NATIONAL BUREAU OF STANDARDS REPORT

10 163

TEST AND EVALUATION OF THE PREFABRICATED LEWIS BUILDING AND ITS COMPONENTS
PHASE I PART I
EVALUATION OF SANDWICH PANEL COMPONENTS

Report to
Naval Civil Engineering Laboratory
Port Hueneme, California

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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EVALUATION OF SANDWICH PANEL COMPONENTS

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TEST AND EVALUATION OF THE PREFABRICATED LEWIS BUILDING AND ITS COMPONENTS

PHASE I, PART 1

EVALUATION OF SANDWICH PANEL COMPONENTS

By

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1. INTRODUCTION

1.1 Objective

The primary objective of this phase of the study was to evaluate the relative quality of three brands of paper honeycomb sandwich panels suitable for use in the Lewis Building. These panels were produced by three manufacturers from essentially identical materials. A secondary objective was to obtain engineering data which might be useful in designing buildings made from these panels.

1.2 General

The sandwich panels had aluminum skins on paper honeycomb cores. The manufacturing processes of the three manufacturers

were similar, varying only in details. The raw materials used by the three manufacturers (designated A, B, and C) were:

1) coiled sheet aluminum, about 49 in. wide;
2) compressed, phenolic impregnated, kraft paper honeycomb, about 48 in. wide;
3) synthetic rubber adhesive with about 25 to 30 percent solids.

The aluminum skins were stucco embossed and prefinished by the aluminum producer, usually with a "finish" coat of paint on one side and a "wash" coat on the side which will be bonded to the honeycomb core. One panel manufacturer (Brand A) purchased the aluminum with a "finish" coat on both sides; each side being a different color to allow the manufacturer a choice of colors.

The Brand A skins were 3105-H264 aluminum, .024 in thick. The skins of the other two brands appeared to be identical although the alloy and thickness were not determined. An aluminum producer stated that the rolling tolerance for these coiled sheets is $\pm$.0025 in.

The compressed paper honeycomb is expanded, cut to size, and then passed through a flash oven to polymerize the phenolic resin. The polymerization stiffens the honeycomb so that it maintains its expanded size and shape. For these panels the core is installed so that the paper "ribbons" of the core are parallel to the width of the panels.

The adhesive is applied to the aluminum and to the honeycomb and then partially "cured" in an oven by evaporating most of the solvent, usually toluene. Finally the components are pressed together and reheated until the required bond is obtained. The manufacturers state that the bond strength increases appreciably with age for at least two weeks.

If the raw materials are assumed to be identical, the main variables affecting the properties of the assembled sandwich panels would be the following:

1) completness of the phenolic polymerization process,
2) the amount and distribution of the adhesive applied to the skins and cores,
3) completness of the adhesive "cure",
4) the orientation of the honeycomb core ribbons with respect to the long dimension of the panel,

5) the magnitude and duration of the pressure used to assemble the sandwich.
6) roughness of core faces
7) presence of core joints

1.3 Scope

In designing the test program for this study the aim was to evaluate the performance of the panels in such a way that production differences would be emphasized. In general this evaluation consisted of tests which would determine panel properties which are dependent on the bond between the skin and the core material. Since the panel manufacturers do process the core materials to some degree, tests were also included with which would evaluate the mechanical properties of the core and the effect of temperature and moisture on the core as well as on the adhesive bond.

Four types of tests were performed. These tests, shown schematically in Figure 1.1, were:

1) edgewise compressive strength test on 6 in x 24 in specimens using ASTM test method C-364,
2) compressive shear test on 6 in x 24 in specimens using ASTM test method C-273,

3) edgewise compressive test on the 4 ft x 8 ft panels using ASTM test method E-72, and
4) flatwise tension test on 3 in square specimens using ASTM method C-297.

The specimens were conditioned prior to testing using the following three methods:

1) conditioned at 50 percent relative humidity and 73°F,
2) conditioned at 100 percent RH and 150°F, and
3) conditioned by the ASTM aging procedure C-481.

2. TEST SPECIMENS

2.1 General

The panels from the three manufacturers are identified in this report as Brands A, B and C. Test results for specimens identified as being Brand D are for a second shipment from the manufacturer of Brand A.

A sample of nine 4 ft x 8 ft sandwich panels 3 in thick were ordered from each manufacturer. Two samples (Brand B and C), shipped by truck, arrived in strong crates in very good condition.

The Brand A panels were packaged in individual paper cartons and arrived by truck in fair condition. All panels of the Brand A sample had bent edges and several had dents in the faces; The cartons had no label to indicate that the contents were fragile or that special handling was required.

Nine 4 ft x 8 ft panels of Brand B and C were received. Six 4 ft x 8 ft and six 4 ft x 4 ft panels of Brand A were received. All panels appeared to have been well protected from the weather and were dry when received.

The only obvious difference between the brands was the color of the honeycomb core and the cell size. Brand A and C core was a reddish-beige color while the Brand B core was a buff or tan color.

The core of Brand A and B was 3/4 in cell size, while the cell size for Brand C was 1/2 in. The producer of Brand C normally makes only steel-skin panels using either 1/2 in or 1 in cell size honeycombs.

The honeycomb cell size is measured by the diameter of the largest circle which can be inscribed in a cell when the honeycomb is expanded. In practice the honeycomb cell is imperfectly shaped and is not fully expanded.

The paper ribbons of the honeycomb core ran perpendicular to the length of the panels. Brand B and C panels were made especially for this study. The date of manufacture is known only for Brand B (3/31/69), however all specimens were at least six weeks old when tested.

The weight of the 4 ft x 8 ft panels varied. The average weight for Brand A was 37.9 lbs.(1.18 lb/ft^2), B was 42.1 lb. (1.32 lb/ft^2), C was 41.6 lb. (1.30 lb/ft^2). Each panel was marked with an identification symbol indicating the brand and a panel number, thus B5 indicates the fifth panel of Brand B.

2.2 Preparation of Test Specimens

The first six of the 4 ft x 8 ft panels from each brand were set aside to be used for the compressive tests on full size panels. Specimens for the other tests were cut from each of the balance of the panels with a carbide tip saw blade. Because of the possibility of edge damage to the panels in shipment and handling, a 3 in wide edge strip along the length and a 6 in wide strip from the ends of each panel were cut off and discarded. Following this, three lengthwise strips 6 in wide were cut from each panel. These strips were marked to identify the Brand, panel number and cut. Small test specimens were cut from each of these strips. A total of at least

eighteen 6 in x 24 in specimens were cut from each brand of panel. The 24 in length of these specimens was dictated by the maximum length of specimen which could be accommodated in the conditioning chamber used for the ASTM C-481 aging procedure described below.

All specimens were cut so that the ribbons of the honeycomb paper ran parallel to the width of the specimen.

2.3 Conditioning of Test Specimens

All test specimens were conditioned prior to test by one of three methods listed in Table 1.1. All specimens were tested at lab air temperature (73°±3°F).

2.3.1 Conditioning Method Number 1

The specimens conditioned by Method Number 1 were stored for at least six weeks prior to test in the laboratory which is controlled at 50%±5% RH and 73°±3°F.

2.3.2 Conditioning Method Number 2

The specimens conditioned by Method Number 2 were placed inside a frame in a fog curing chamber maintained at nearly 100 percent

RH and at about 73°F. Several layers of six mill polyethylene film covered the frame in such a way that the film did not contact the specimen. Fine jets of steam were fed into this tent through small holes in copper tubing placed around the perimeter of the frame at the floor level. The number of layers of plastic film was adjusted so that the temperature within the tent remained constant at 148°F with a constant supply of steam. The specimens and film were placed so that very little of the liquid moisture deposited on the film would fall on the specimens.

Specimens were conditioned at this temperature and humidity for eight days. Thereafter the specimens remained in the tent until just prior to test, thus these specimens were tested at 100% RH but at the lab air temperature of about 73°F.

The average moisture picked up by the full size panel specimens while being conditioned by this method was as follows:

Brand A - 6.5 lb or 17% of the dry weight (0.215 lb/ft^2)
Brand B - 9.0 lb or 21% of the dry weight (0.281 lb/ft^2)
Brand C - 8.3 lb or 20% of the dry weight (0.260 lb/ft^2)

2.3.3 Conditioning Method Number 3

Conditioning method 3 is cycle B of ASTM Test Method C-481 entitled "Laboratory Aging of Sandwich Constructions." All specimens were subjected to six complete cycles of the procedure. There was no apparent damage to the specimens as a result of this conditioning, although slight fraying of the edges of the honeycomb paper was obvious. The specimens were weighed at the end of step 2 of the first cycle to determine water absorbed into the specimen. However it was obvious that most of the weight gain was due to water trapped within the honeycomb cells. The weight gains recorded were highly variable as they were dependent on the rate at which the water could drain from the cells.

This data was not considered to be significant to this study.

3. TEST PROCEDURES

3.1 General

The test methods adopted for this study are shown schematically in Figure 1.1. The most important production item in a structural sandwich is the bond between the core and skin. To be able to take full advantage of the strength and stiffness

of the core this bond must by strong enough to develop the strength of the core without excessive creep.

Under edgewise compressive loads (test 1 and 3 Figure 1.1) one of the functions of the core is to stabilize the relatively thin skins against intercell buckling or wrinkling. (The failure terminology usually used in discussing sandwich panels is illustrated in Figure 1.2.) When the bond and core strength is sufficient to prevent face wrinkling under concentrice compression thin-skin sandwiches such as those for this study will fail by intercell buckling of the skins between the cellwalls of the core. The load at which this intercell buckling would occur is dependent on the stiffness of the skin and the compressive strength, stiffness and cell size of the core.

3.2 Edgewise Compressive Tests on 6 in x 24 in Specimens

The test procedure was that described in ASTM C-364. Figure 1.3 illustrates a typical test-setup; note one of two extensometers used to determine if the load was distributed uniformly in the 6 in x 24 in specimen. Strain data from these extensometers were also used to plot a stress-strain diagram for each specimen. The modulus of elasticity for the composite sandwich was determined from the stress-strain data.

3.3 Compressive Shear Tests on 6 in x 24 in Specimens

The test procedure was that described in ASTM C-273. Figure 1.4 illustrates a typical test-setup using the 6 in x 24 in specimen. C-273 recommends that the length of the specimen be 12 times the thickness. According to this recommendation the specimen length should be 36 in. However, the length of the specimen was dictated by the maximum length (24 in) which could be placed in the ASTM C-481 conditioning chamber.

The test specimens were bonded to 3/4 in steel plates with an epoxy resin. The compressive load was applied through a spherical loading head to the steel plates so that the line of action of the force passed through the diagonally opposed corners of the sandwich.

The 0.001 in dial gage visible in Figure 1.4 measured the relative movement between the steel plates. The shear strain and modulus reported are for the composite sandwich.

This test measures the shear properties of the core and the skin-to-core bond. It should be remembered that these specimens were tested in the "weak" shear plane of the honeycomb.

3.4 Edgewise Compressive Tests on 4 ft x 8 ft Specimens

The test procedure was that described in ASTM E-72. A typical test-setup is shown in Figure 1.5. The specimens were the 4 ft x 8 ft panels as received from the manufacturer, except that the Brand B panels were not usable as received because the aluminum skins had not been sheared perpendicular to their length. Approximately 3/4 in was cut from each end of the Brand B specimens to insure uniform loading along the width of the specimen.

Aluminum extrusions were fastened to the top and bottom of the specimens. These extrusions were the members used for the top of the end walls in the Navy Mark III structure. Number 8 sheet metal screws at 6 inches on center were used to connect the panels to the extrusions. To insure good bearing between the extrusions and the skins a bedding of high strength plaster was used.

The bottom extrusion was seated on a flat steel plate placed on the platen of a 600 kip hydraulic testing machine. A 6 in wide strip of 3/4 in plywood was placed on the top extrusion. The load was applied to this plywood through a 6 in "Eye" beam.

The load was applied in 1-kip increments to 6 kips and in 2-kip increments thereafter until failure.

In this test procedure the test specimens are loaded similar to those in the compressive tests on the 6 in x 24 in specimen (Section 3.1), but the height of the specimen in this test is more representative of conditions encountered in service.

3.5 Flatwise Tensile Tests

This test procedure was as described in ASTM C-297. Steel blocks (3 in x 3 in x 1 in thick) were bonded to both skins of the 3 in x 3 in specimens with a "hot glue." Universal joints were connected to both blocks. The tensile load was applied through the universal joints to the specimen by using 3/8 in pull rods gripped in the heads of a hydraulic testing machine. No measurements were made other than the maximum load obtained.

This test evaluates the strength in tension of the skin-to-core bond or the tensile strength of the core.

4. TEST RESULTS

4.1 Compressive Tests of 6 in x 24 in Specimens

The test results are presented in Table 1.2. The strength values are based on the gross cross sectional area of the composite sandwich. The modulus of elasticity values are secant values from the stress-strain curves at 50 percent of the ultimate stress. A typical stress-strain curve is shown in Figure 1.6. The dashed lines on this figure indicate the method of determining the secant modulus of elasticity.

All Brand A and B specimens failed by face wrinkling (Figure 1.2) of the skin when the skin-core bond failed. Figure 1.3 illustrates a typical failure of this type. All Brand C specimens failed by intercell buckling of the skin near the top or bottom load-bearing area.

These results indicate that the skin-to-core bond strength of Brand C is greater than for Brand A or B and that Brand B is slightly better than A.

As the skins contribute most of the compressive stiffness of the sandwich it follows that the modulus of elasticity values determined by this test should vary with the skin thickness. The results of these tests indicate that the skins of Brand B

are thicker than Brand A or C and that Brand A and C are very nearly the same thickness.

It should be pointed out the thickness tolerance for these skins is about ± 10 percent.

Since the preconditioning should not affect the properties of aluminum skin, the moduli for all specimens of the same brand should be the same under all conditioning methods. The test results bear this out. The average modulus of all Brand A specimens is 176 x 10^3 psi with a range of 16 percent. The average modulus for Brand B was 194 x 10^3 psi with a range of 20 percent. For Brand C the average was 175 x 10^3 psi and the range was 22 percent. The variation in the reported modulus values appears to have no relationship to the conditioning method. This observation is not true for the strength values.

The results show that the compressive strength of specimens conditioned, and tested at 100% RH will be about 40 percent lower than those conditioned and tested at 50% RH. A strength loss had been expected since the stiffness of the paper core and presumably its strength is reduced as its moisture content increases.

Under these loading conditions the core stabilizes the skins to prevent face wrinkling and buckling. If the stiffness of the core is reduced the skins will tend to wrinkle or to buckle between the cell walls at a lower load. This theory is reinforced by the fact that the C-481 conditioned specimens tested with the cores at 50% RH were also stronger than the specimens tested at 100% RH.

4.2 Compressive Shear Tests

Results for these tests are given in Table 1.3. Typical curves of shear stress versus shear strain are shown in Figure 1.7. The shear modulus values reported in Table 1.3 are assumed to be for the core alone because failure was in the core for all specimens. No adjustment was made to eliminate the small effect from the skin on the shear modulus.

Since all specimens failed in shear of the core, the strength and modulus data can be used to compare the cores of the panel material. The data in Table 1.3 indicates that the cores used in the three brands of panels are all different.

It should be noted that one of the three Brand A specimens conditioned at 50 percent RH and 73°F is quite different than the other two Brand A specimens. All specimens were to

have been cut so that the ribbons of paper making up the core would be parallel with the width of the specimen. However, the core in specimen A-12-1A was oriented in the opposite direction to all other specimens. This resulted in a large increase in the shear strength and modulus. Figure 1.7, which is the shear test data for four Brand A specimens, clearly illustrates the effect of core orientation and conditioning method on the shear strength and modulus of the core.

Using the test values from specimens preconditioned and tested at 50 percent RH, 73°F as a base, the 100 percent RH conditioning reduced the average shear strength and modulus of the cores by 61 percent and 64 percent respectively.

The effect of the ASTM C-481 conditioning on the cores was variable. This conditioning reduced the shear strength and modulus of Brand A and B specimens but not the Brand C specimens. At this time there is no data which can explain this variability. It should be remembered, however, that the cell size of the Brand C core was 1/2 in while the others were 3/4 in.

4.3 Compressive Tests on 4 ft x 8 ft Specimens

The results of the compressive tests on full-size panels are summarized in Table 1.4. The modes of failure were similar to those of the compressive tests on the 6 in x 24 in specimens (Section 4.1), except that the face wrinkling, when the skin-to-core bond failed, generally occurred near the top or bottom end. Figures 1.8. 1.9, and 1.10 illustrate typical failures.

The shortening data was used to determine the effective secant modulus of elasticity (at 50% ultimate strength) for the composite sandwich. The modulus values were slightly lower and the variability was greater than was found in the compressive test on the 6 in x 24 in specimens. Any effect from the 100% RH conditioning was not apparent. The average modulus for the Brand A sandwich was 147×10^3 psi, for Brand B it was 163×10^3 psi and for Brand C it was 159×10^3 psi.

4.4 Flatwise Tensile Tests

The results from the flatwise tensile tests are presented in Table 1.5. All specimens failed in the adhesive interface

between the core and skin. The conditioning method affected the bond strength of the Brand A and B specimens but not Brand C.

The differences in the bond strength between the three brands are rather significant with Brand A being very low. One Brand A specimen (8-1C) conditioned by C-481 came apart while setting up for the test.

The bond strength values reported in Table 1.5 are for the gross areas of the specimens and are a good evaluation of the bond affecting the performance of a structural panel. To compare the effectiveness of the adhesive and of the bonding process in specimens with different cell sizes the strengths of the adhesive fillets ware calculated.

These calculated fillet strength values are presented in Table 1.6. A comparison of these values indicate that the adhesive and/or the laminating process for the three brands are quite different. For specimens conditioned in the lab air at 50 percent - 73°F, Brand B and C bonds are comparable, but with the other conditioning methods Brand C bond is outstanding.

It was learned following this test that the honeycomb core used in the Brand C panels had been "sanded". This is a process by which, prior to expansion, the edges of the core are frayed slightly by using an ordinary power sander. The frayed edges apparently provide a better base for the adhesive.

5. DISCUSSION OF RESULTS

5.1 General Considerations

The primary objective of this study was to evaluate the relative quality of the three brands of panels. From the results of the four types of tests there is no doubt that there are very significant differences. In most tests the relative performance of the Brand C specimens was superior and the Brand B specimens performed better than Brand A.

The reason for the wide variations in the performance of the three brands can be attributed either to differences in panel production details, to difference in component materials or as is most likely a combination of the two.

The relative strength and rigidity of the core was based on results from a compressive shear test. The relative tensile

bond strength of the adhesive was based on the results of a direct tensile test. To evaluate the effect that the properties of the core and bond have on the structural properties of the sandwich panels two types of compressive edge loading tests were used.

5.2 Comparison of the Honeycomb Cores

As mentioned previously there were two apparent differences in the cores used by the three manufacturers. The core cell size for Brand C was 1/2 in while it was 3/4 in for the others. The smaller the cell size the more area available for bonding to the skin. Also, unless the basic paper weight and impregnation are different the smaller cell size means more paper and presumably greater core density, core strength and core rigidity.

The other difference noted was in the color of the paper. Brand A and C core paper was a reddish-beige color while B was a buff color. The color variation could mean a variation in the impregnation or in the paper stock.

The test results of the compressive shear tests on the three brands are summarized in Figure 1.11. From these data the following conclusions concerning the core can be made.

1) The relative standing of the three cores under the three conditioning methods are approximately the same with Brand C being the highest and A the lowest. It was expected that the strength and rigidity of Brand C would be the highest because of its smaller cell size. The reason for Brand B being better than A is not obvious, but it could be related either to the weight of the paper or to the amount of impregnation.

2) The effects of the rather severe ASTM C-481 conditioning on the strength and modulus of Brand C core was negligible, but was significant for the other brands. This indicates that some strengthening additive must have been leached from the Brand A and B cores by this conditioning method.

3) The strength and rigidity of all the cores when damp (100% RH) was considerably lower than when relatively dry (50% RH).

5.3 Comparison of the Adhesive Bond

The adhesive bond between the skins and the core for the three brands varied considerably, with Brand C being very much better than the other two under all three conditioning methods. The bond strength of Brand C was not affected by the conditioning

method but the other two brands were reduced significantly when conditioned at 100% RH - 150°F and by the ASTM C-481 Method. These results, which are summarized in the bar chart of Figure 1.12, point out that the adhesive bond need not be affected by the conditioning method. It is not known why the Brand C bond performed so much better, but it could be a result of the "sanded" edges on the honeycomb.

5.4 Comparison of Panel Performance

5.4.1 General

The performance of the three brands of panels in the compressive tests should be related to three factors; the thickness of the skin, the strength and stiffness of the paper and the strength of adhesive bond. The skins appeared to be approximately the same thickness. As noted in Section 4.1 the modulus values from the compression test of the 6 in x 24 in specimens indicate that the skins of Brand B was slightly thicker than the other two brands. The strength and stiffness of the cores, as shown in Table 1.3 and Figure 1.11, indicate that the overall performance of the Brand C core is outstanding. The bond strength of the Brand C specimens was also outstanding, as indicated in Table 1.5

and Figure 1.12. From these relative performances of the core and bond it would appear that the Brand C panels should outperform the others. The average compressive test results for the three brands are presented in chart form in Figure 1.13.

5.4.2 Edgewise Compressive Tests on 6 in x 24 in Specimens

The performance of the Brand C specimens was outstanding under all conditioning methods as would be expected from the foregoing discussion. The superior bond strength of Brand C is evident from the mode of failure (Table 1.2) in this test.

5.4.3 Edgewise Compressive Tests on the 4 ft x 8 ft Specimens

The results from the 4 ft x 8 ft specimens are somewhat contradictory to those for the 6 in x 24 in specimens. The overall performance of the Brand B and C specimens were comparable, but with Brand B having a slight edge in strength. The strengths were only slightly affected when tested in the 100% RH condition. An explanation for this contradiction may be suggested by remembering that the Brand B specimens failed by intercell buckling (3 out of 4) in the 4 ft x 8 ft tests while in the 6 in x 24 in tests all the specimens

failed by face wrinkling. The specimens of the other brands failed in the same mode in both tests.

6. CONCLUSIONS

1. The shear strengths and moduli of all honeycomb cores were reduced over 60% by conditioning at 100% RH.

2. The average compressive strength of the large 4 ft x 8 ft specimens were reduced less than 10% by conditoning at 100% RH.

3. The rather severe aging procedure of ASTM C-481 need not have much affect on the sandwich core shear strength or on the adhesive bond strength as was demonstrated by the results for Brand C.

4. The compressive strength of the 4 ft x 8 ft panels tested by the ASTM E-72 Method was not changed significantly by a significant change in the core or adhesive bond properties. The test results indicate that the skin properties are of greater importance in such tests on full size panels than on small specimens.

5. The data obtained from tests on small specimens indicate that small specimens may not provide data suitable for estimating the structural properties of full size panels.

6. Overall performance of the panels varied considerably from brand to brand. Clearly Brand C performed the best of

all, however it came in a close second to Brand B in the most important tests on the full-size panels.

TABLE 1.1

Test Conditions for Sandwich Panel Specimens

	Conditioning Method	Specimen Condition at Test
	Humidity-Temp.	Humidity-Temp.
1	50% - 73°F	50% - 73°F
2	100% - 150°F	100% - 73°F
3	ASTM C-481, Cycle B	50% - 73°F

TABLE 1.2

Test Results - Edgewise Compression Test (ASTM C-364), 6"x24" Specimens

Brand of Panel	Conditioning Method											
	50% - 73°F				100% - 150°F				ASTM C-481 (Cycle B)			
	Specimen	Strength	Modulus	Type of Failure	Specimen	Strength	Modulus	Failure	Specimen	Strength	Modulus	Failure
		psi	10^3 psi			psi	10^3 psi			psi	10^3 psi	
A	7-3a	141	176	Face Wrinkle	10-3a	54	185	Face Wrinkle	10-2a	79	163	Face Wrinkle
	8-1a	171	176	Face Wrinkle	11-1a	87	192	Face Wrinkle	11-2a	73	168	Face Wrinkle
	9-3a	128	168	Face Wrinkle	12-3a	58	185	Face Wrinkle	12-2a	81	174	Face Wrinkle
Avg.		147	173			70	187			78	168	
B	7-2a	152	181	Face Wrinkle	7-1b	91	206	Face Wrinkle	7-1a	98	179	Face Wrinkle
	7-2b	137	203	Face Wrinkle	7-3b	80	214	Face Wrinkle	7-3a	116	174	Face Wrinkle
	8-2a	167	198	Face Wrinkle	8-1b	114	191	Face Wrinkle	8-1a	154	203	Face Wrinkle
Avg.		152	194			95	204			123	185	
C	7-2b	247	173	Inter-cell Buckling	7-1b	176	185	Inter-cell Buckling	7-1a	181	182	Inter-cell Buckling
	8-2a	211	173	Inter cell Buckling	8-1b	167	176	Inter-cell Buckling	7-3a	245	167	Inter-cell Buckling
	7-2a	252	168	Inter-cell Buckling	7-3b	142	171	Inter-cell Buckling	8-1a	199	182	Inter-cell Buckling
Avg.		237	171			163	177			208	177	

Notes: 1. Strength and modulus values are based on gross cross-sectional area of the specimens (18 $in.^2$)

2. The modulus values are the secant values from the stress-strain curves at 50% of the ultimate stress.

Test Results - Compressive Shear Test (ASTM C-273), 6"x24" Specimen

Brand of Panel	Conditioning Method								
	50% - 73°F			100% - 150°F			ASTM C-481		
	Specimen	Strength 1/	Modulus 2/	Specimen	Strength 1/	Modulus 2/	Specimen	Strength 1/	Modulus 2/
		psi	psi		psi	psi		psi	psi
A	10-1a	11.7	1210	7-1a	3.8	500	9-2a	6.0	530
	11-3a	11.8	1400	8-3a	3.7	450	7-2a	8.2	600
	12-1a 3/	26.4 3/	6020 3/	9-1a	3.5	470	8-2a	6.0	440
Avg.		11.8 4/	1300 4/		3.7	470		6.7	520
B	8-2b	21.9	1620	9-3b	11.0	520	9-1a	16.4	822
	9-2b	23.2	1920	9-1b	7.2	400	9-3a	15.6	838
	9-2a	23.8	1980	8-3b	8.5	400	8-1a	16.0	832
Avg.		23.0	1840		8.9	440		16.0	831
C	7-1	23.8	1740	9-3b	10.6	770	9-1a	23.9	2270
	8-2b	25.8	1590	9-1b	10.8	790	8-3a	23.4	1750
	9-2b	25.4	1860	8-3b	13.2	900	9-3a	23.7	2270
Avg.		25.0	1730		11.5	820		23.7	2300

Notes:
1/ Shear strength is the maximum load divided by 144 in.^{2} (length x width).

2/ Shear modulus is the secant value at 50% of the ultimate stress.

3/ For this specimen the core had been placed in opposite direction to all others

4/ Average for two specimens.

5/ Failure was in the core of all specimens.

TABLE 1.4

Test Results-Endwise Compressive Tests (ASTM E-72) 4'x8' Specimens

Brand of Panel	Conditioning 50% - 73°F				Method 100% - 150°F			
	Specimen	Max. Load kips	Strength psi	Failure	Specimen	Max. Load kips	Strength psi	Failure
A	A - 4	6.0	42	Face Wrinkle	A - 3	6.0	42	Face Wrinkle
	A - 5	14.0	97	Face Wrinkle	A - 2	7.6	53	Face Wrinkle
		____	__		A - 1	5.6	39	Face Wrinkle
	Average	10.0	69		Average	6.4	44	
B	B - 2	28.7	199	Inter-cell Buckle	B - 6	26.0	181	Inter-cell Buckle
	B - 1	25.6	178	Face Wrinkle	B - 5	22.0	153	Inter-cell Buckle
	B - 3	____	___			____	___	
	Average	27.1	188		Average	24.0	167	
C	C - 3	22.0	153	Inter-cell Buckle	C - 2	22.7	158	Inter-cell Buckle
	C - 4	19.5	136	Inter-cell Buckle	C - 6	26.0	181	Inter-cell Buckle
	C - 5	24.0	167	Inter-cell Buckle		____	___	
	Average	21.8	151		Average	24.4	169	
D[2]	D - 1	19.2	133	Inter-cell Buckle				

Notes: 1. Strength is the maximum load divided by 144 $in.^2$ (length x width).

2. Brand D is second shipment from A.

TABLE 1.5

Test Results - Tension Test (ASTM C-297), 3"x3" Specimens

Brand of Panel	Conditioning Method					
	50% - 73°F		100% - 150°F		ASTM C-481	
	Specimen	Bond Strength 1/ psi	Specimen	Bond Strength 1/ psi	Specimen	Bond Strength 1/ psi
A	7-1a	11.	7-b	2.7	8-1c	0
	8-1f	11.	8-1a	1.1	7-1c	1.9
	9-1d	7.	9-1e	.5	9-1c	1.5
Avg.		10.		1.4		1.7
B	7-a	27.	7-e	4.8	7-c	3.4
	8-a	23.	8-f	5.2	8-c	3.7
	9-a	27.	9-d	4.8	9-c	2.5
Avg.		26.		4.9		3.2
C	7-b	40.	7	35.0	7	34.
	8-a	54.	8-a	49.0	8	51.
	9-e	36.	9-m	43.0	9	43.
Avg.		43		42.0		43
D 2/	2-1a	16.				
	2-1b	18.				
	2-1c	16.				
Avg.		17.				

Note: 1/ Strength is the maximum load divided by 9 $in.^2$

2/ Brand D was 2nd shipment from A.

3/ All specimens failed in the adhesive.

TABLE 1.6

Adhesive Fillet Strength (ASTM C-297)

Brand of Panel	Average Fillet Strength, 16 per lin. in.[1/]		
	Conditioned at 50% - 73°F	Conditioned at 100% - 150°F	Conditioned by ASTM C-481
A	1.9	0.3	0.3
B	4.9	0.9	0.6
C	5.4	5.2	5.4
D	3.2	___	___

1/ Fillet length per sq. in. of specimen area is $\frac{4}{S}$ in., where S is the cell size. For Brand A, B and D the fillet length was 5.3 in. per sq. in. For Brand C it was 8 in. per sq. in.

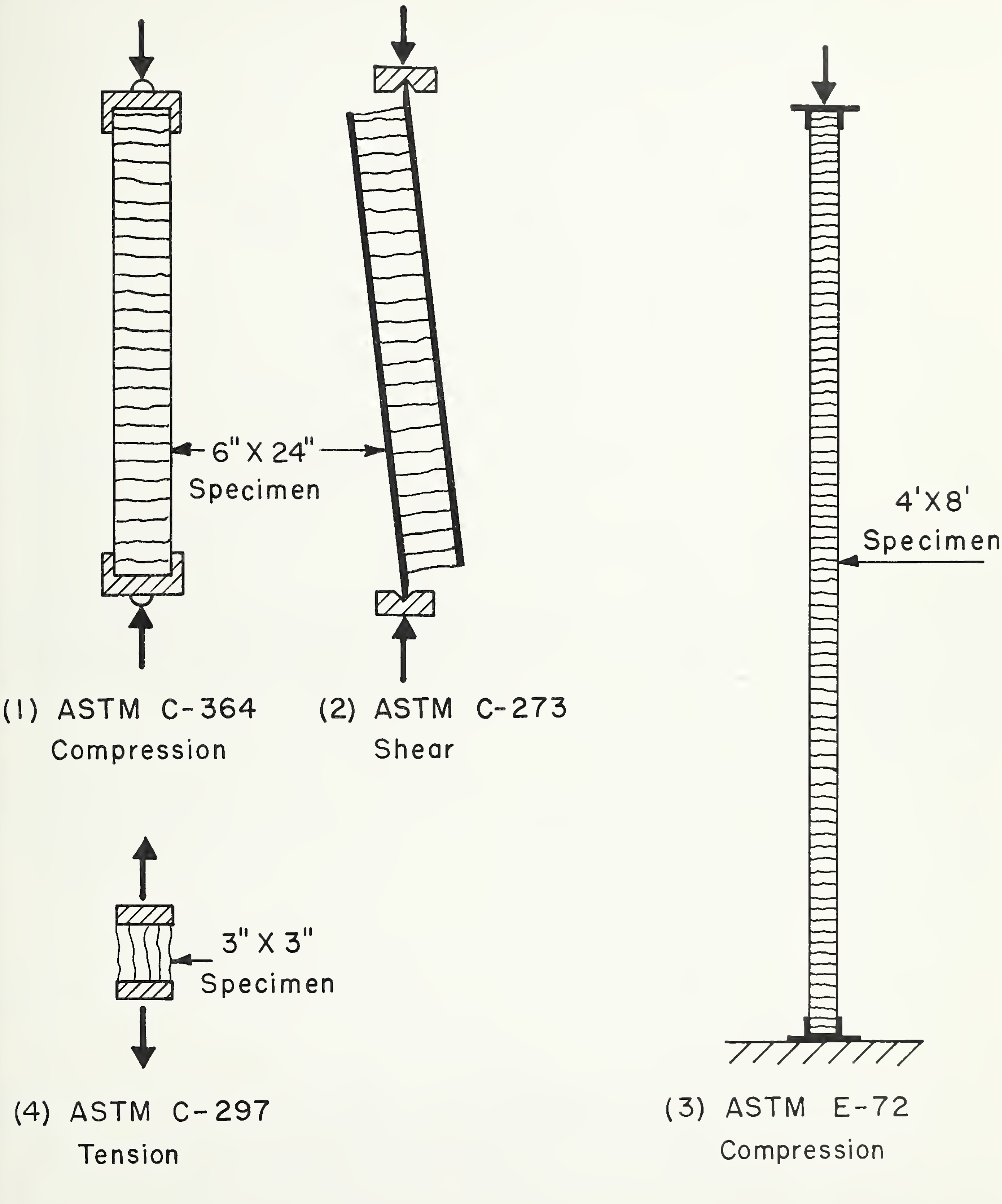


Figure 1.1 Test Methods Used on Sandwich Panels

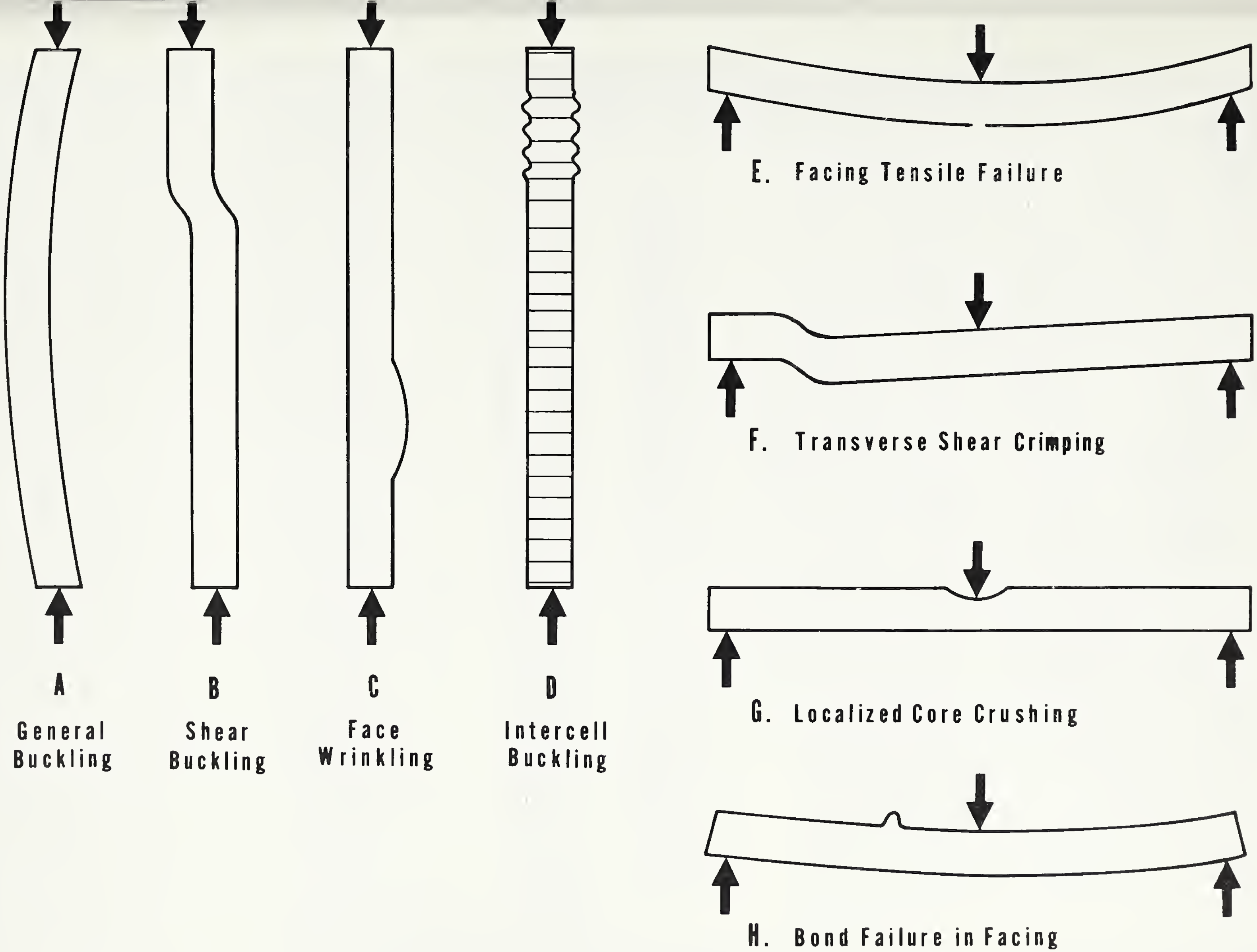


Figure 1.2 Possible Modes of Failure in Sandwich Panels

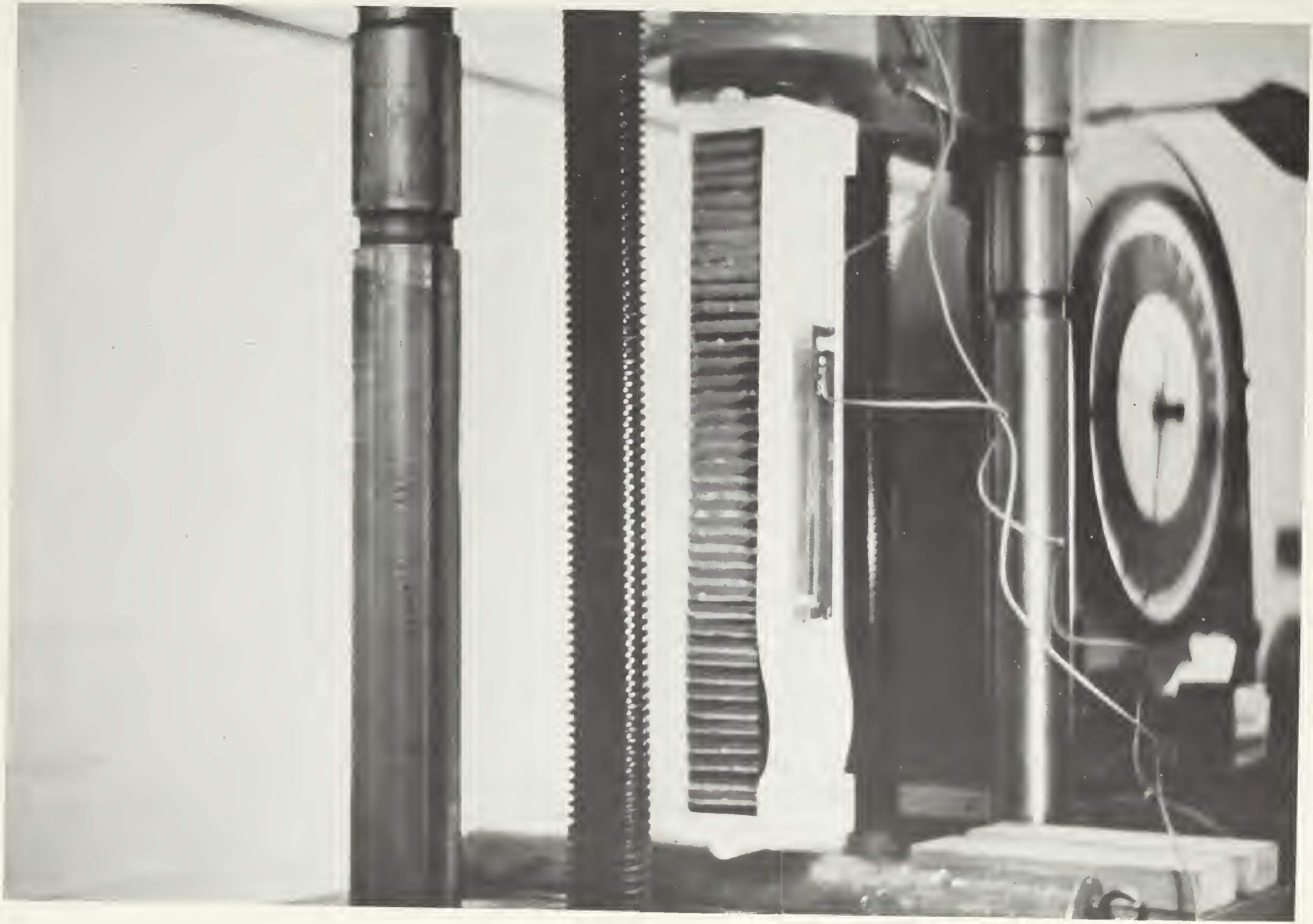


Figure 1.3 Edgewise compressive test on 6 in. x 24 in. specimen.

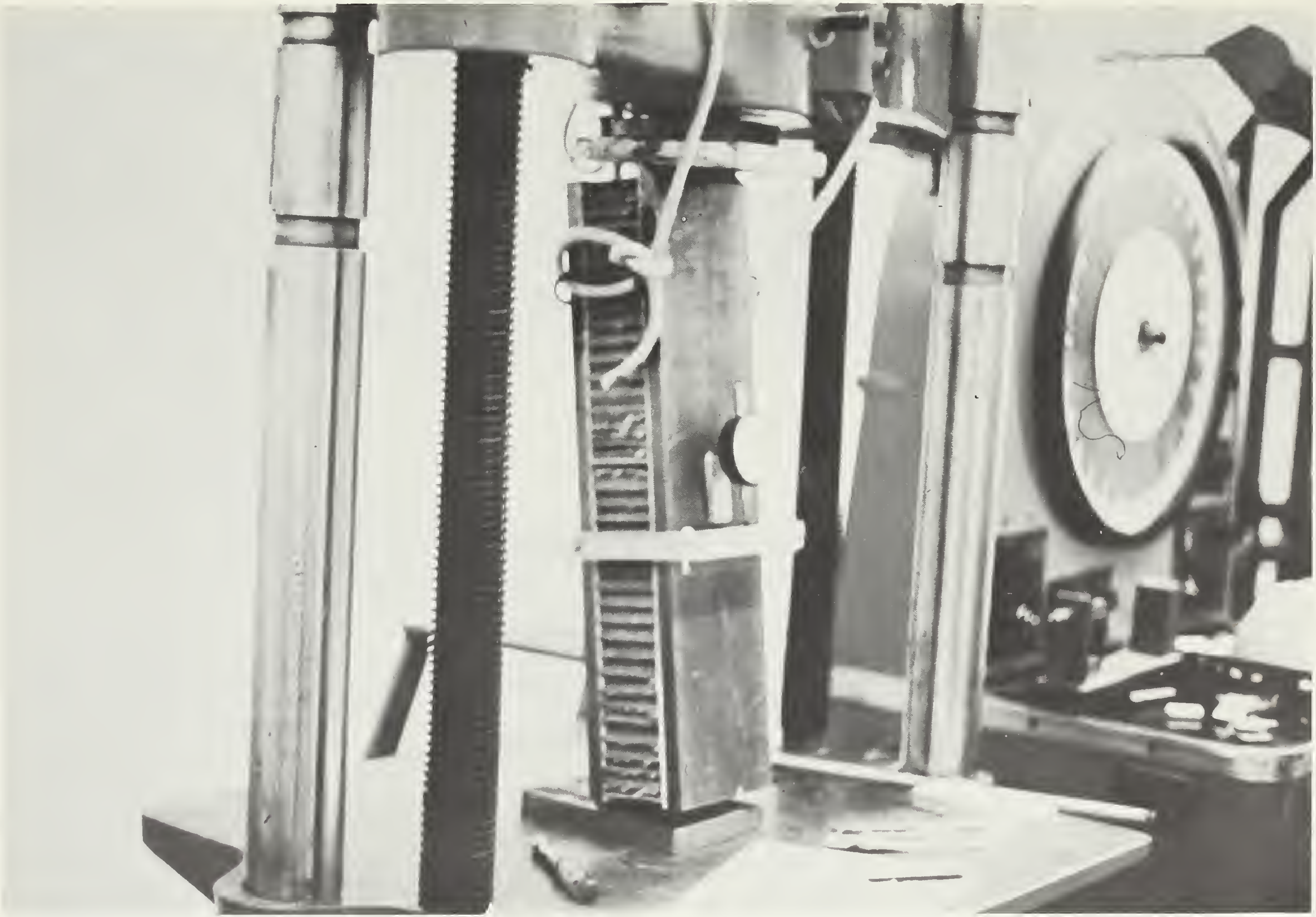


Figure 1.4 Compressive shear test on 6 in. x 24 in. specimen.

Figure 1.5 Endwise compressive test on 4 ft. x 8 ft. specimen.

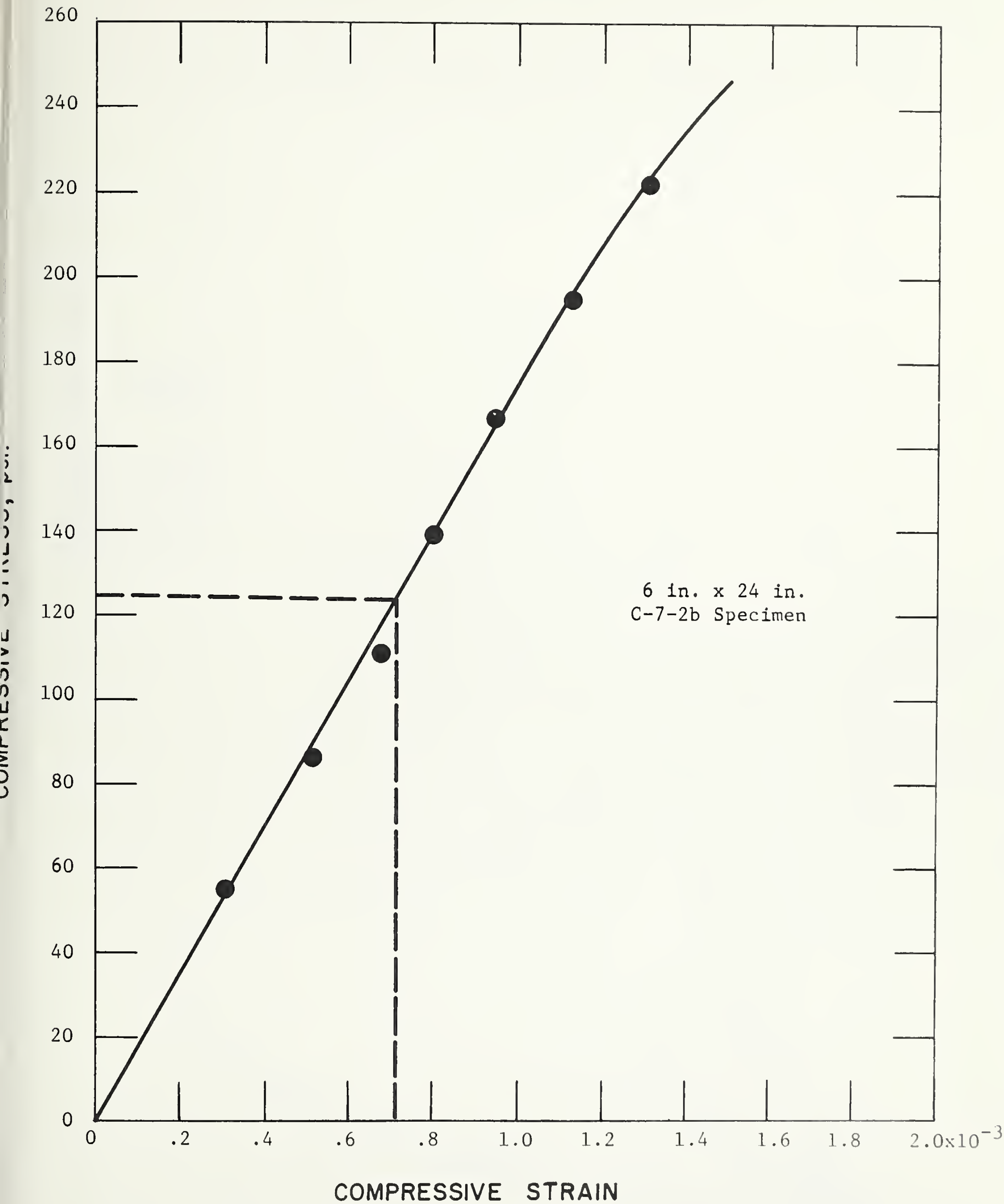


Figure 1.6 Typical stress-strain curve for edgewise compressive test on 6 in. x 24 in. specimen.

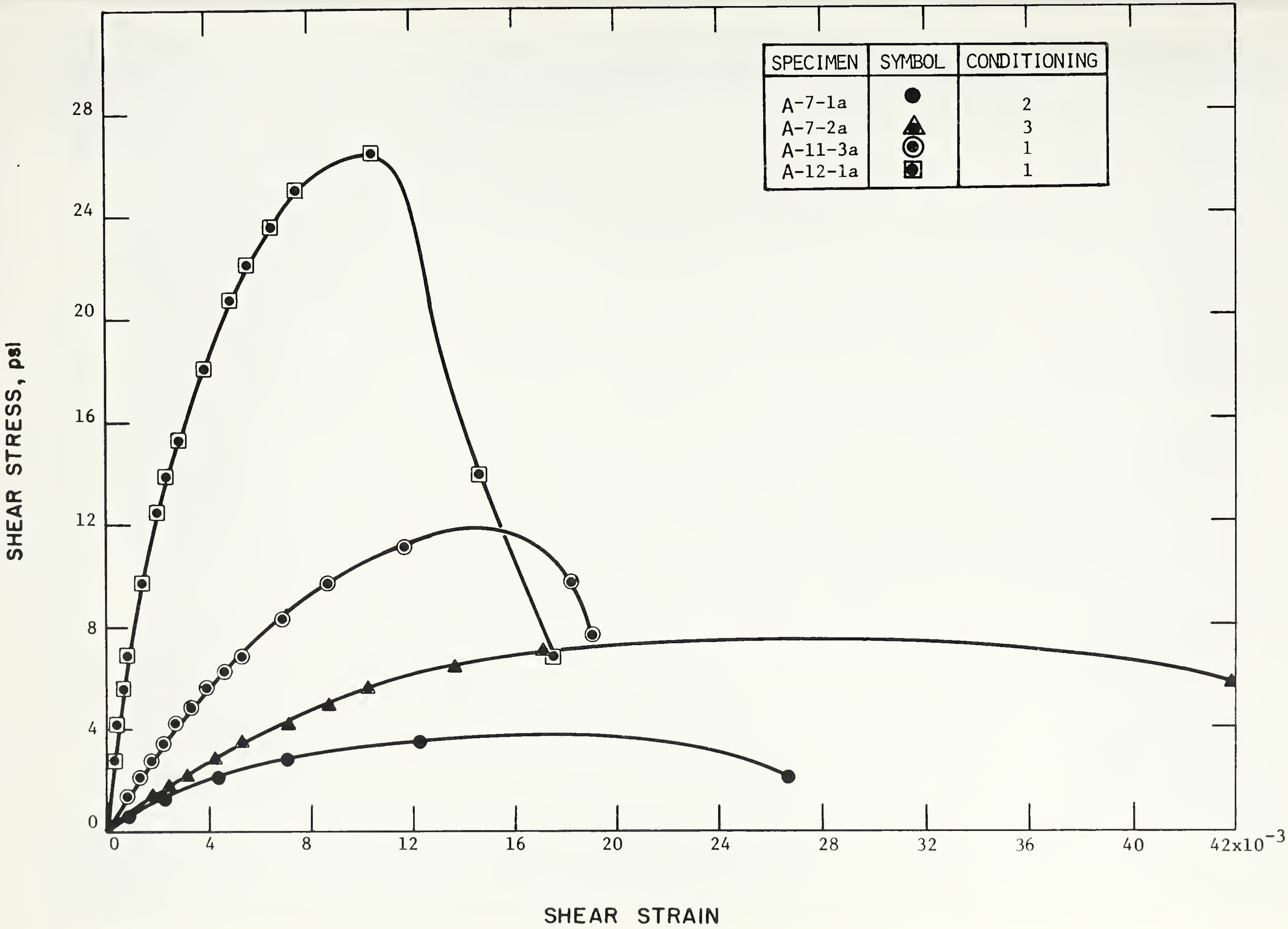


Figure 1.7 Typical stress-strain curve for compressive shear test on Brand A specimen.

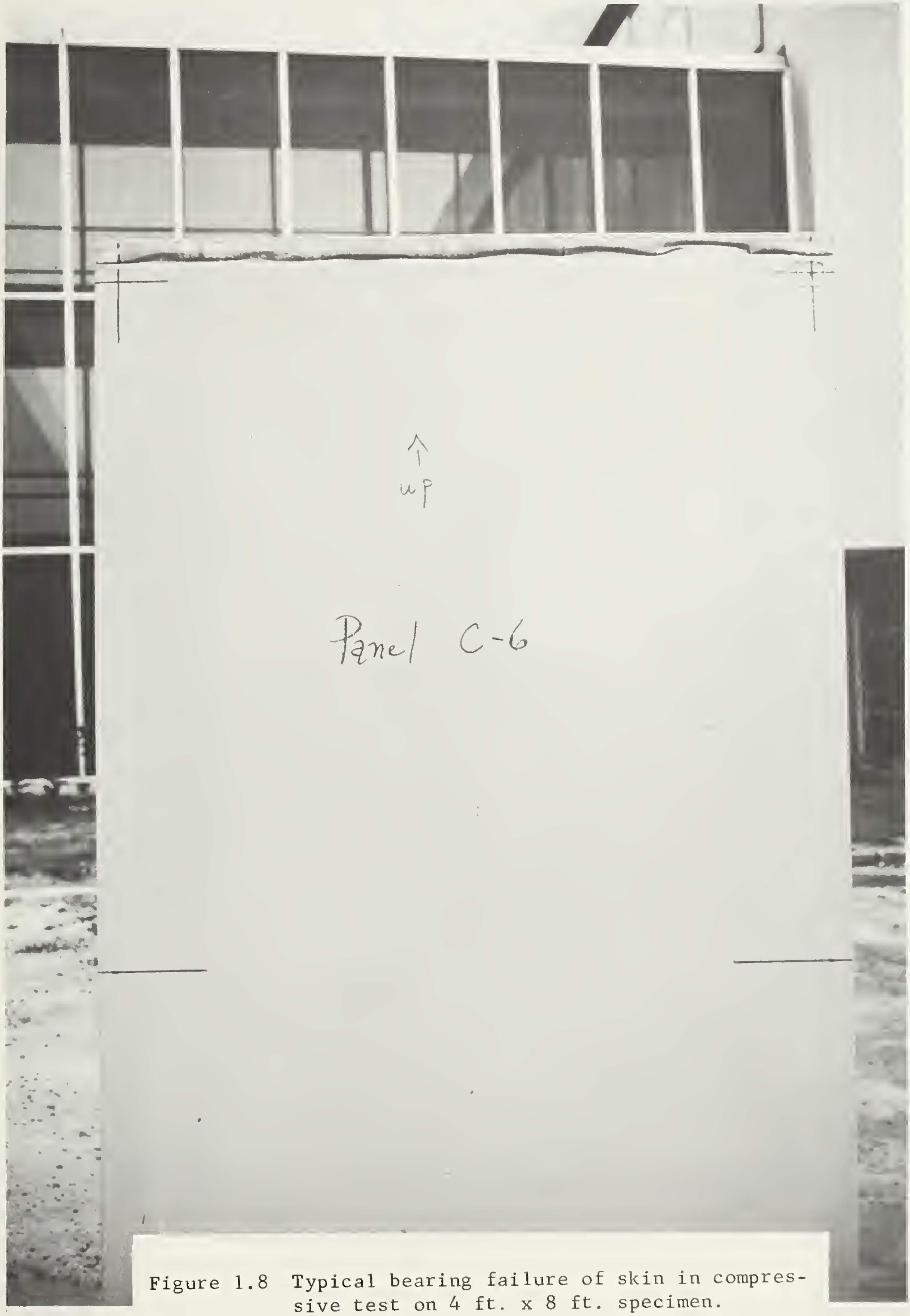
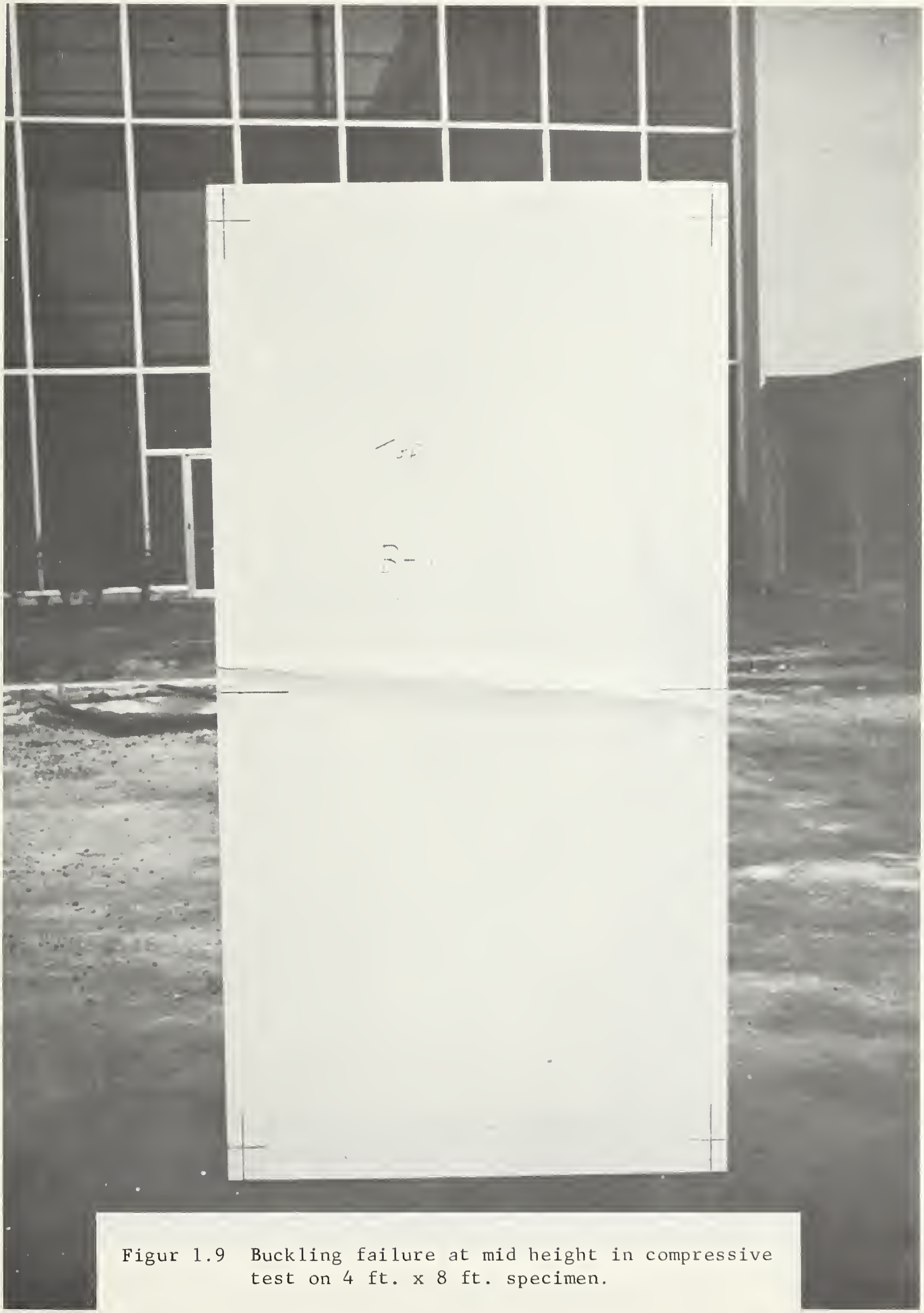


Figure 1.8 Typical bearing failure of skin in compressive test on 4 ft. x 8 ft. specimen.



Figur 1.9 Buckling failure at mid height in compressive test on 4 ft. x 8 ft. specimen.

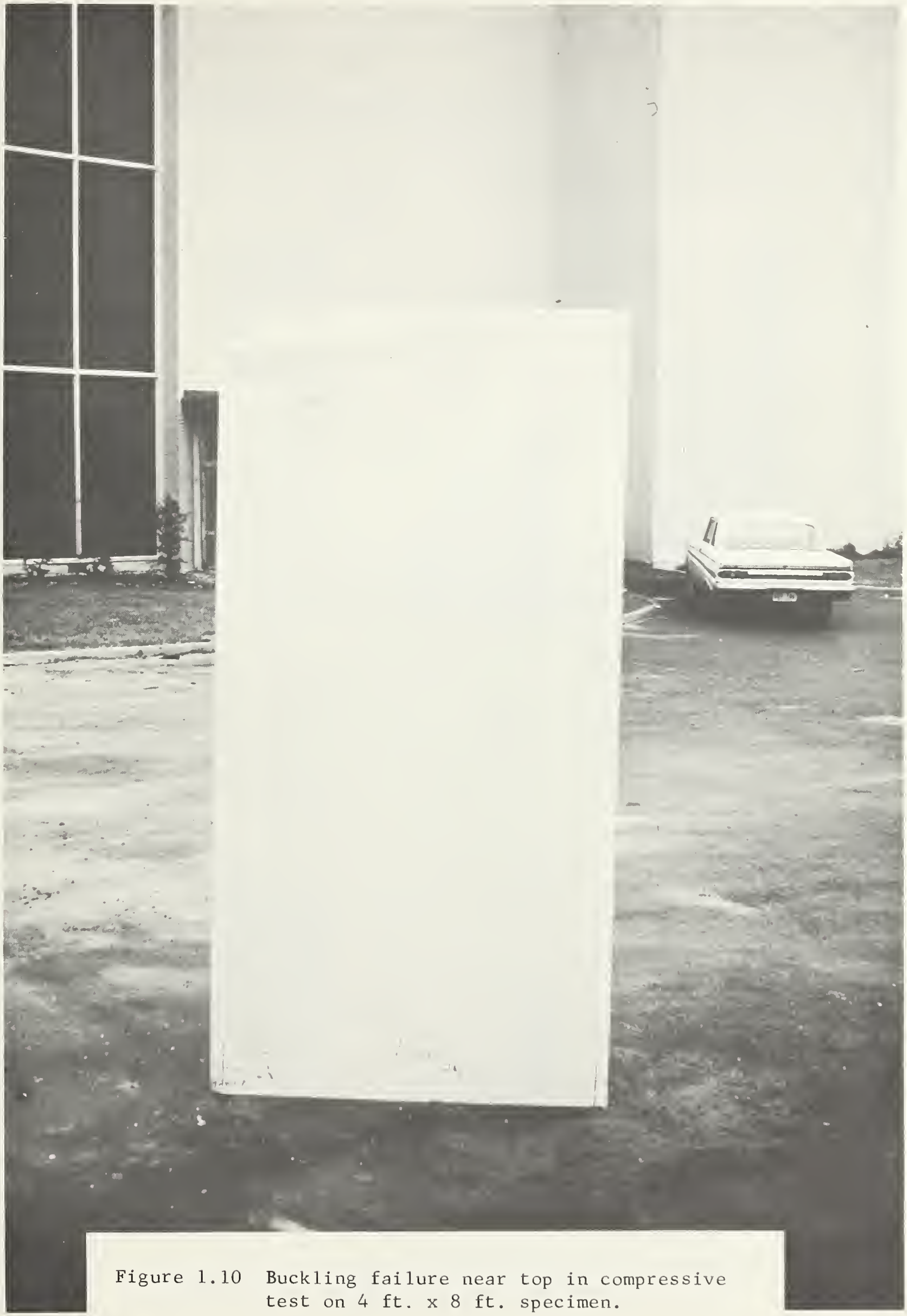


Figure 1.10 Buckling failure near top in compressive test on 4 ft. x 8 ft. specimen.

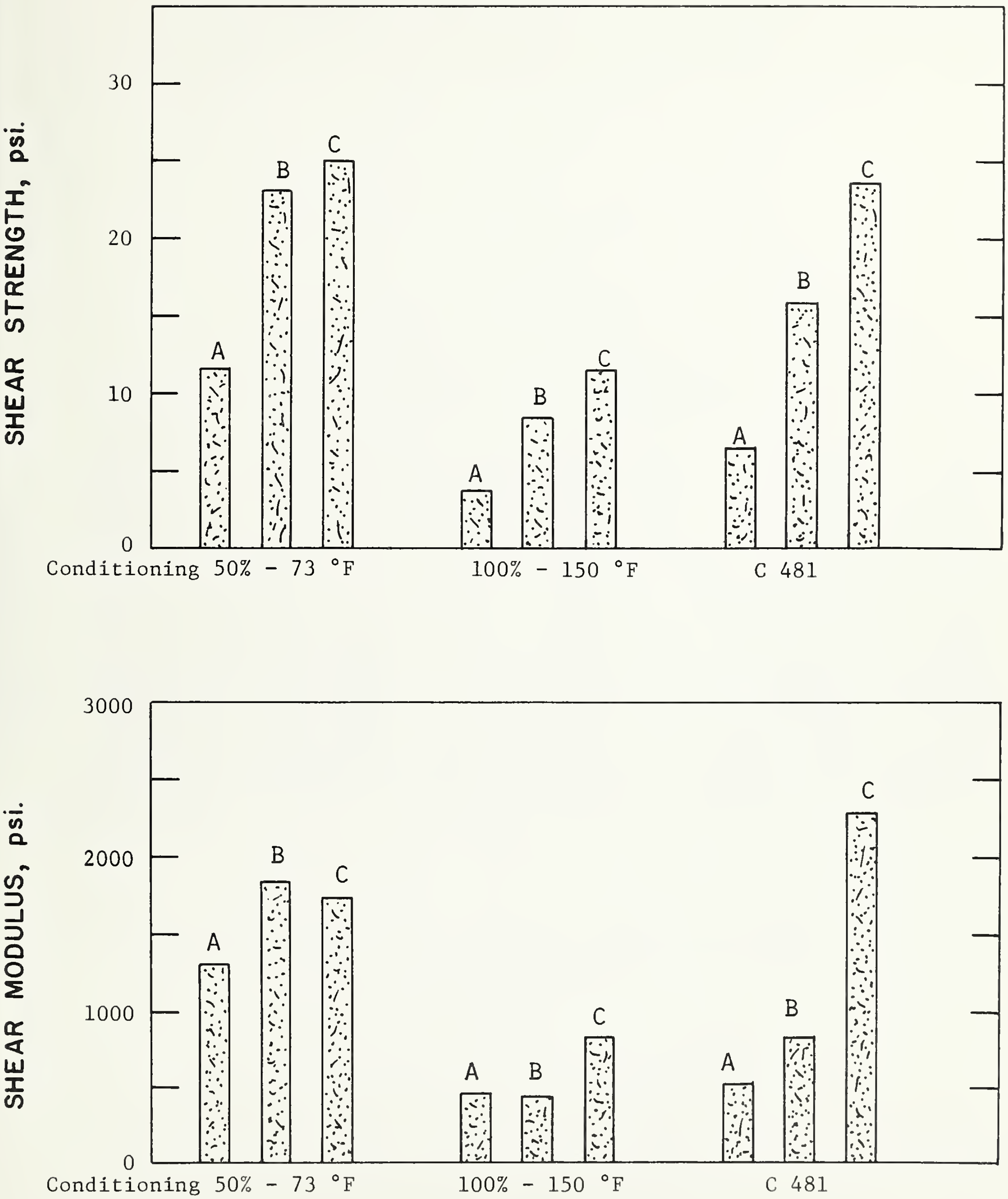


Figure 1.11 Comparison of the shear test results for the three brands of panels.

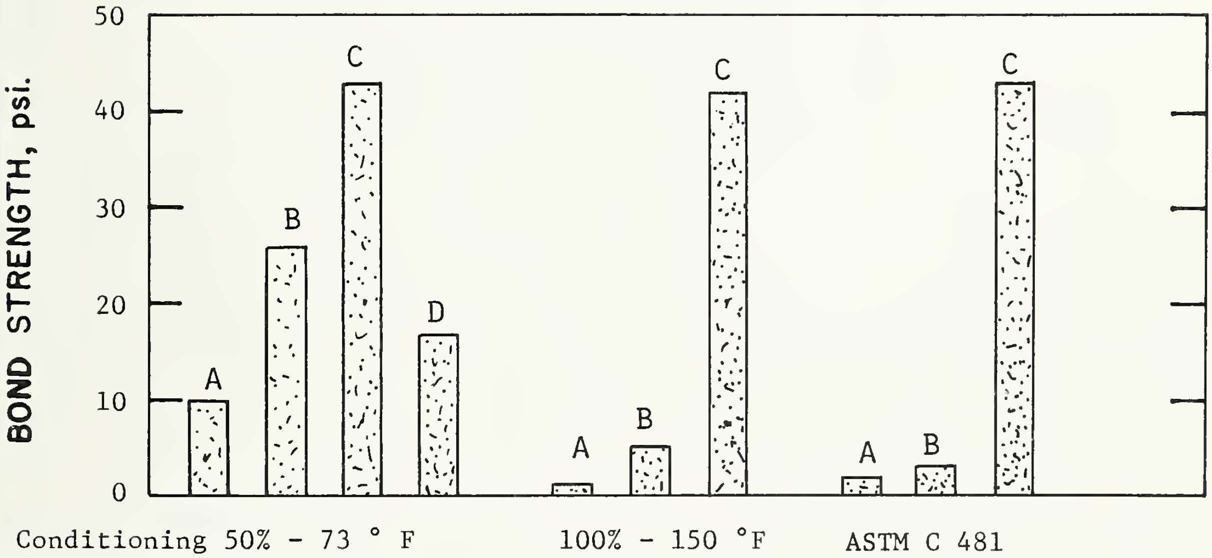
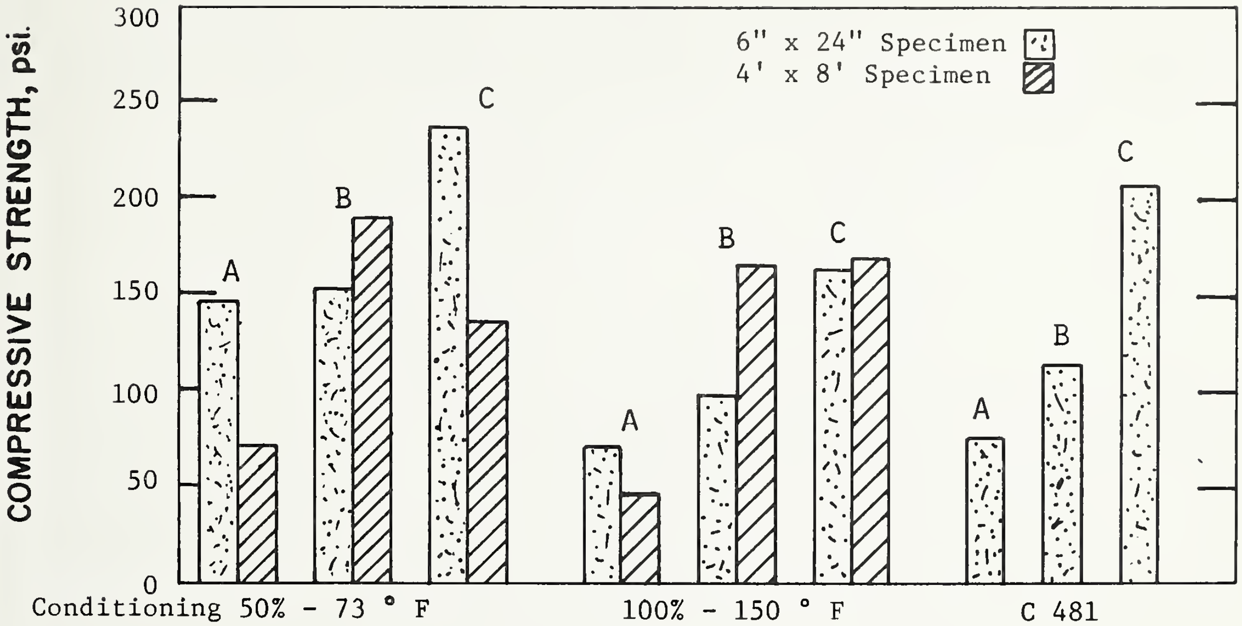


Figure 1.12 Comparison of the bond test results for the three brands of panels.



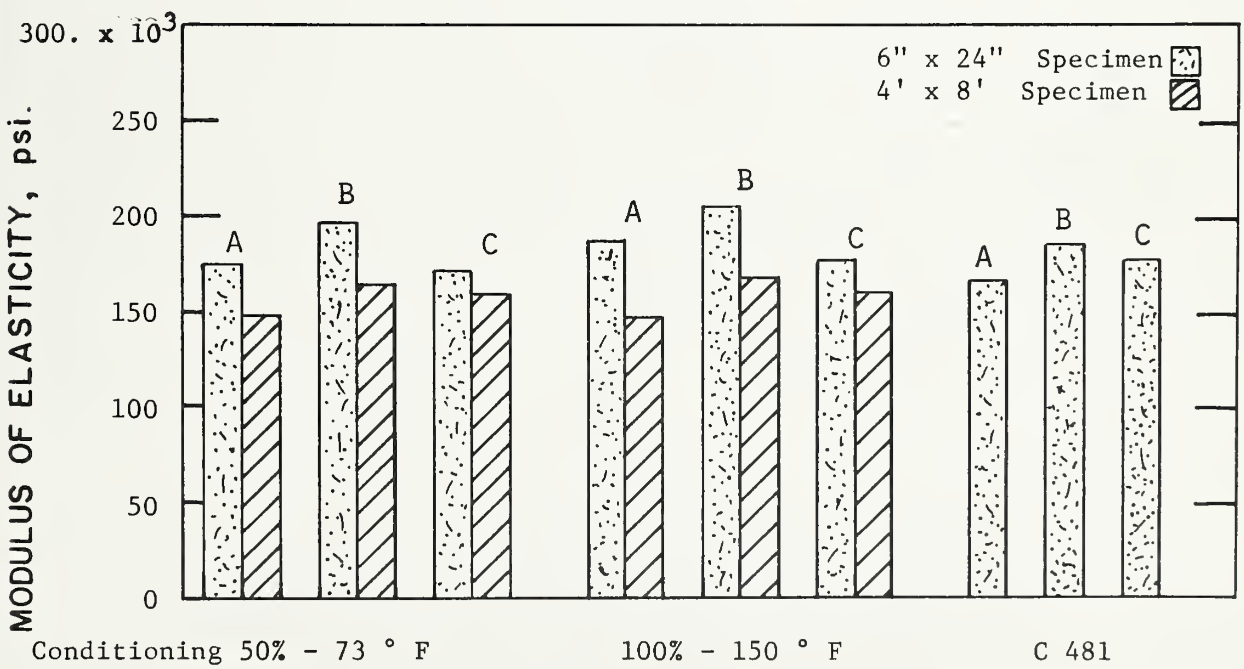


Figure 1.13 Comparison of the compressive test results with 2 sizes of specimens of the three brands of panels.

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