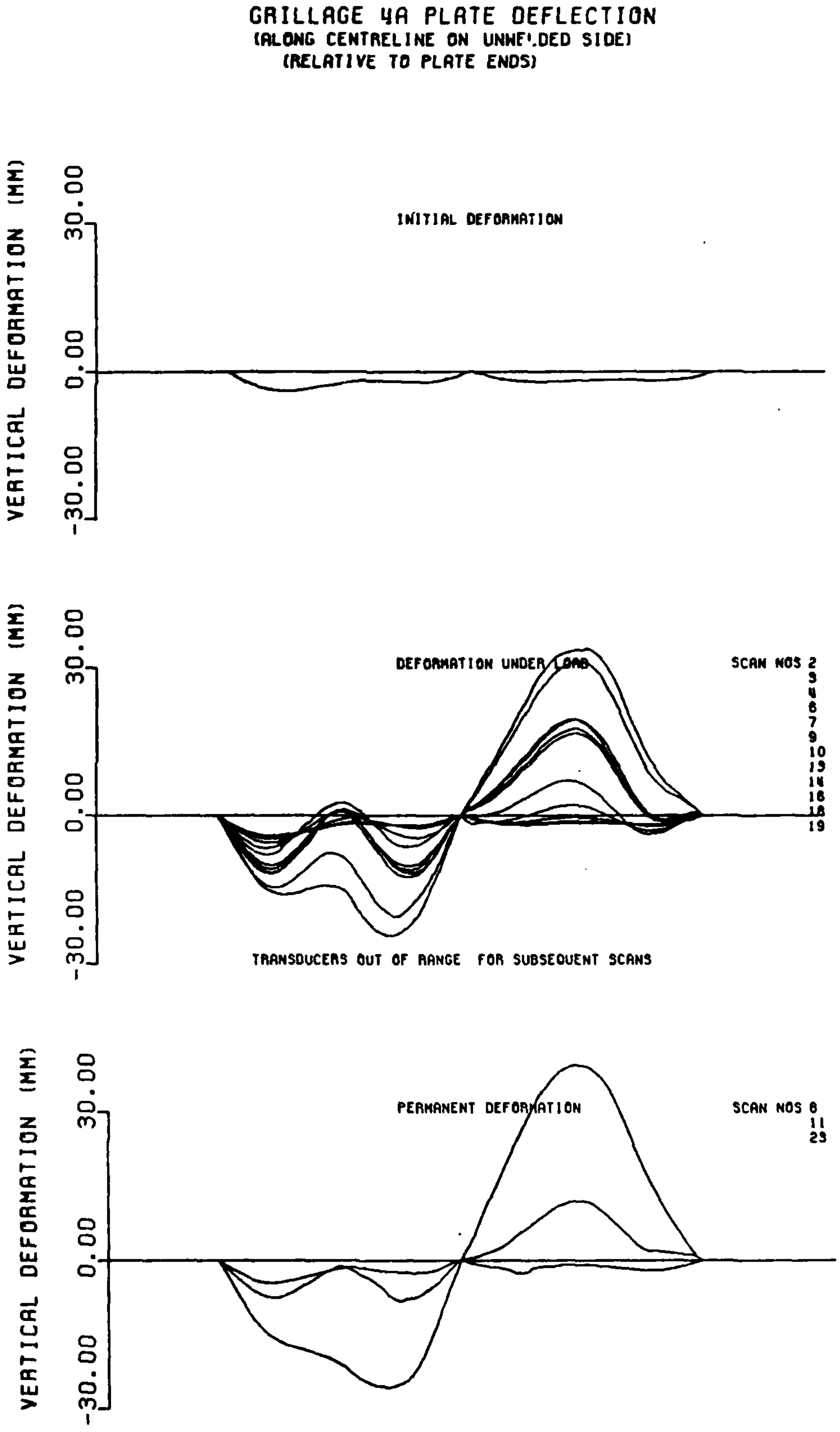
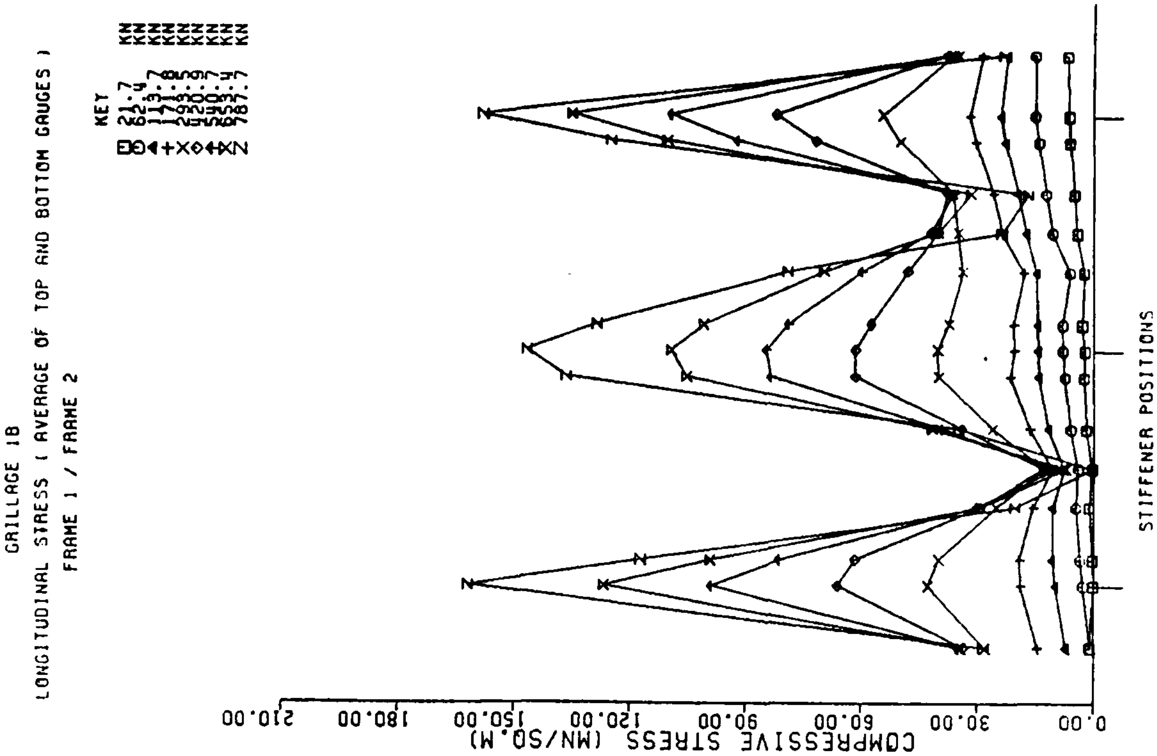


FIGURE 23


GRILLAGE 1B
LONGITUDINAL STRESS (AVERAGE OF TOP AND BOTTOM GAUGES)
FRAME 1 / FRAME 2
KEY
STIFFENER POSITIONS
COMPRESSIVE STRESS (MN/SQ.M)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00

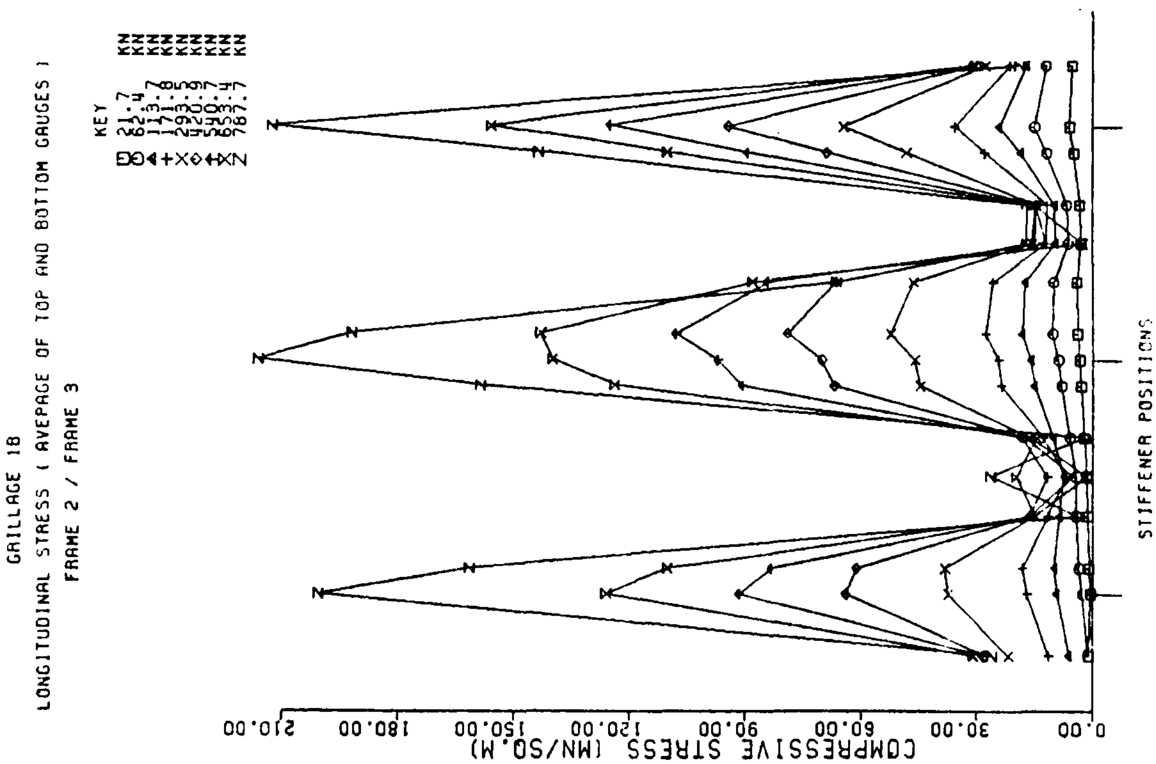
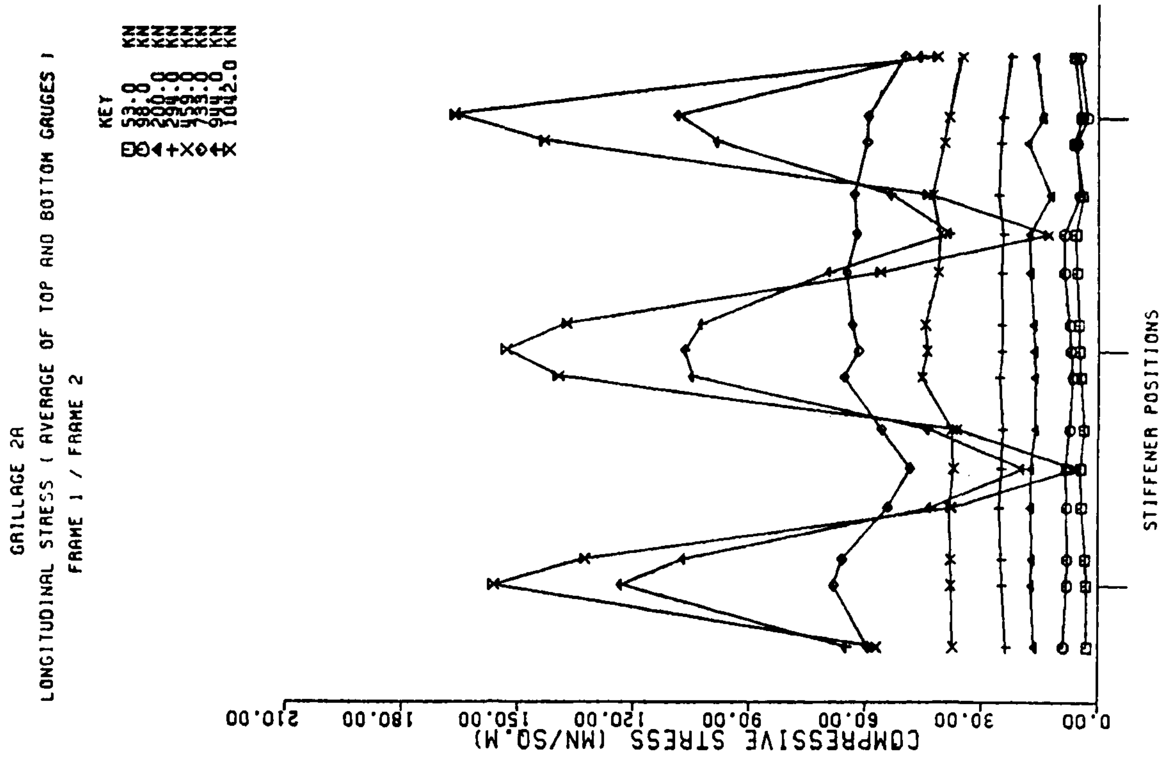

GRILLAGE 1B
LONGITUDINAL STRESS (AVERAGE OF TOP AND BOTTOM GAUGES)
FRAME 2 / FRAME 3
KEY
STIFFENER POSITIONS
COMPRESSIVE STRESS (MN/SQ.M)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00

FIGURE 24


GRILLAGE 2A
LONGITUDINAL STRESS (AVERAGE OF TOP AND BOTTOM GAUGES)
FRAME 1 / FRAME 2
KEY
53.0 KN
98.0 KN
200.0 KN
294.0 KN
459.0 KN
733.0 KN
944.0 KN
1042.0 KN
COMPRESSIVE STRESS (MN/SQ.M)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
STIFFENER POSITIONS

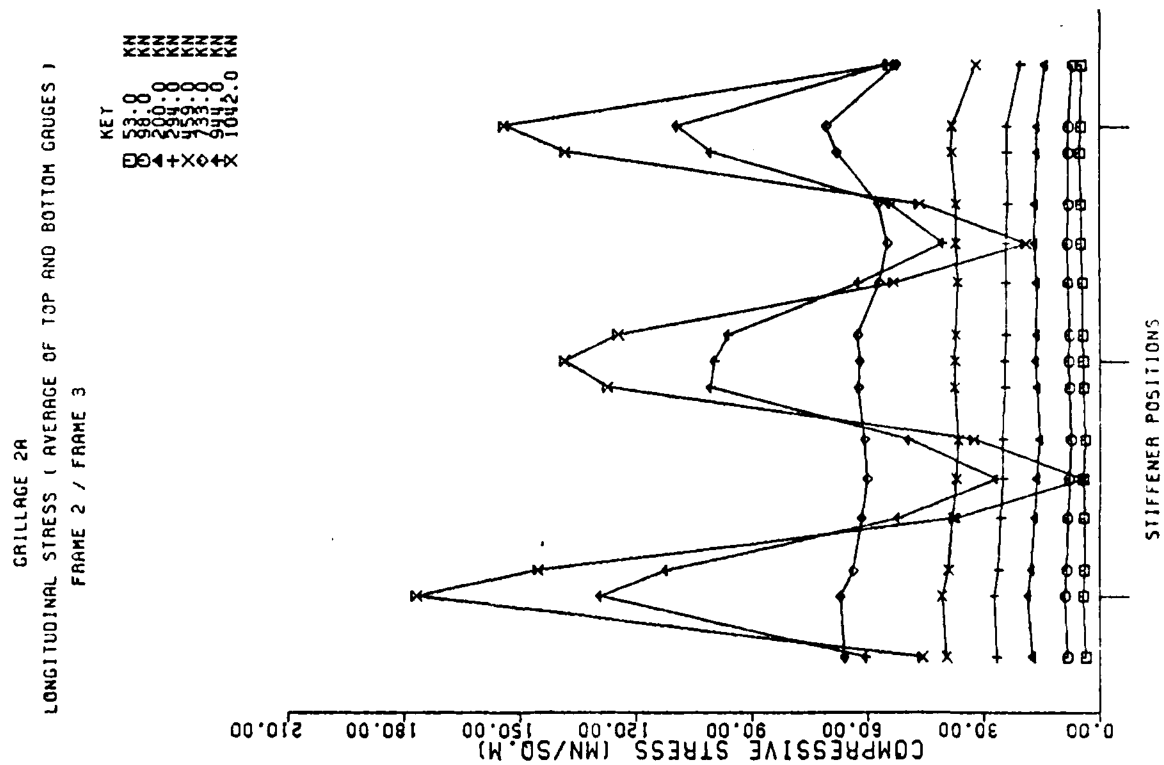
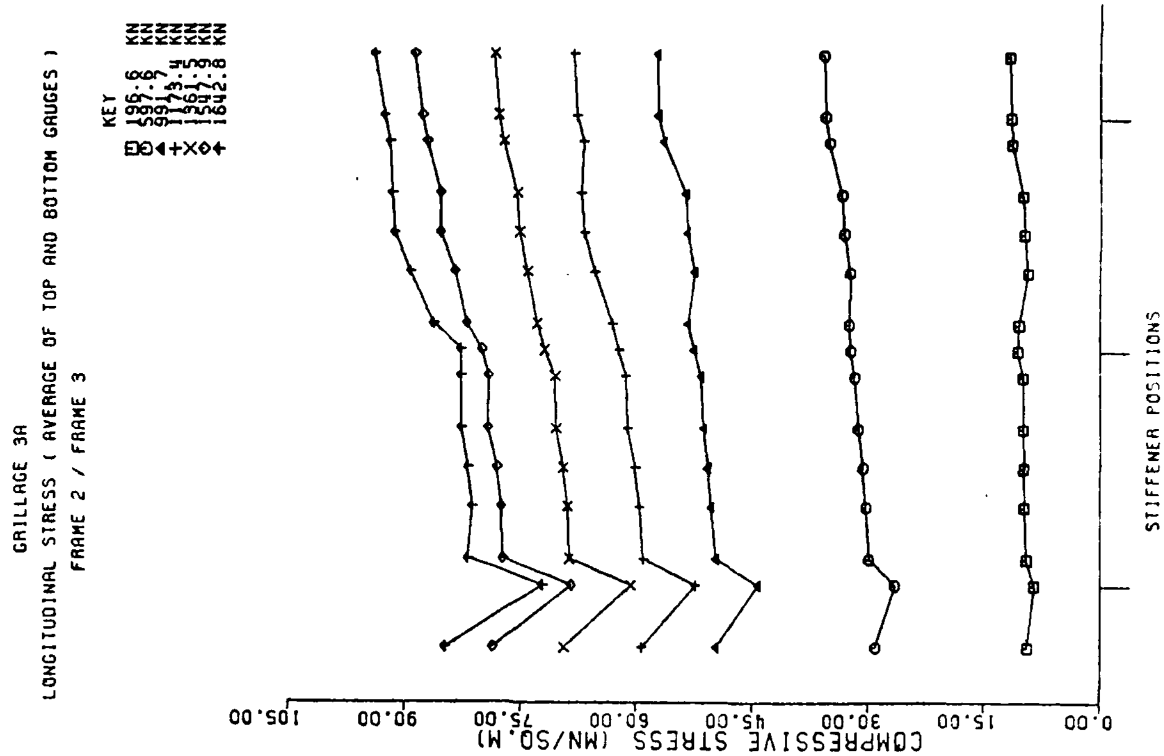

GRILLAGE 2A
LONGITUDINAL STRESS (AVERAGE OF TOP AND BOTTOM GAUGES)
FRAME 2 / FRAME 3
KEY
53.0 KN
98.0 KN
200.0 KN
294.0 KN
459.0 KN
733.0 KN
944.0 KN
1042.0 KN
COMPRESSIVE STRESS (MN/SQ.M)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
STIFFENER POSITIONS

FIGURE 25


GRILLAGE 3A
LONGITUDINAL STRESS (AVERAGE OF TOP AND BOTTOM GAUGES)
FRAME 2 / FRAME 3
KEY
196.6 KN
597.6 KN
991.7 KN
1173.4 KN
1361.5 KN
1547.9 KN
1642.8 KN
COMPRESSIVE STRESS (MN/SQ.M)
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
STIFFENER POSITIONS

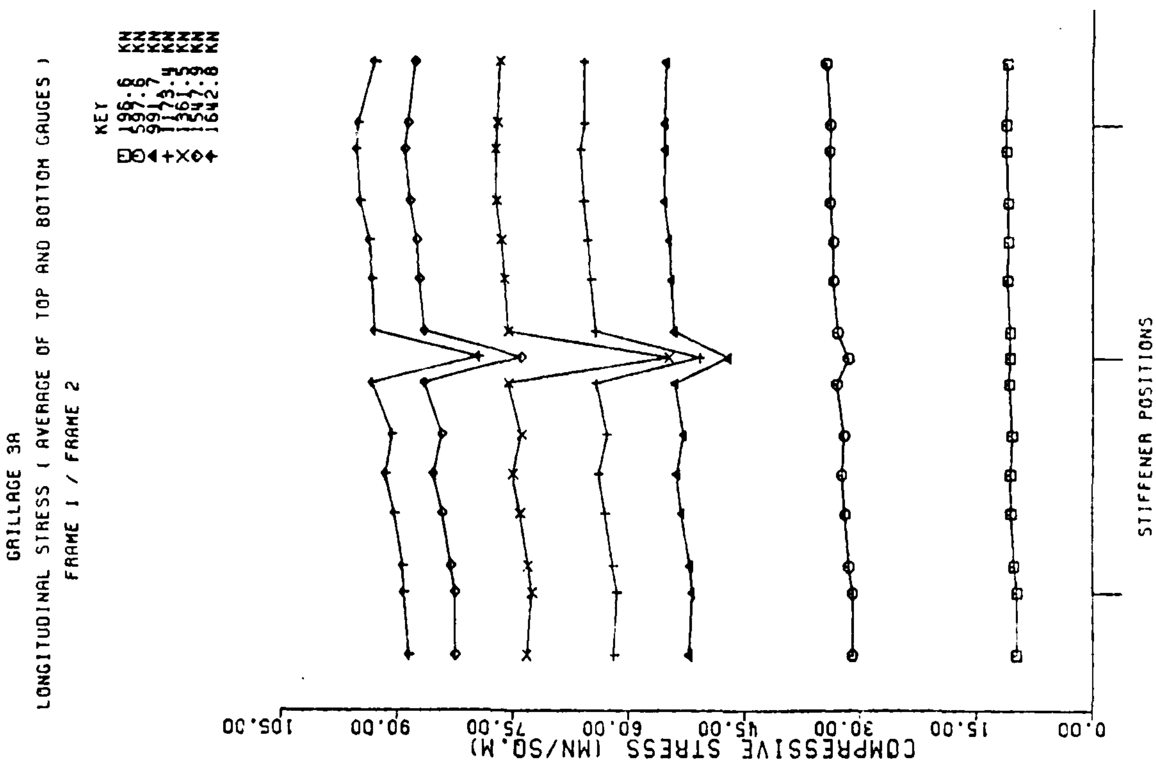

GRILLAGE 3A
LONGITUDINAL STRESS (AVERAGE OF TOP AND BOTTOM GAUGES)
FRAME 1 / FRAME 2
KEY
196.6 KN
597.7 KN
991.7 KN
1173.4 KN
1361.5 KN
1547.9 KN
1642.8 KN
COMPRESSIVE STRESS (MN/SQ.M)
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
STIFFENER POSITIONS

FIGURE 26

AVERAGE PLATE STRESS / EDGE STRAIN

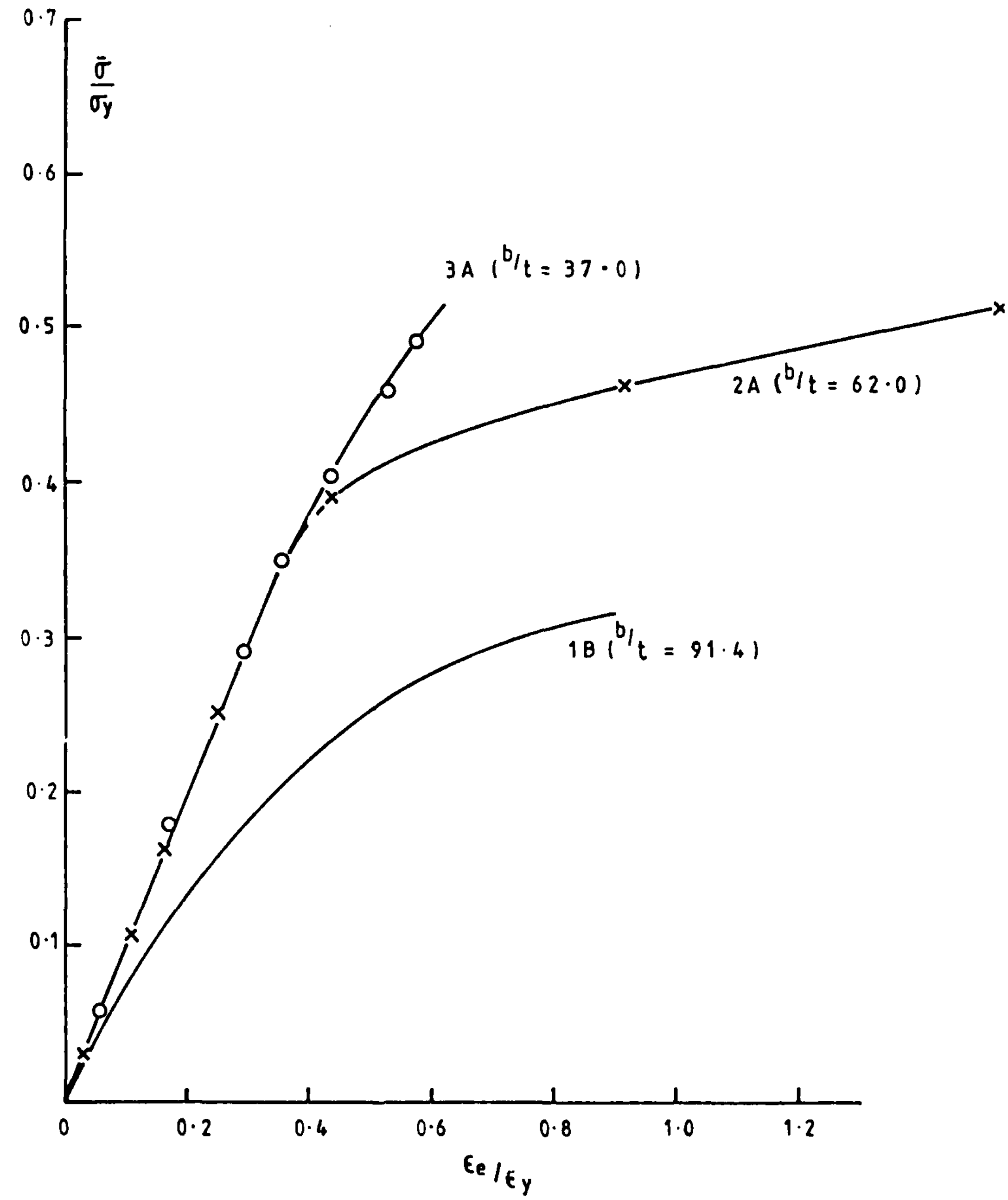


FIGURE 27

GRILLAGE 1B - COMPARISON OF LOAD / SHORTENING WITH THEORY (N106)

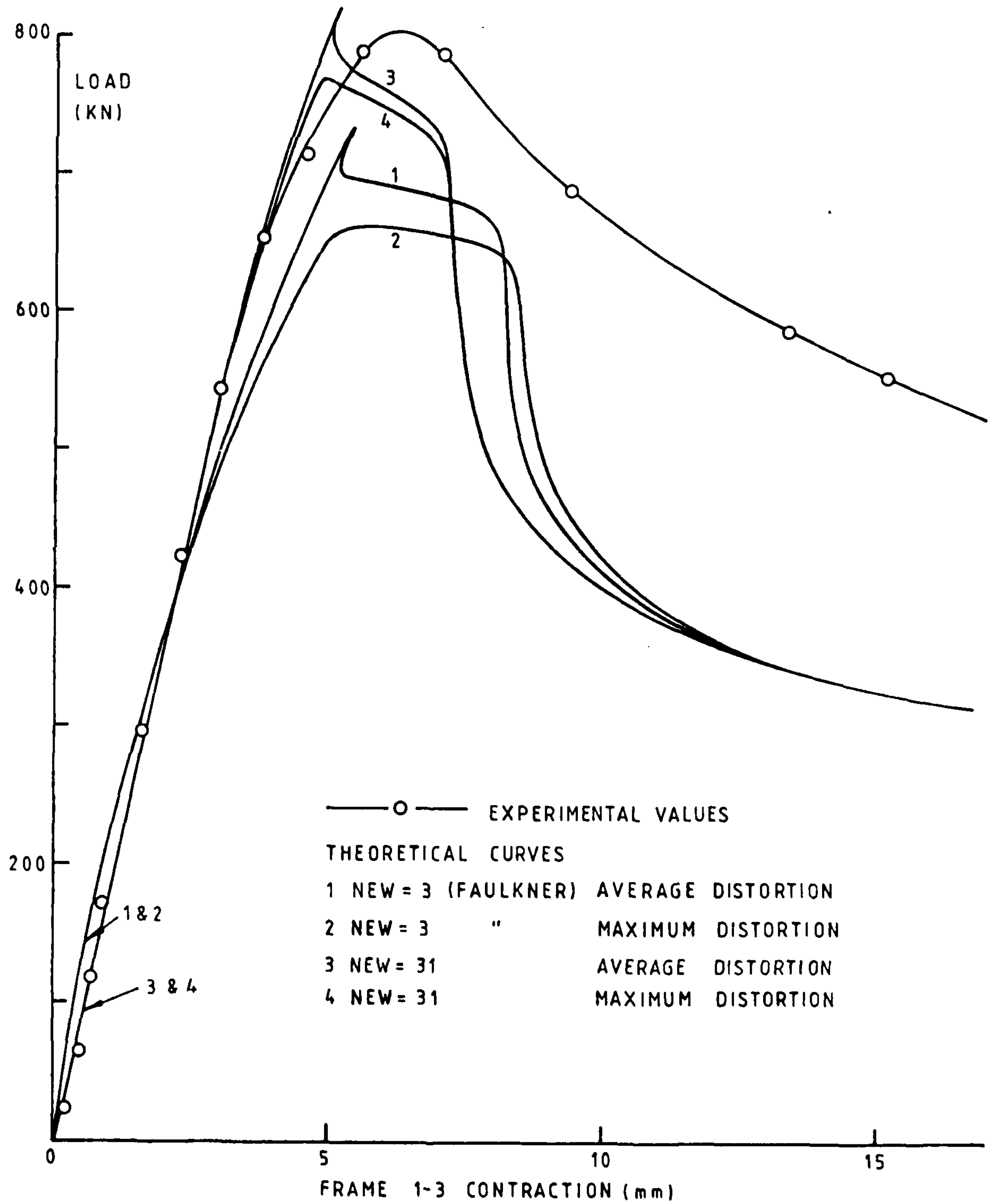


FIGURE 28

GRILLAGE 2A - COMPARISON OF LOAD / SHORTENING WITH THEORY (N106)

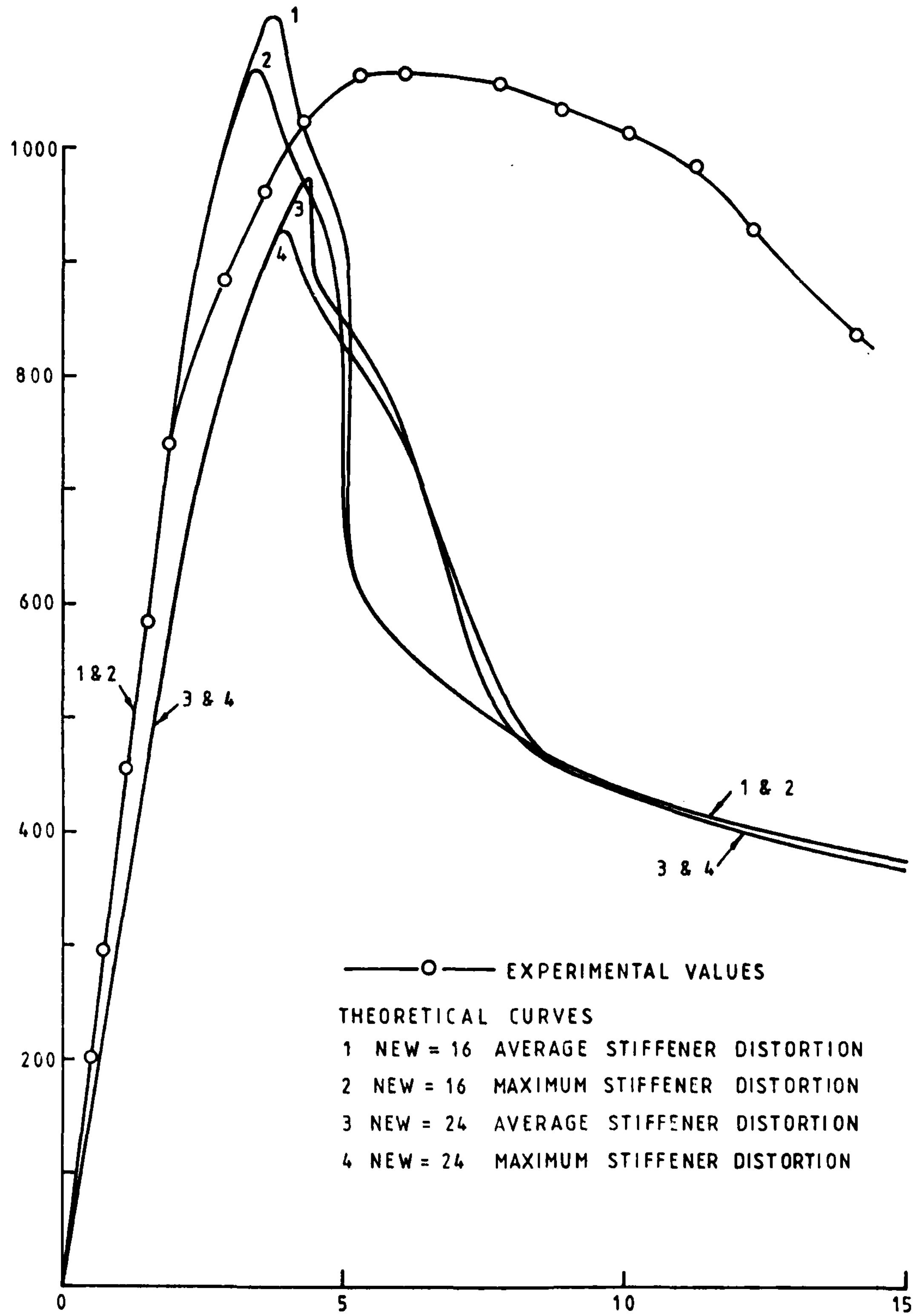


FIGURE 29

GRILLAGE 3A - COMPAR'SON OF LOAD / SHORTENING WITH THEORY (N'106)

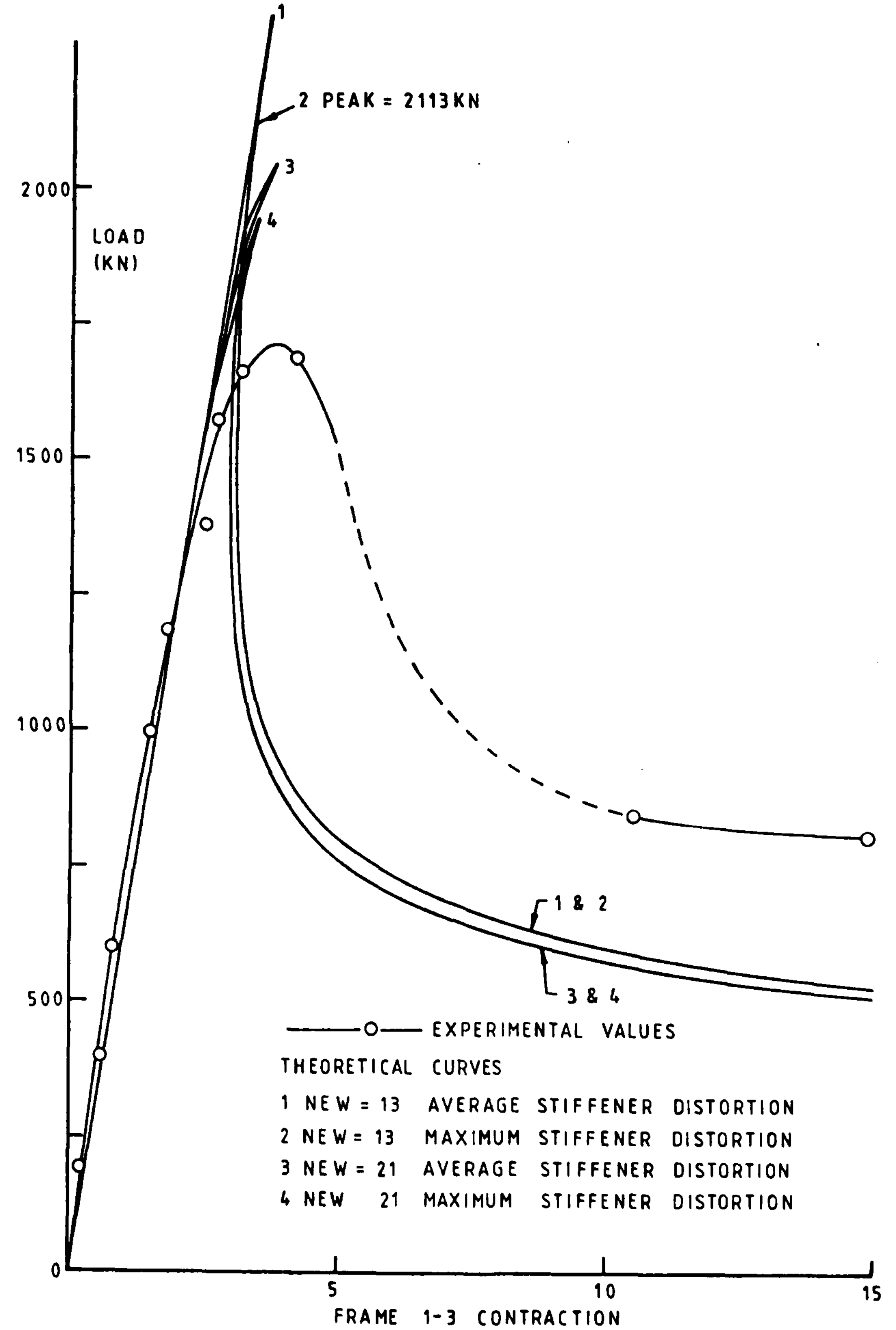


FIGURE 30

GRILLAGE 4A - COMPARISON OF LOAD SHORTENING WITH THEORY (N106)

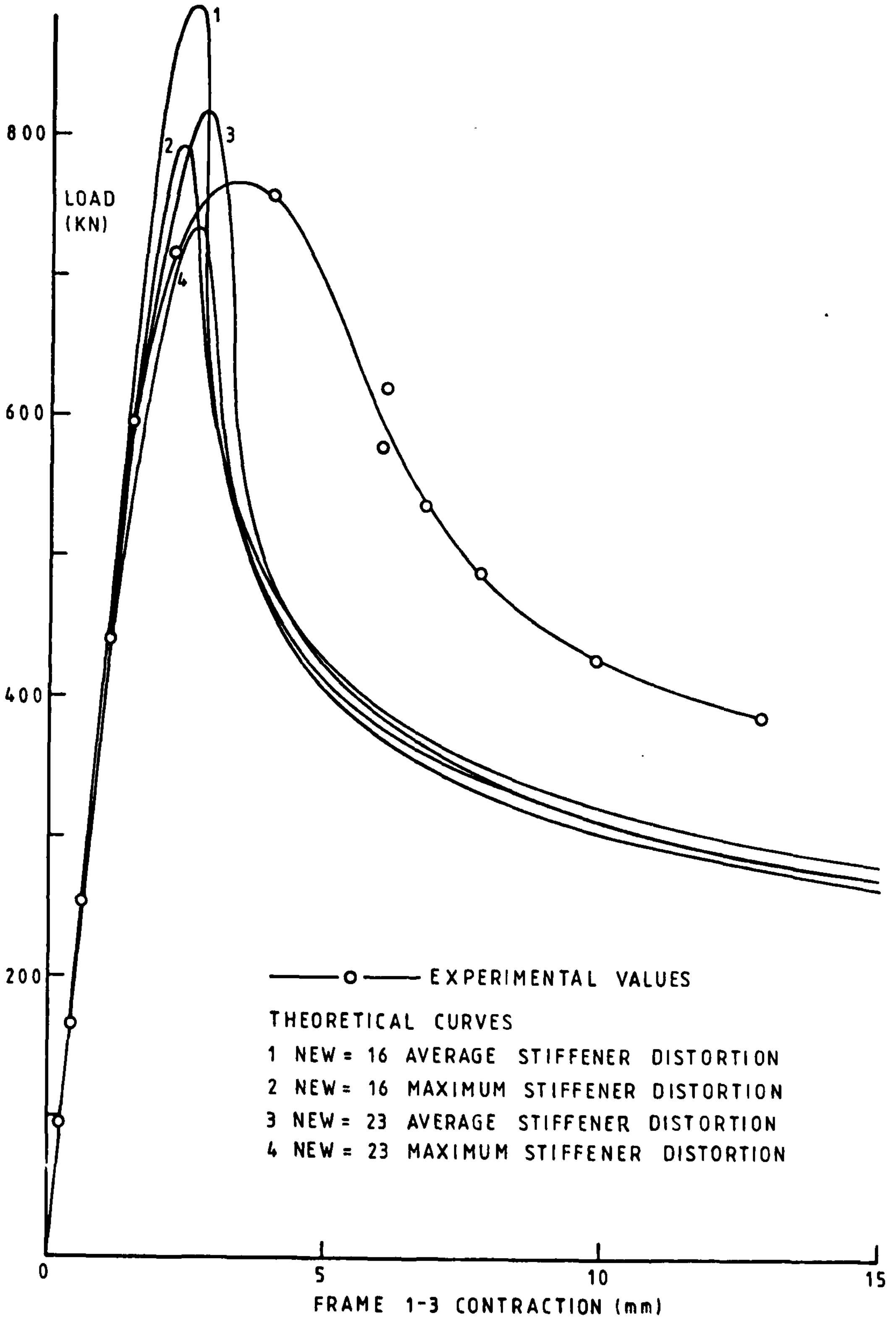


FIGURE 31

ROTATIONAL STIFFNESS OF FRAME SUPPORTS

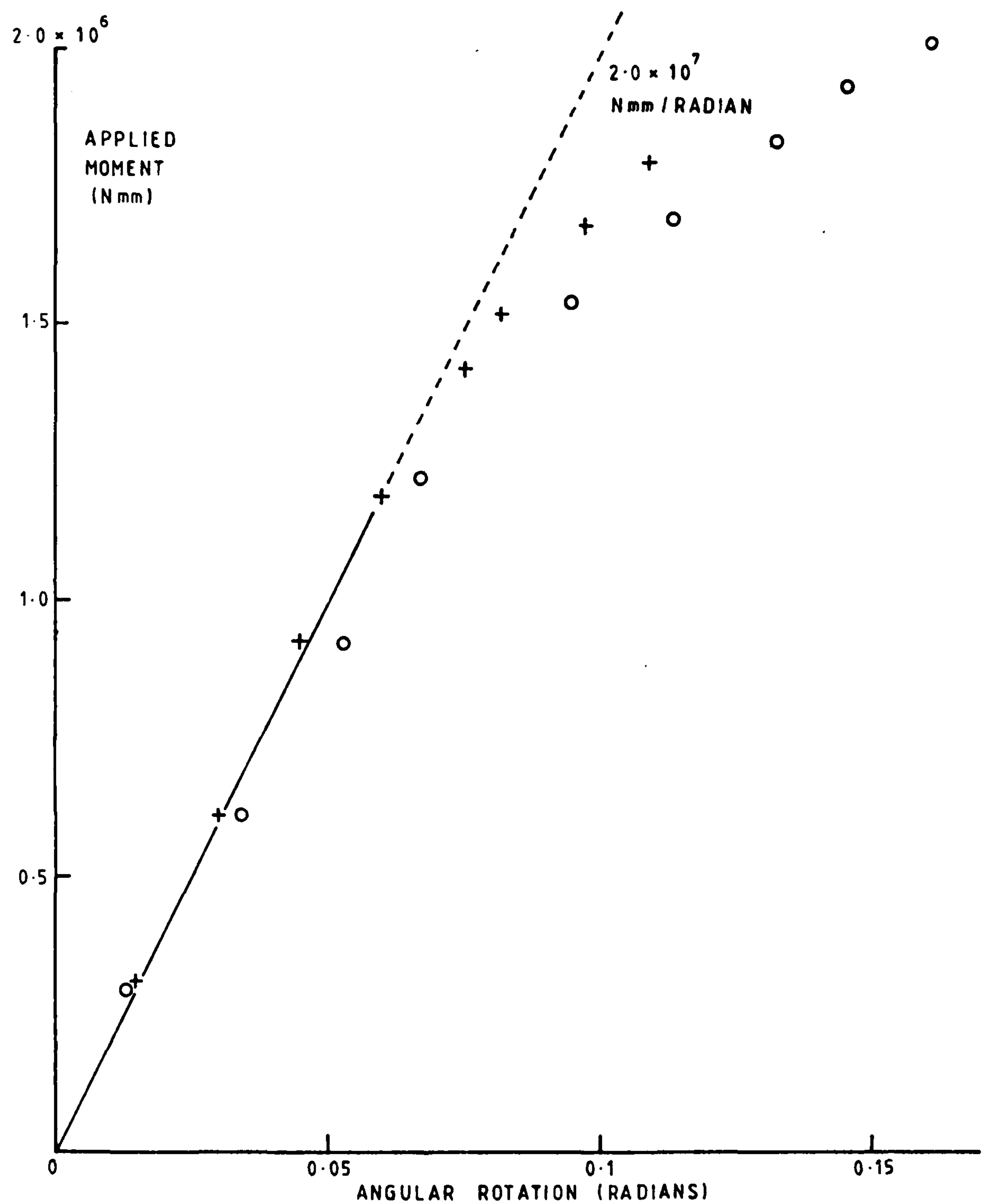


FIGURE 32

GRILLAGE 1B - COMPARISON OF LOAD SHORTENING WITH THEORY
EFFECT OF ROTATIONAL RESTRAINT AT FRAME ENDS

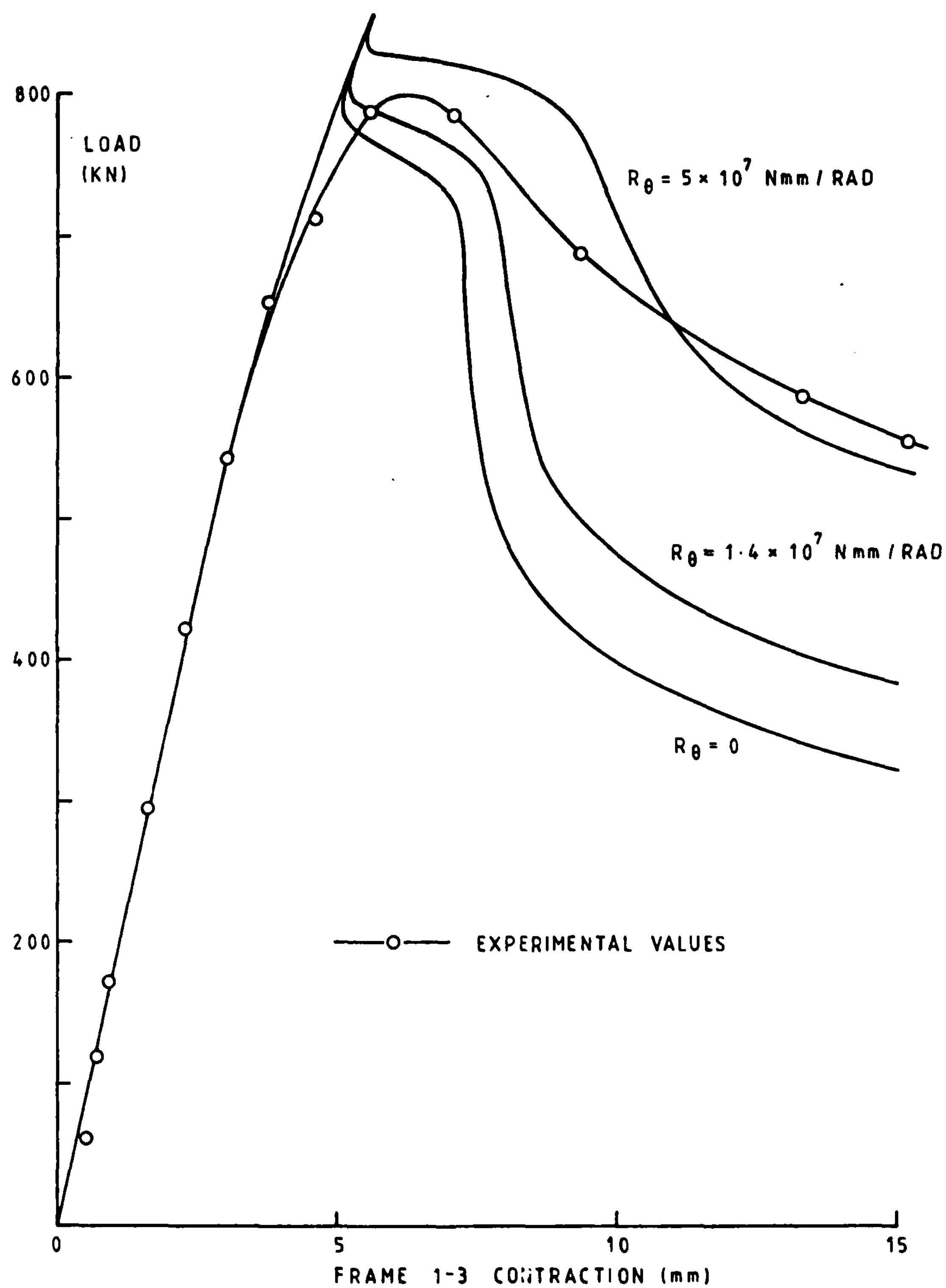


FIGURE 33

APPENDIX A

CORRECTION OF LONGITUDINAL DISPLACEMENTS FOR ROTATION OF TRANSVERSE FRAMES

Figure A1 shows the arrangement adopted for the measurement of longitudinal displacements. In order to avoid errors due to contact between the transducer and the plating when buckling and vertical movement of the grillage occurred it was found necessary to raise the pointer above the neutral axis for later tests. Even in the initial tests the small vertical movement of the frames relative to the transducer supports was sufficient to introduce an error in the longitudinal measurement.

If the point is a distance h above the neutral axis rotation of the frame by an angle θ introduces an error h sin θ.

If the ends of the frames were simply supported and the stiffener exhibited constant curvature the radius of curvature is given by

$$R = \frac{L^2}{8w} \quad (\text{for } w \ll L)$$

and the angle at the ends is given by

$$\sin\theta = L/2R$$

where L is the length of the frame

and w is the vertical deflection at the centre of the stiffener (+ve upwards)

Hence the correction due to this rotation is given by

$$\Delta L = \frac{4\,h\,w}{L}$$

The fractional error in this correction associated with assuming $w \ll L$ is equal to $(2w/L)^2$ which is less than 1% for the maximum vertical deflection measured (35 mm).

The ends of the stiffeners are not simply supported but are influenced by the deflection in the adjacent frames. For the central frame it is assumed that if $w_1 = -w_2$ the rotation will be as assumed above, but if $w_1 = w_2$ the rotation will be zero.

For $w_1 \neq w_2$ a linear relation between these two extremes is assumed giving corrections of:

$$-\frac{2\,h}{L}(w_1 - w_2) \text{ for the first frame space}$$

and $$+\frac{2\,h}{L}(w_1 - w_2) \text{ for the second frame space.}$$

The deformation of the outer frame spaces with doubler plates is small and is assumed to be negligible so that using the same assumption the corrections for the outer frames are

$$-\frac{2\,h\,w_1}{L} \quad \text{for the first frame space}$$

and $$-\frac{2\,h\,w_2}{L} \quad \text{for the second frame space}$$

giving total corrections of

$$-\frac{2\,h}{L}(2w_1 - w_2) \quad \text{for the first frame space}$$

and $$-\frac{2\,h}{L}(2w_1 - w_2) \quad \text{for the second frame space.}$$

The correction over both frame spaces is given by

$$-\frac{2\,h}{L}(w_1 + w_2)$$

which in most cases is less since w_1 and w_2 tend to have opposite signs.

These corrections have been applied to the measured longitudinal end shortening using the mean vertical displacements of the three stiffeners in each case.

MEASUREMENT OF LONGITUDINAL DISPLACEMENTS

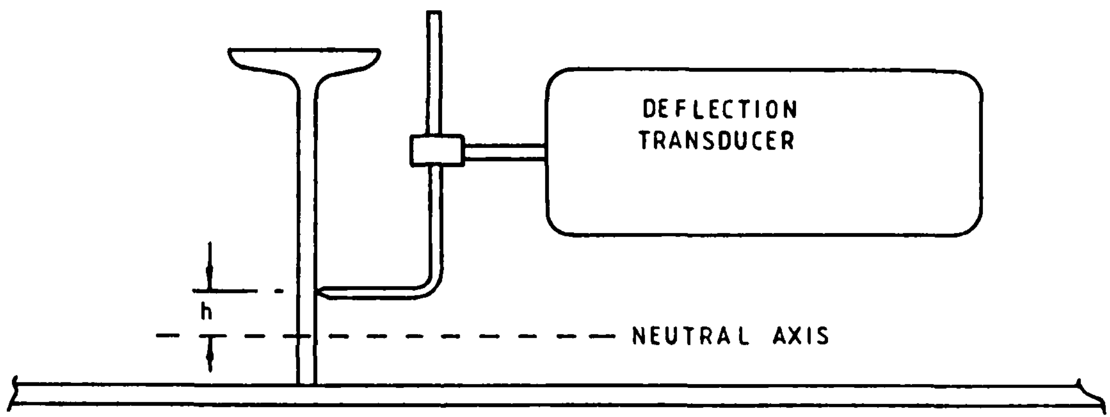


FIGURE A1

DOCUMENT CONTROL SHEET

AD A 163808

(Notes on completion overleaf)

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	AMTE(S) R85104		UNLIMITED

5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location
	Admiralty Research Establishment Dunfermline St Leonard's Hill, Dunfermline, Fife, KY11 5PW
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location

7. Title

INTERFRAME BUCKLING OF ALUMINIUM ALLOY STIFFENED PLATING (UL)

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers). Title, place and date of conference

8. Author 1,Surname,initials	9a. Author 2	9b. Authors 3, 4...	10. Date	pp	ref
Clarke, J D	Swan, J W		10.1985	66	10

11. Contract Number	12. Period	13. Project	14. Other References

15. Distribution statement

Distribution controlled by MOD Technical Policy Authority, Research Area Leader 1, CS, ARE Dunfermline

Descriptors (or keywords)

Aluminium, buckling, strength, test, compression, stiffened plate, interframe, yield .

Summary (UL)

Compression tests on five stiffened N8 aluminium alloy plates covering typical full scale warship scantlings are described. The panels were manufactured using normal shipyard production methods to ensure typical initial distortion and residual stresses.

Maximum loads and post-buckling load/deflection results are compared with theoretical predictions using the ARE computer program N106C. Keywords:

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3. Agency reference: Enter reference number allocated by sponsoring agency (contract authority) in the case of contract reports.

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*5a. Sponsoring Agency's Code: Code number for the DRIC-standardised form of the entry appearing in Box 6a.

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8. Author 1: Enter the name of the first author, followed by his initials.

9a. Author 2: Enter the name of the second author, followed by his initials.

9b. Authors 3,4...: Enter third and following authors' names.

10. Date: Enter the month (in figures) and the year of the report (Dec., 1969 is written 12.1969). If the report is undated but a period covered by the report is indicated, enter the date at the end of the period. pp. ref. Enter the inclusive number of pages in the report containing information, i.e. including appendices, tables and illustrations, and the total number of references cited.

11. Contract Number: Enter the number of the contract or grant under which the report was written.

12. Period: (always associated with the Contract Number). Only to be used for reports covering a specific period, e.g. quarterly, annual or final reports. Enter QR-1, AR, FR, as appropriate.

13. Project: Enter project name or number.

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Abstract: The abstract should preferably not exceed 150 words, i.e. it can be considerably shorter than the Abstract to be provided on the Title Page of the Report. Information available in the report title need not be included in the abstract.

AMTE(S) R85104 UNLIMITED
INTERFRAME BUCKLING OF ALUMINIUM ALLOY STIFFENED PLATING (UL) by J D Clarke and J W Swan, 1985

(UL) Compression tests on five stiffened N8 aluminium alloy plates covering typical full scale warship scantlings are described. The panels were manufactured using normal shipyard production methods to ensure typical initial distortion and residual stresses.

Maximum loads and post-buckling load/deflection results are compared with theoretical predictions using the ARE computer program N106C.

SUBJECT INDEX

Aluminium
Buckling
Strength
Test
Compression
Stiffened plate
Interframe
Yield

AMTE(S) R85104 UNLIMITED
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(UL) Compression tests on five stiffened N8 aluminium alloy plates covering typical full scale warship scantlings are described. The panels were manufactured using normal shipyard production methods to ensure typical initial distortion and residual stresses.

Maximum loads and post-buckling load/deflection results are compared with theoretical predictions using the ARE computer program N106C.

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