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THE STRUCTURAL USE OF PARTICLEBOARD REINFORCED WITH FIBERGLASS

by

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Master of Science

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PREFACE

This thesis was carried out with the intent of determining the structural integrity of a beam and floor deck system constructed from particleboard reinforced with fiberglass. Appropriate tests on the materials were performed to determine their properties. Then a composite floor-beam section was designed and load tested to failure.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Professor J.I. Glanville for his continual guidance throughout this thisis as well as a careful checking of the final draft. Special thanks is due to Mr. A.F. McLellan, P.Eng., an associate of M. Block and Associates, who conceived the idea, donated most of the materials for testing and provided valuable suggestions throughout the investigation.

The author is also indebted to Mr. E. Lemke and the Civil Engineering laboratory staff for their constructive help in the structural laboratory. Thanks to Fiberglas Canada Ltd. and The Department of Civil Engineering who donated materials for the tests. Many thanks to the people not mentioned above who helped even if only in a small way.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOTATION

A - Area

D - Density

E_f - Modulus of elasticity of fiberglass

E_p - Modulus of elasticity of particleboard

f_b - Bending Stress

$f_{bp\parallel}$ - Bending stress of particleboard parallel to surface

$f_{bp\perp}$ - Bending stress of particleboard perpendicular to surface

$f_{cp\parallel}$ - Compressive stress of particleboard parallel to surface

$f_{cp\perp}$ - Compressive stress of particleboard perpendicular to surface

$f_{tf\parallel}$ - Tensile stress of fiberglass parallel to surface

$f_{tp\parallel}$ - Tensile stress of particleboard parallel to surface

$f_{tp\perp}$ - Tensile stress of particleboard perpendicular to surface

f_v - Shear stress

$f_{vp\parallel}$ - Shear stress of particleboard parallel to surface

$f_{vp\perp}$ - Shear stress of particleboard perpendicular to surface

H - Horizontal force

I - Moment of inertia

L - Span length

M - Bending moment

Q - First moment area

S - Spacing of joists

S_m - Section modulus

t_p - Thickness of particleboard

U_{ff} - Bond stress in epoxy glue between two fiberglass pieces

U_{pf} - Bond stress in epoxy glue between particleboard and fiberglass

U_{pp} - Bond stress in white resin glue between two particleboard pieces

V - Vertical force

y - Distance from CG. of sections to bottom of the beam

y_1 - Distance from CG. of sections to neutral axis

$\bar{y}$ - Distance from neutral axis to bottom of the beam

ε - Strain

Δ - Deflection

all. - Allowable

CG. - Center of gravity

DL. - Deal load

LL. - Live load

max. - Maximum

NA. - Neutral axis

PL. - Proportional limit

Ult. - Ultimate

CHAPTER I

INTRODUCTION

1.1 Historical Background

The current shortage of building materials is a serious problem in construction work, and is likely to remain a problem. This shortage has led to spiralling construction cost, and to the need for developing new and cheaper materials and methods of construction.

Wood has been used as a building material since the dawn of history, from the wattle and mud shelters of antiquity to the graceful, long-span glue-laminated structures of today. In particular, house construction today is almost exclusively wood frame, and consequently has been subjected to the same cost increase experienced in other areas of construction. Advances in technology have enabled the waste products of the timber industry, such as bark, sawdust and chips, to be combined with an adhesive medium and compressed into a profitable building material called "particleboard" or "chipboard". For the most part, particleboard is used in furniture, door and wall panelling, and in some floor deck surfacing. It has been used mainly in non-structural applications.

Particleboard is high in compressive strength and low in tensile strength so that it is not suitable for use in main structural elements such as beams and floor systems. Fiberglass on the other hand has exceptionally high tensile strength properties and can be used to provide the tensile resistance in particleboard structural elements. The idea is similar to the use of steel bars or cables to reinforce concrete. Particleboard reinforced with fiberglass appears to have been investigated first by A.F. McLellan, P. Eng., of Winnipeg, Manitoba, who used some of the material in the construction of his own home. He investigated some beam and floor deck assemblies with apparently good results. His early investigations have led to research being initiated at the University of Manitoba. Although some good introductory work was performed by two undergraduate students [1], the present thesis is the first serious step in a proposed research programme to develop a method of producing low-cost housing with structural integrity using particleboard reinforced with fiberglass.

1.2 Objective

The object of the study reported in this thesis was to determine the structural integrity of a beam and floor deck system constructed from particleboard reinforced with fiberglass; to assess the degree to which composite action between the beam and floor joist and deck system could be relied upon; and to recommend, where possible, a set of guide lines for structural design.

1.3 Work Performed

The properties of particleboard and fiberglass were investigated by running a series of tests on them. The properties of particleboard required for design purposes are tensile strength, compressive strength, modulus of elasticity, shear strength, flexural strength and creep behaviour. The only property of fiberglass required is the behaviour in tension. The bond strength of the glue between two particleboard pieces, two fiberglass pieces, and between particleboard and fiberglass was also checked. The glue that was used to bond two particleboard pieces was white resin glue. Epoxy glue was used to bond two fiberglass pieces, and particleboard and fiberglass

The composite floor-joist-beam section was designed following the requirements of the CSA standard 086-1970 code [2]. The arrangement of the floor unit is shown in Fig. 1.3.1. The allowable strength properties were used from the tests by dividing the lowest mean value (see p. 50) of the ultimate strength by a safety factor of 2.0. The composite floor-joist-beam section was built using representative full-scale dimensions. Lag screws were used as fasteners between joists and beam. The shear strength between joist and beam was also checked. The composite structure was tested simply supported with two point loads instead of uniformly distributed load. The loads were applied at one-third of the span length from each support. The composite action was observed by measuring longitudinal strain variation with depth of a number of cross-sections. The slip between fiberglass and particleboard beam was checked. The slipping of joist was also checked. It was found from the full-scale load test that the deck was approximately 80% effective in its composite action with the beam under full design load. The composite action was reduced when the load was increased. The structure failed under a load of approximately 2.7 times the design load. Structural collapse of the test floor occured when bond failure in a fiberglass splice occured. Just prior to collapse, the structure was suffering considerable deflection and tension cracks were evident

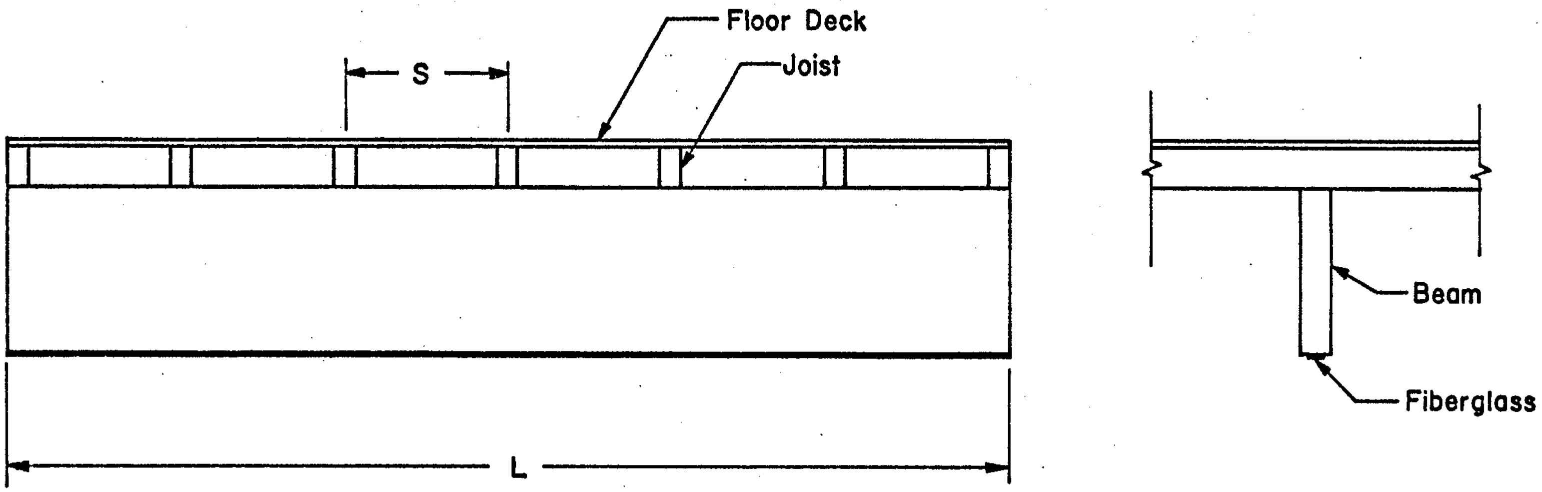


Fig.1.3.1 Arrangement of Floor Unit.

in the particleboard webs. It can be seen from the test that particleboard and fiberglass act together very well but that shear between the floor deck and the beam is a serious problem. It is hoped that a suitable fastener can be developed to use at this location so that the floor deck can act as a fully composite part of the beam.

CHAPTER II

INVESTIGATION OF MATERIAL PROPERTIES

2.1 Particleboard

The nature of the manufacturing process of particleboard leads to the particles aligning themselves parallel to the surface of the board but in random directions within any plane parallel to the surface. The material then has distinct properties parallel and perpendicular to the surface. Tests were performed to determine the behaviour in tension, compression, shear, flexure and creep both parallel and perpendicular to the surface, respectively.

2.1.1 Tension Parallel to Surface

The test conformed to ASTM Specification D 805-63 [3]. Each test specimen was prepared as shown in Fig. 2.1.1. The specimens were made both with the long dimension parallel and transverse to the long dimension of particleboard. The reduced section was cut to the size shown with a band saw. The minimum width and thickness of each specimen at the reduced section were measured to an accuracy of 0.001 in. with vernier calipers to determine the actual net cross-sectional area. The density of each specimen was also determined.

The 60,000 lb. testing maching shown in Fig. 2.1.2 was used for loading. The demec gauge shown in Fig. 2.1.3 was used for measuring strain. Each specimen was gripped in the fixed head of the testing maching and the demec gauge was attached to the specimen using elastic rubber as shown in Fig. 2.1.4. The load was applied continuously throughout the test. The load and the demec gauge readings were

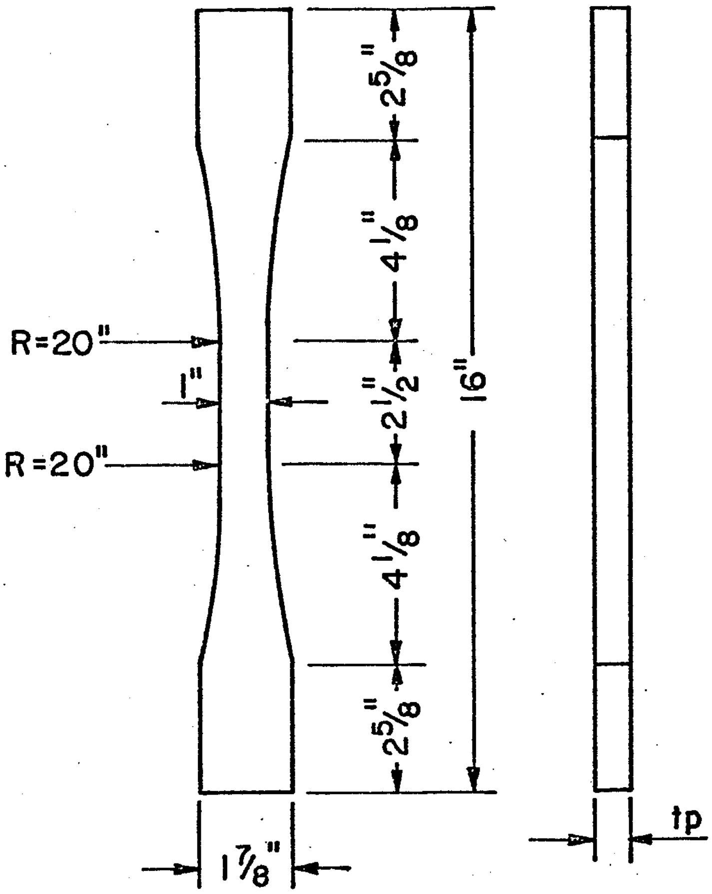


Fig. 2.1.1 Details of Particleboard Specimen for Tension Test Parallel to Surface.

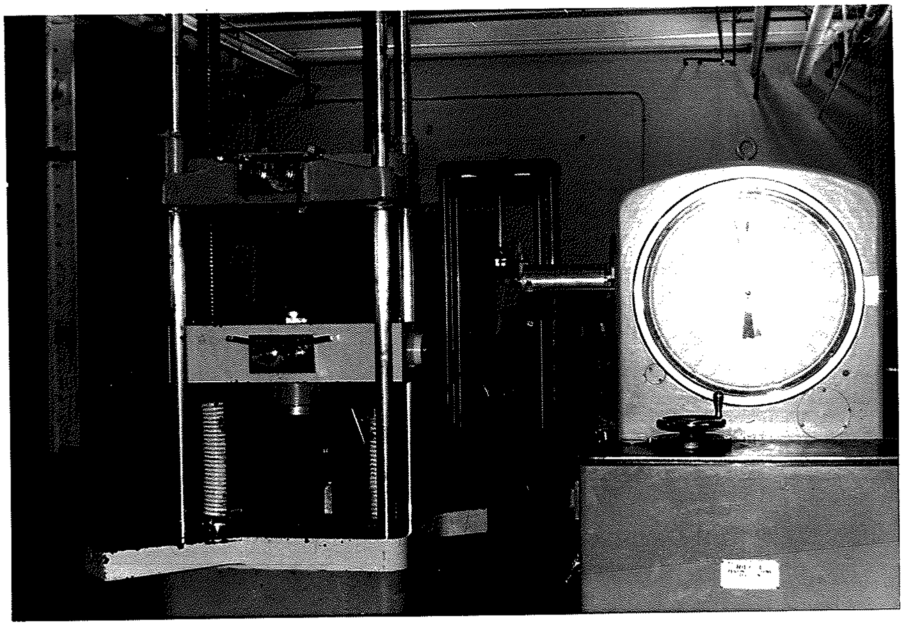


Fig. 2.1.2 - Testing Machine

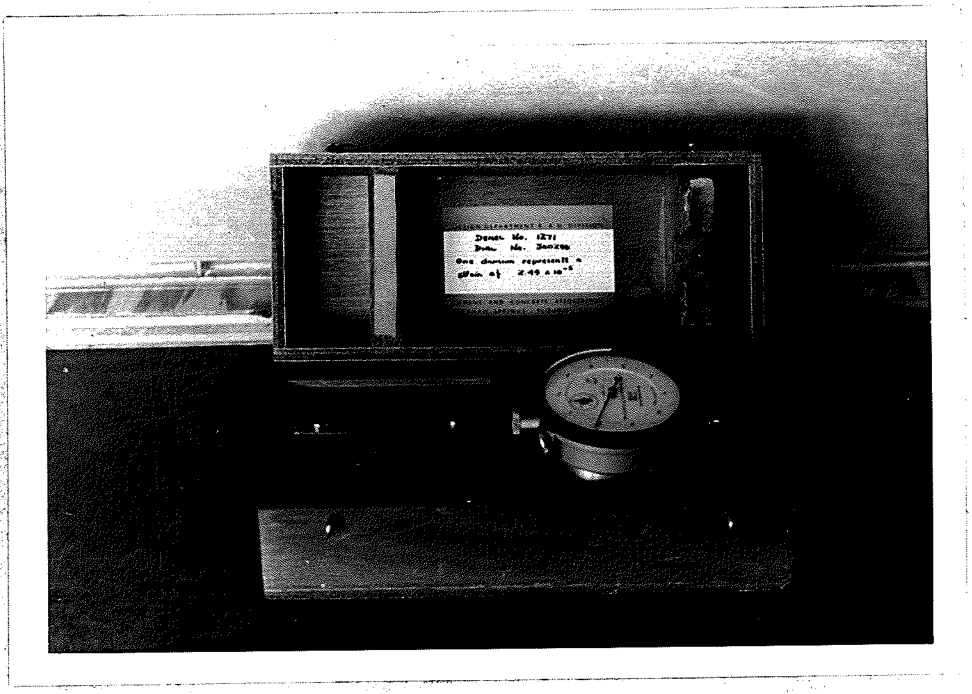


Fig. 2.1.3 - Demec Gauge with 2 in. Gauge Length

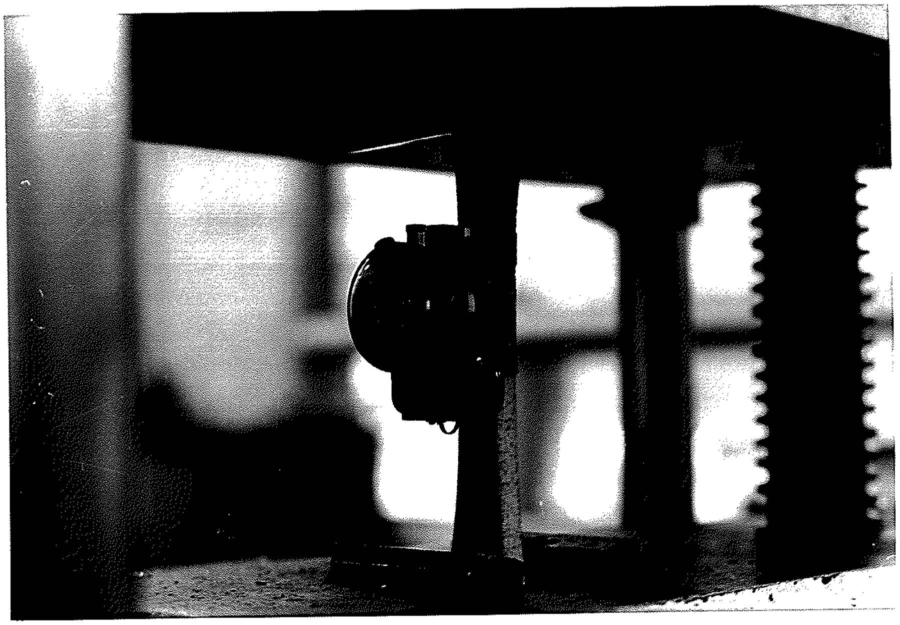


Fig. 2.1.4 - Assembly of Particleboard Specimen for Tension Test Parallel to Surface

observed to determine stress and strain properties. The stress-strain curve was plotted and the modulus of elasticity was determined.

The results are presented inTable A-1.1 to A-1.4. It could be seen that the strength of particleboard was dependant upon its density. The relationship between tensile strength and density is shown in Fig. 2.1.5. The mean value of tensile stress parallel to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 902 psi. with a standard deviation of 82.6 psi., and a coefficient of variation of 9.16%. The mean value of tensile stress parallel to the surface of 1/2 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 1,093 psi. with a standard deviation of 77.1 psi., and a coefficient of variation of 7.05%. The mean value of tensile stress parallel to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board was found to be 667 psi. with a standard deviation of 59.3 psi., and a coefficient of variation of 8.89%. The mean value of tensile stress parallel to the surface of 1/2 in. thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board was found to be 816 psi. with a standard deviation of 59.6 psi., and a coefficient of variation of 7.30%.

2.1.2 Tension Perpendicular to Surface

The method of test was based on ASTM Standard D 143-52 [3]. Each test specimen was composed of particleboard pieces bonded together by white resin glue as shown in Fig. 2.1.6. Each specimen was weighed

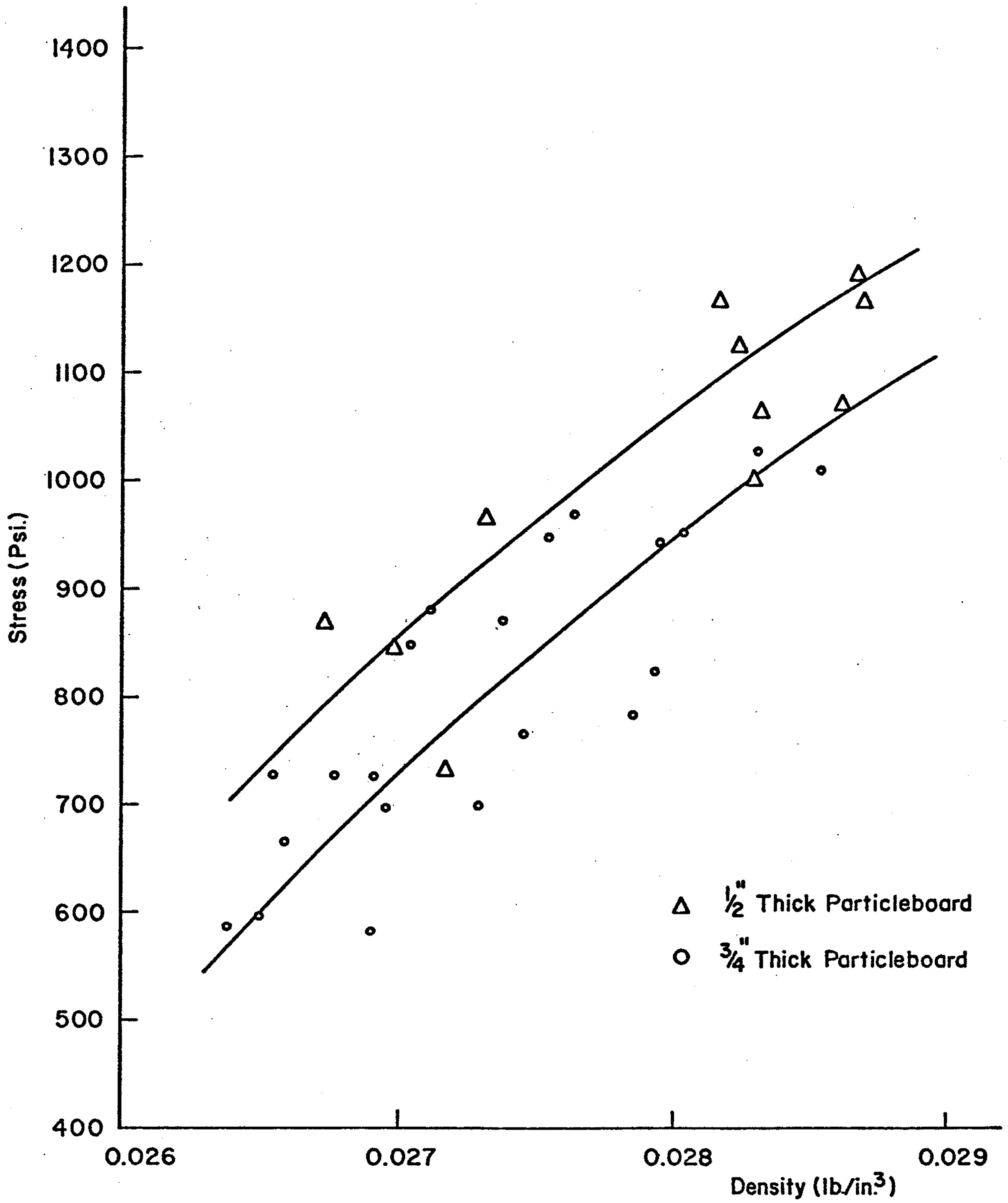
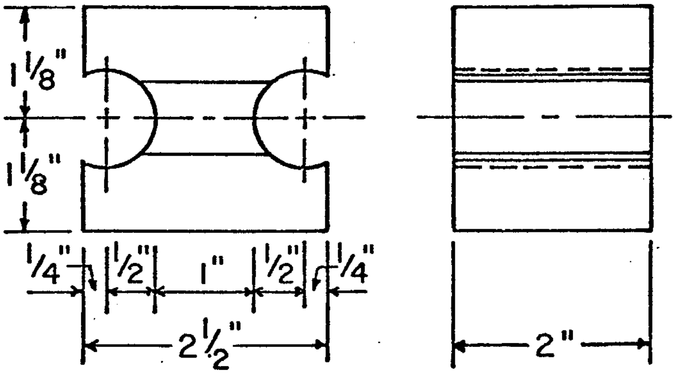
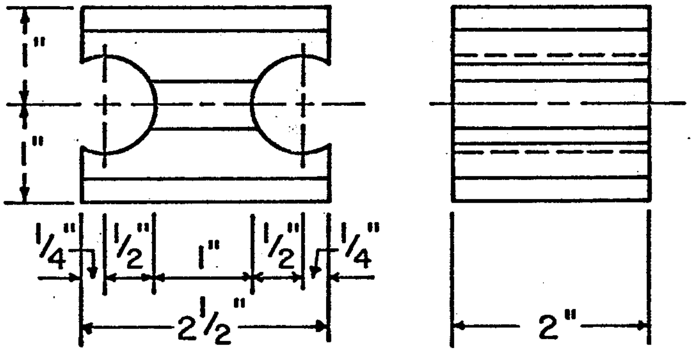


Fig. 2.1.5 Relationship Between Tensile Strength Parallel to Surface and Density of Particleboard.



(a) 3/4" Thick Particleboard



(b) 1/2" Thick Particleboard

Fig. 2.1.6 Details of Particleboard Specimen for Tension Test Perpendicular to Surface.

before testing. The actual width and length of each specimen at minimum section were measured to an accuracy of 0.001 in. with vernier calipers to determine the actual net cross-sectional area.

Each specimen was held in the special grips shown in Fig. 2.1.7. The 60,000 lb. testing machine shown in Fig. 2.1.2 was used for loading. The load was applied continuously throughout the test and only the maximum load was observed. The results are presented in Table A-1.5 and A-1.6.

The mean value of tensile stress perpendicular to the surface of 3/4 in. thick particleboard was found to be 46 psi. with a standard deviation of 2.1 psi., and a coefficient of variation of 4.57%. The mean value of tensile stress perpendicular to the surface of 1/2 in. thick particleboard was found to be 103 psi. with a standard deviation of 7.8 psi., and a coefficient of variation of 7.57%.

2.1.3 Compression Parallel to Surface

The method of test was based on ASTM Standard D 143-52 [3]. Each test specimen was composed of particleboard pieces bonded together by white resin glue as shown in Fig. 2.1.8. The specimens were made both with the long dimension parallel and transverse to the long dimension of particleboard. Each specimen was made with special care to ensure that the end surfaces were parallel to each other and at right angles to the longitudinal axis. Each specimen was weighed before test. The actual cross-section dimensions and the length of each specimen were measured to an accuracy of 0.001 in. with vernier calipers to determine the actual net cross-sectional area and density.

The 60,000 lb. testing maching shown in Fig. 2.1.2 was used for

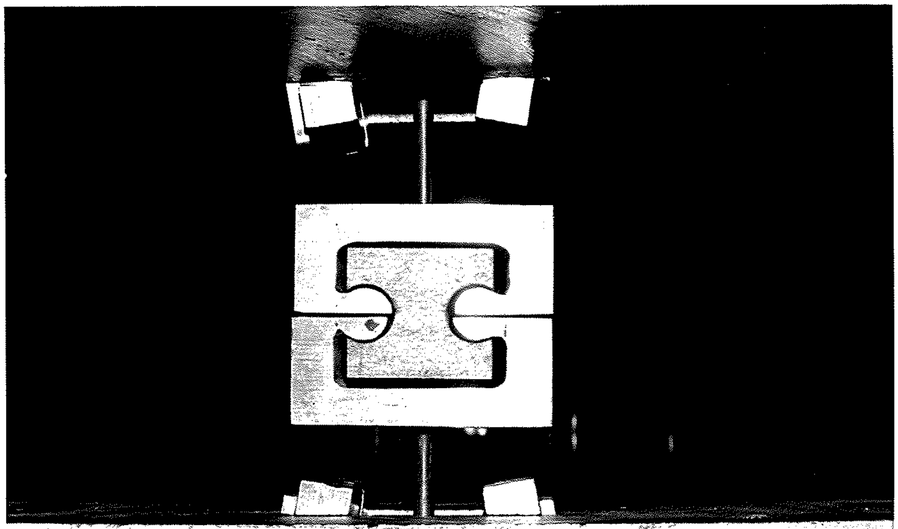
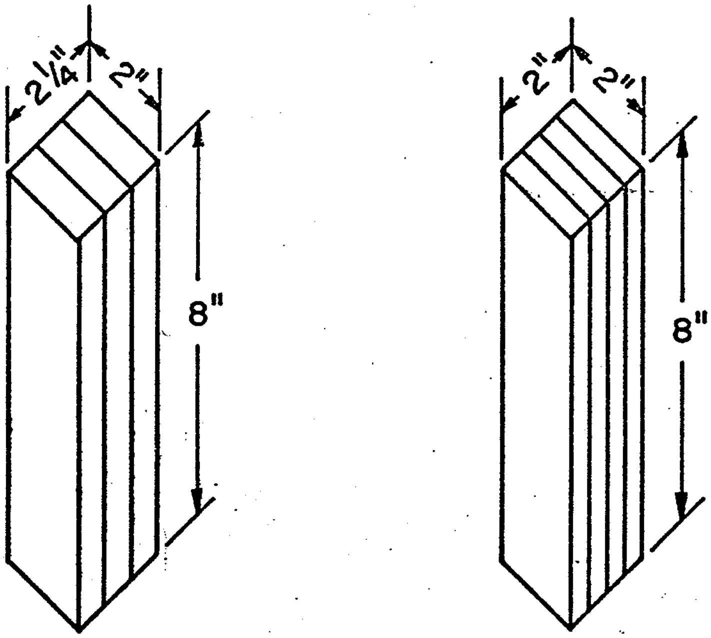


Fig. 2.1.7 - Assembly of Particleboard Specimen for Tension Test Perpendicular to Surface



(a) 3/4" Thick Particleboard (b) 1/2" Thick Particleboard

Fig. 2.1.8 Details of Particleboard Specimen for Compression Test Parallel to Surface.

loading. The top platen of the testing machine was equipped with a spherical bearing to obtain uniform distribution of load over the ends of the specimen. Each specimen was centered on the table of the testing machine and a demec gauge shown in Fig. 2.1.3 was attached to the specimen using elastic rubber as shown in Fig. 2.1.9 for measuring strain. The load was applied continuously throughout the test. The load and the demec gauge readings were observed to determine stress and strain properties. The stress-strain curve of each specimen was plotted and the modulus of elasticity was determined.

The results are presented in Table A-1.7 to A-1.10. The strength of particleboard was found to be dependant upon its density. The relationship between compressive strength and density is shown in Fig. 2.1.10. The mean value of compressive stress parallel to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 2,008 psi. with a standard deviation of 127.4 psi., and a coefficient of variation of 6.34%. The mean value of compressive stress parallel to the surface of 1/2 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 2,461 psi. with a standard deviation of 154.7 psi., and a coefficient of variation of 6.29%. The mean value of compressive stress parallel to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board, was found to be 1,642 psi. with a standard deviation of 35.1 psi., and a coefficient of variation of 2.14%. The mean value of compressive stress parallel to the surface of 1/2 in.

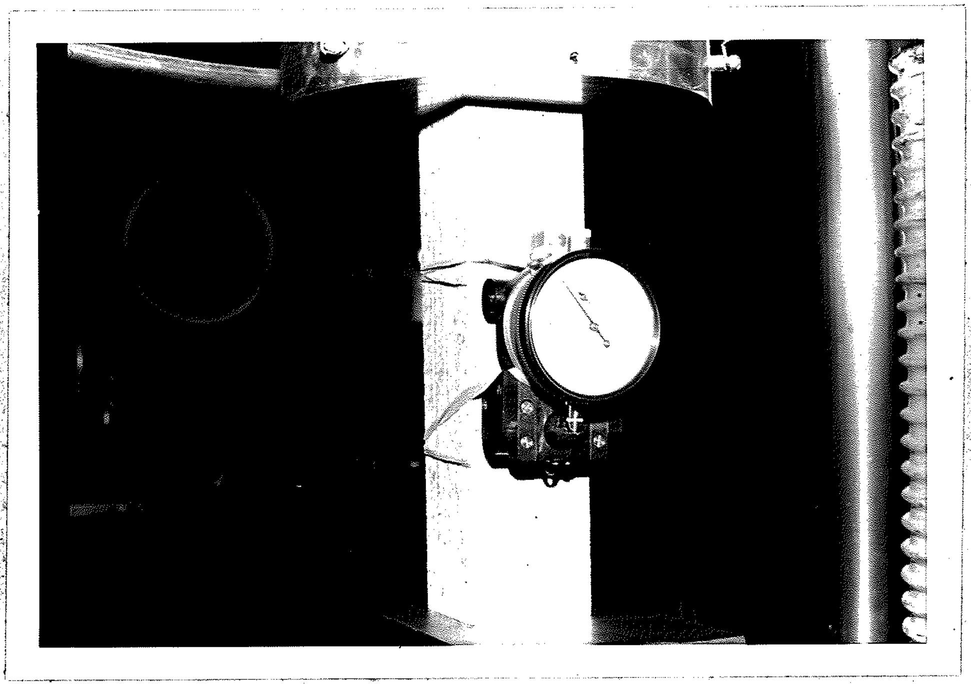


Fig. 2.1.9 - Assembly of Particleboard Specimen for Compression Test Parallel to Surface

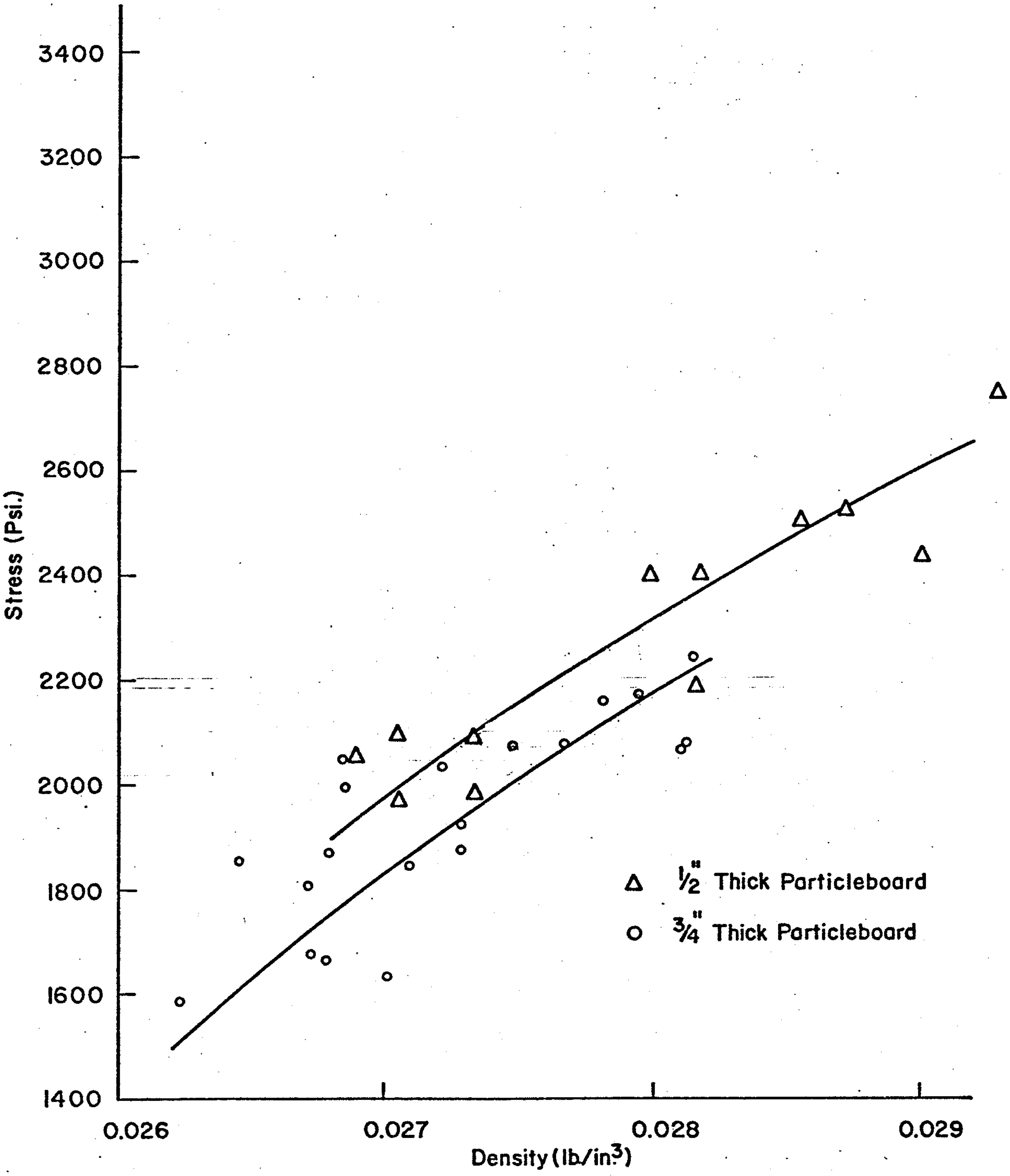


Fig. 2.1.10 Relationship Between Compressive Strength Parallel to Surface and Density of Particleboard.

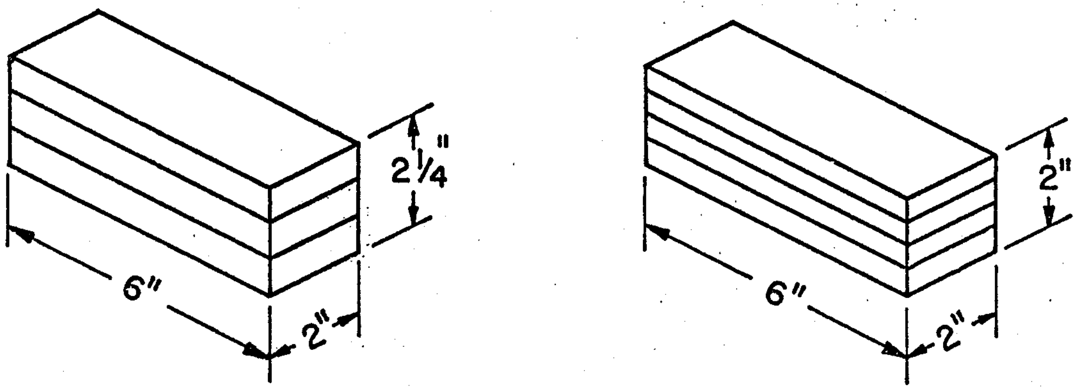
thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board was found to be 2,042 psi. with a standard deviation of 51.8 psi., and a coefficient of variation of 2.54%.

2.1.4 Compression Perpendicular to Surface

The method of test was based on ASTM Standard D 143-52 [3]. Each test specimen was composed of particleboard pieces bonded together by white resin glue as shown in Fig. 2.1.11. Each specimen was weighed before test. The actual height, width, and length of each specimen was measured to an accuracy of 0.001 in. with vernier calipers. The density of each specimen was also determined.

The 60,000 lb. testing machine shown in Fig. 2.1.2 was used for loading. Each specimen was placed flat on the table of the testing machine. A 2 in. wide steel plate was placed across the middle third of the specimen with the long axis of the plate normal to the long axis of the specimen and the dial gauge was placed under the plate as shown in Fig. 2.1.12. The load was applied continuously throughout the test. The load and the dial gauge readings were observed to determine load and compression properties. The results are presented in Table A-1.11 and A-1.12.

The mean value of compressive stress perpendicular to the surface of 3/4 in. thick particleboard was found to be 4,556 psi. with a standard deviation of 204.6 psi., and a coefficient of variation of 4.49%. The mean value of compressive stress perpendicular to the surface of 1/2 in. thick particleboard was found to be 7,490 psi. with a standard deviation of 368.9 psi., and a coefficient of variation of 4.93%.



(a) 3/4" Thick Particleboard.

(b) 1/2" Thick Particleboard

Fig. 2.1.11 Details of Particleboard Specimen for Compression Test Perpendicular to Surface.

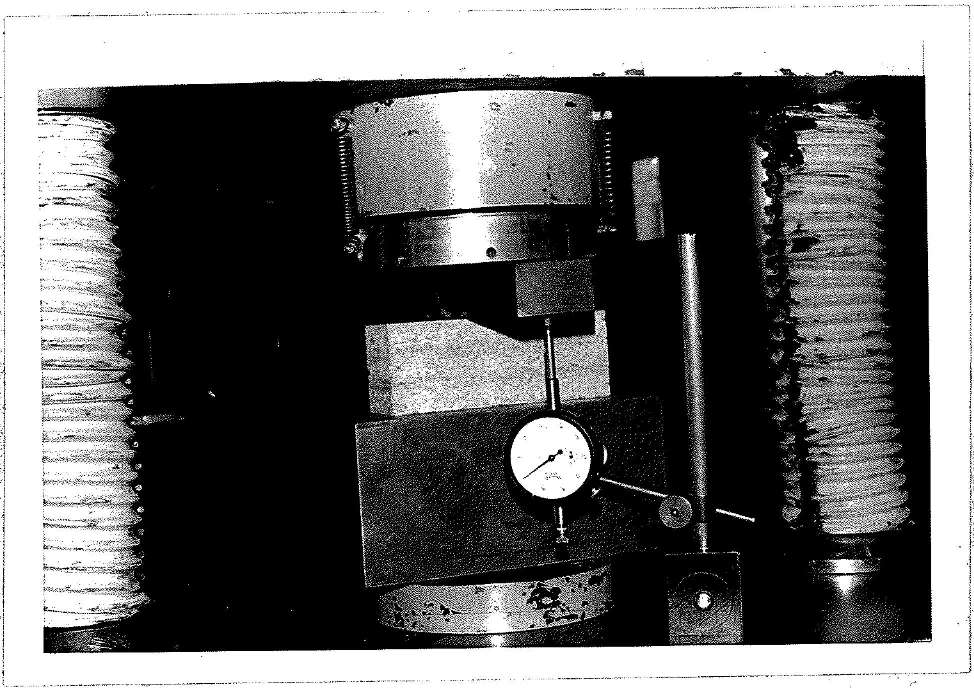


Fig. 2.1.12 - Assembly of Particleboard Specimen for Compression Test Perpendicular to Surface

2.1.5 Shear Parallel to Surface

The test conformed to ASTM Standard D 1037-64 [3]. Each test specimen was composed of particleboard pieces bonded together by white resin glue as shown in Fig. 2.1.13. Each specimen was weighed before test. The actual dimensions of the shearing surface were measured to an accuracy of 0.001 in. with vernier calipers to determine the actual net shearing area.

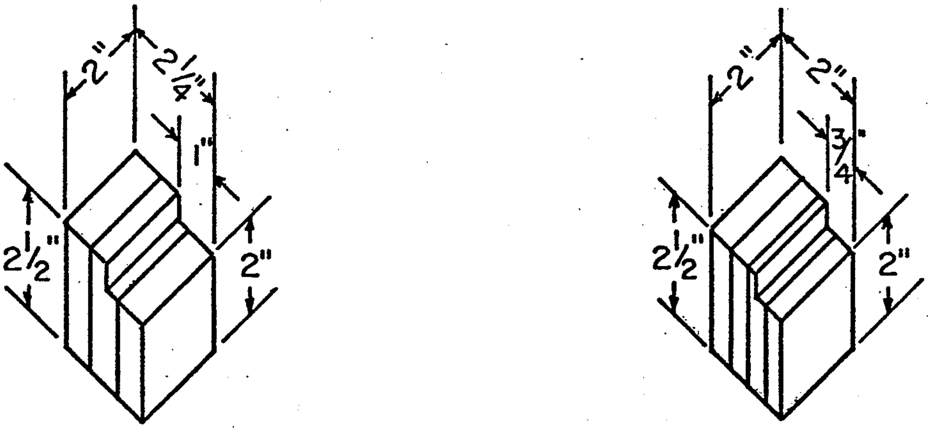
The 60,000 lb. testing machine shown in Fig. 2.1.2 was used for loading. Each specimen was placed with special care into the shear block and the shear block centered on the table of the testing machine as shown in Fig. 2.1.14. The load was applied continuously throughout the test and only maximum load was observed. The results are presented in Table A-1.13 and A-1.14.

The mean value of shear stress parallel to the surface of 3/4 in. thick particleboard was found to be 234 psi. with a standard deviation of 15.7 psi., and a coefficient of variation of 6.71%. The mean value of shear stress parallel to the surface of 1/2 in. thick particleboard was found to be 343 psi. with a standard deviation of 17.7 psi., and a coefficient of variation of 5.16%.

2.1.6 Shear Perpendicular to Surface

The method of test was similar to the shear test parallel to surface. There are two types of the specimen to test. Each type of test specimen is shown in Fig. 2.1.15 and 2.1.16. The results are presented in Table A-1.15 to A-1.18, respectively.

The mean value of shear stress perpendicular to the surface of 3/4 in. thick particleboard type I was found to be 895 psi. with a standard deviation of 56.8 psi., and a coefficient of variation of



(a) 3/4" Thick Particleboard (b) 1/2" Thick Particleboard

Fig. 2.1.13 Details of Particleboard Specimen for Shear Test Parallel to Surface.

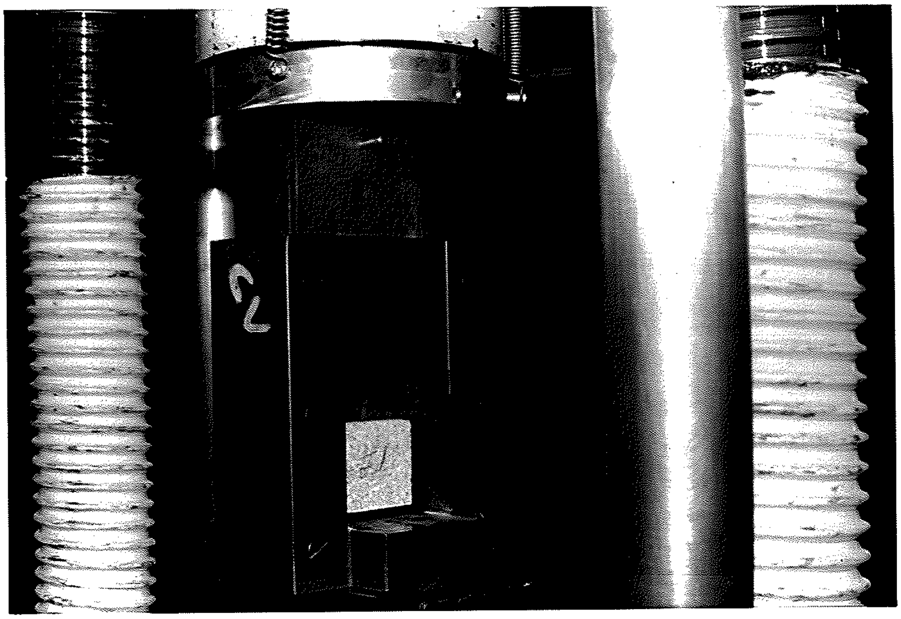
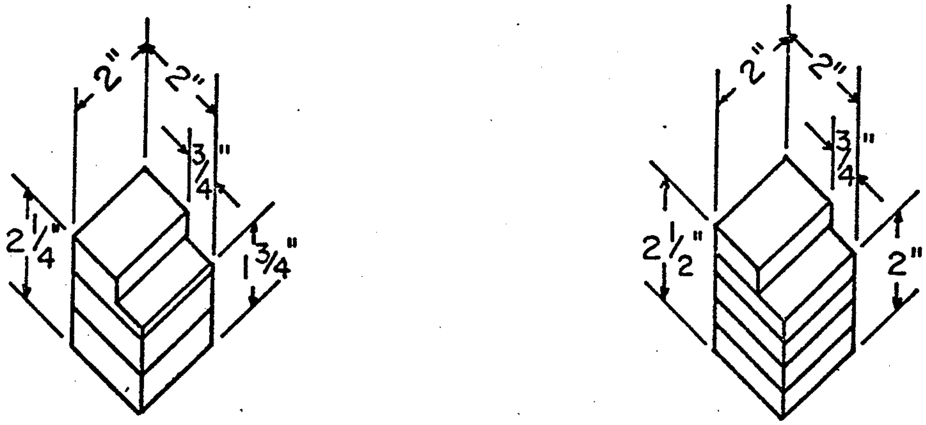
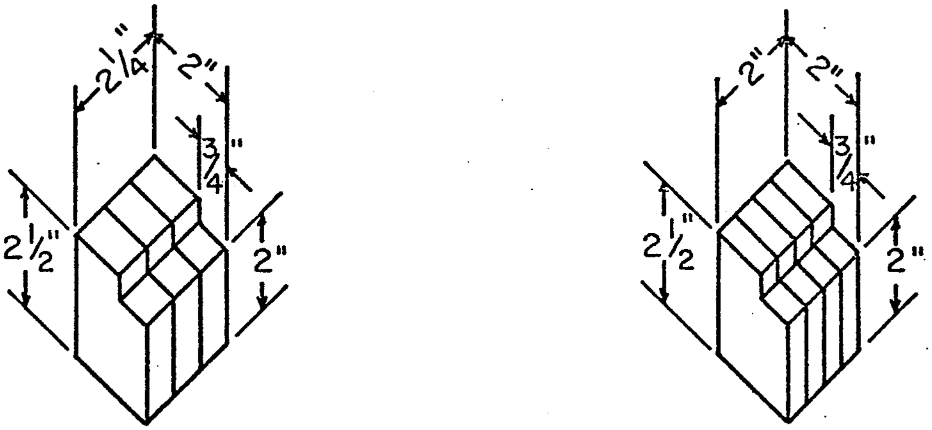


Fig. 2.1.14 - Assembly of Particleboard Specimen for Shear Test Parallel to Surface



(a) 3/4" Thick Particleboard (b) 1/2" Thick Particleboard

Fig. 2.1.15 Details of Particleboard Specimen for Shear Test Perpendicular to Surface (Type I).



(a) 3/4" Thick Particleboard

(b) 1/2" Thick Particleboard

Fig. 2.1.16 Details of Particleboard Specimen for Shear Test Perpendicular to Surface (Type II).

6.35%. The mean value of shear stress perpendicular to the surface of 1/2 in. thick particleboard type I was found to be 1,086 psi. with a standard deviation of 77.6 psi., and a coefficient of variation of 7.14%. The mean value of shear stress perpendicular to the surface of 3/4 in. thick particleboard type II was found to be 1,138 psi. with a standard deviation of 45.6 psi., and a coefficient of variation of 4.01%. The mean value of shear stress perpendicular to the surface of 1/2 in. thick particleboard type II was found to be 1,535 psi. with a standard deviation of 67.3 psi., and a coefficient of variation of 4.38%.

2.1.7 Flexure in a Plane Parallel to the Particleboard Surface

The method of test was based on ASTM Standard D 1037-64 [3]. Each test specimen was prepared as shown in Fig. 2.1.17. The specimens were made both with the long dimension parallel and transverse to the long dimension of particleboard. The center and end points of each specimen were marked for a 20 in. span. Each specimen was weighed before test. The actual depth and width at the center and the length were measured to an accuracy of 0.001 in. with vernier calipers. The density of each specimen was also determined.

The 60,000 lb. testing machine shown in Fig. 2.1.2 was used for loading. The beam supports were set for a 20 in. span on the table of the testing machine. Each specimen was placed on the supports and the dial gauge was attached to the center of span under the specimen as shown in Fig. 2.1.18. The load was applied at mid-span continuously throughout the test. The load and the dial gauge readings were observed for plotting load-deflection curve. The stress at proportional limit,

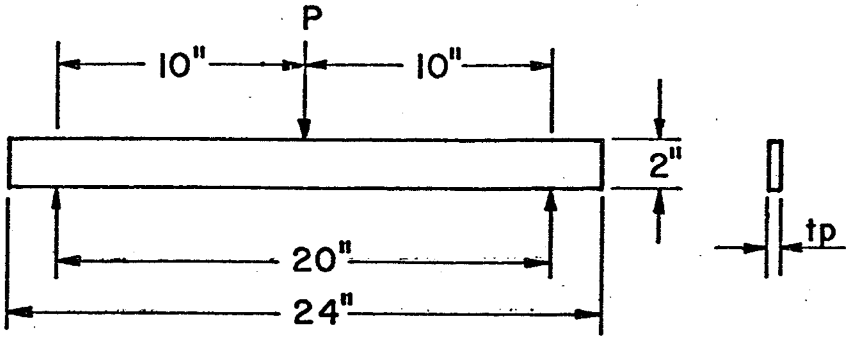


Fig.2.1.17 Details of Particleboard Specimen for Flexure Test Parallel to Surface.

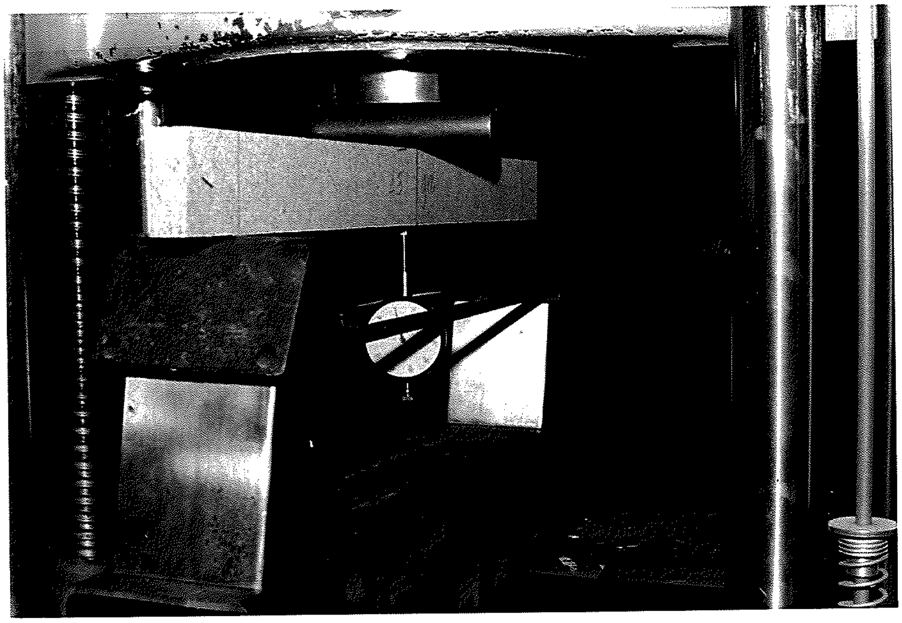


Fig. 2.1.18 - Assembly of Particleboard Specimen for Flexure Test Parallel to Surface

the ultimate stress and the modulus of elasticity were determined. The results are presented in Table A-1.19 to A-1.22 respectively.

The mean value of bending stress in a plane parallel to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 842 psi. with a standard deviation of 4.0 psi., and a coefficient of variation of 0.48%. The mean value of bending stress in a plane parallel to the surface of 1/2 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 1,104 psi. with a standard deviation of 3.0 psi., and a coefficient of variation of 0.27%. The mean value of bending stress in a plane parallel to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board was found to be 699 psi. with a standard deviation of 11.0 psi., and a coefficient of variation of 1.57%. The mean value of bending stress in a plane parallel to the surface of 1/2 in. thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board was found to be 844 psi. with a standard deviation of 12.2 psi., and a coefficient of variation of 1.44%.

2.1.8 Flexure in a Plane Perpendicular to the Particleboard Surface

The method of test was similar to that of the flexure test parallel to the particleboard surface. Each test specimen was prepared as shown in Fig. 2.1.19. The test assembly of each specimen was shown in Fig. 2.1.20. The results are presented in Table A-1.23 to A-1.26, respectively.

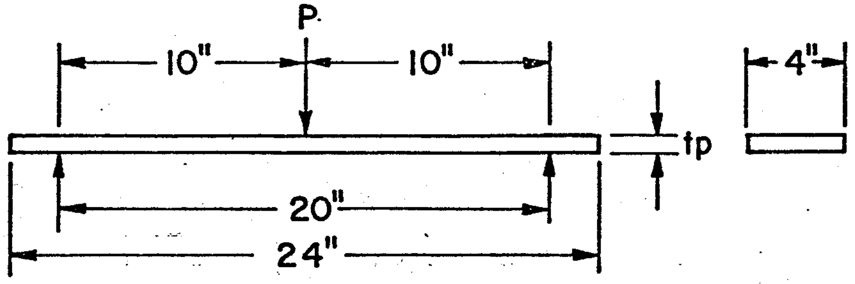


Fig. 2.1.19 Details of Particleboard Specimen for Flexure Test Perpendicular to Surface.

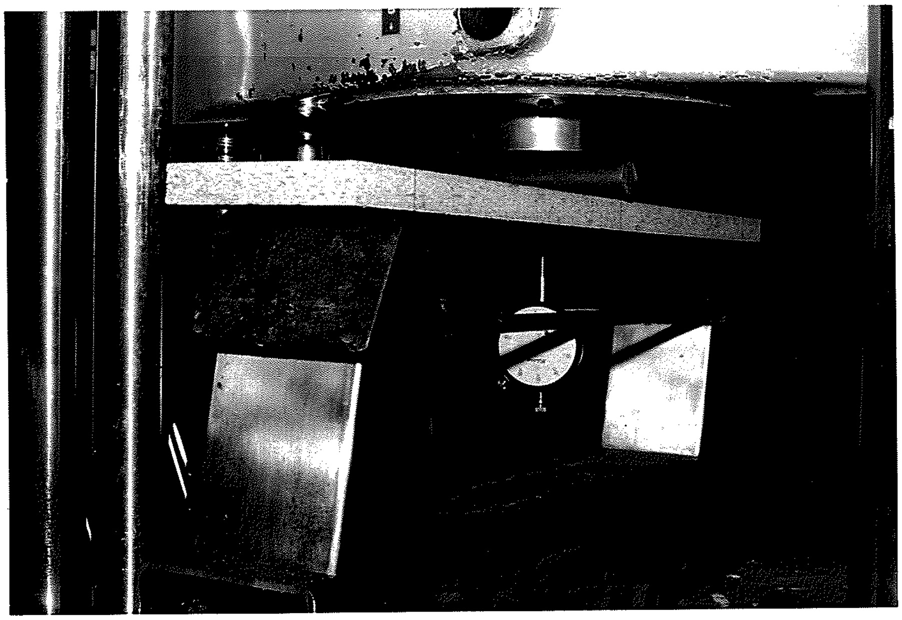


Fig. 2.1.20 - Assembly of Particleboard Specimen for Flexure Test Perpendicular to Surface

The mean value of bending stress in a plane perpendicular to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 955 psi. with a standard deviation of 14.0 psi., and a coefficient of variation of 1.47%. The mean value of bending stress in a plane perpendicular to the surface of 1/2 in. thick particleboard for which the long dimension of the specimen was parallel to the long dimension of the board was found to be 968 psi. with a standard deviation of 12.0 psi., and a coefficient of variation of 1.24%. The mean value of bending stress in a plane perpendicular to the surface of 3/4 in. thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board was found to be 903 psi. with a standard deviation of 1.0 psi., and a coefficient of variation of 0.11%. The mean value of bending stress in a plane perpendicular to the surface of 1/2 in. thick particleboard for which the long dimension of the specimen was transverse to the long dimension of the board was found to be 910 psi. with a standard deviation of 1.0 psi., and a coefficient of variation of 0.11%.

2.1.9 Creep Behaviour

The creep behaviour was investigated by flexure test. The flexure creep investigations were performed both parallel and transverse to the surface of particleboard. The same size and shape of flexure test specimens were used in these investigations. Tests were set up as shown in Fig. 2.1.21 and 2.1.22. A 50 lb. constant load which stressed the material to about 50% of the ultimate, was used for loading and the dial gauge was used for measuring deflection of each

Fig. 2.1.21 - Assembly of Particleboard Specimen for Creep in Flexure Parallel to Surface

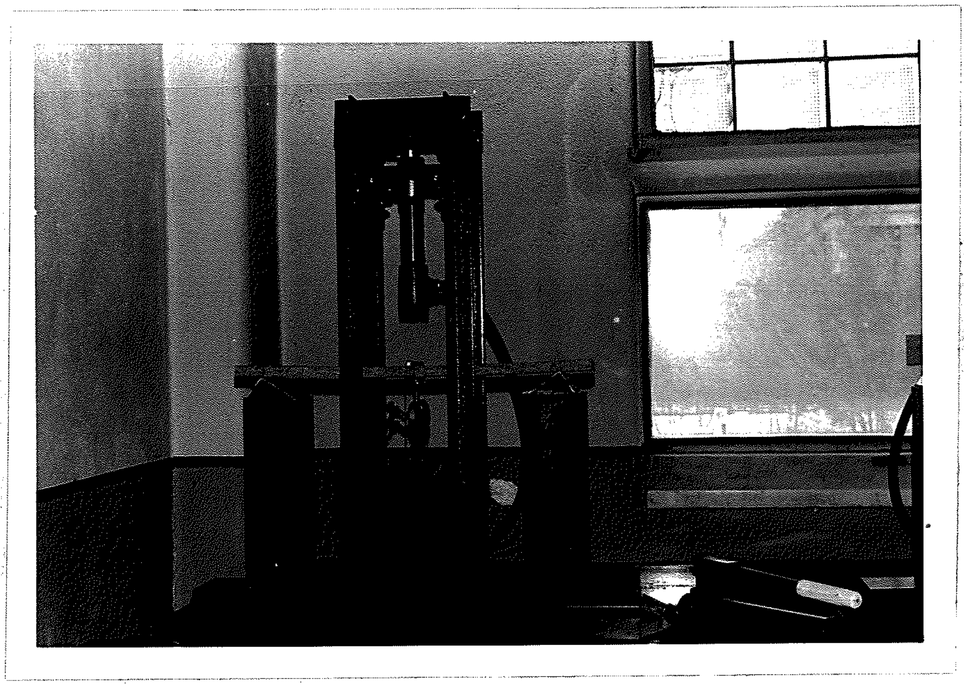


Fig. 2.1.22 - Assembly of Particleboard Specimen for Creep in Flexure Perpendicular to Surface

specimen. Each specimen was loaded for 30 days and the load was then removed. The deflections were observed for 30 days under constant load and another 30 days after the load was removed for recovery. The results are presented in Fig. A-1.1 to A-1.4, respectively.

2.2 Fiberglass

The fiberglass used in this investigation consisted of glass fibres oriented in the longitudinal direction and embedded in a resin matrix. This material is low in weight, corrosion resistant, non-conducting and offers enormous tensile and flexural strength. The rectangular cross-section of fiberglass was used in this project. Tests were performed only to determine the behaviour in tension parallel to the surface.

2.2.1 Tension Parallel to Surface

The test was based on ASTM Special Technical Publication 460 [4]. Each test specimen was prepared as shown in Fig. 2.2.1. The glue that was used to bond the fiberglass pieces together was M-Bond 200, a strain-gauge adhesive. The actual width and thickness of each specimen at the center was measured to an accuracy of 0.001 in. with vernier calipers to determine the actual net cross-sectional area.

The 60,000 lb. testing machine shown in Fig. 2.1.2 was used for loading. The strain indicator shown in Fig. 2.2.2 was used for measuring strain. The strain gauge with 67 mm. gauge length was attached to each specimen using M-Bond 200 adhesive. Each specimen was gripped in the fixed head of the testing maching as shown in Fig. 2.2.3. The load was applied continuously throughout the test.

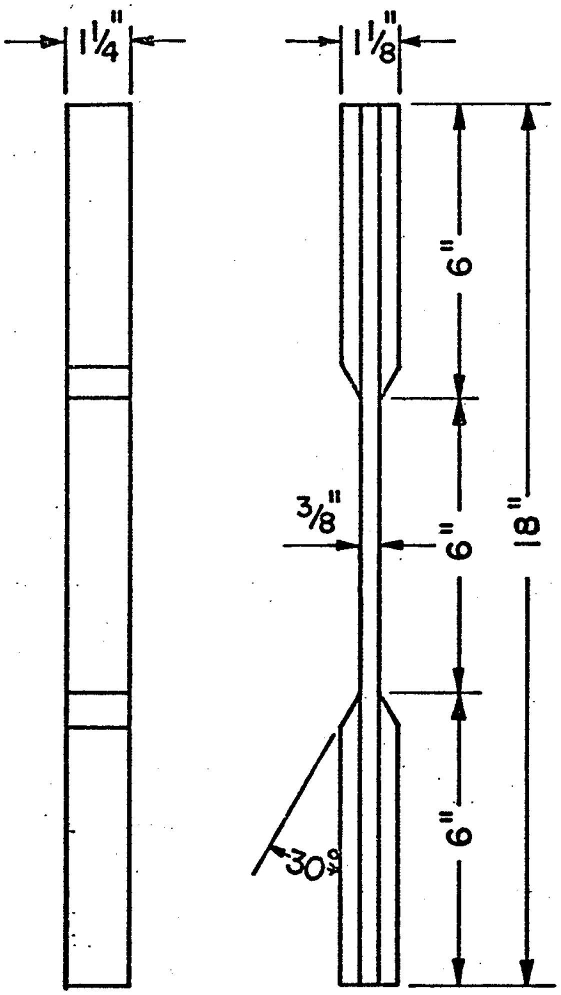


Fig. 2. 2.1 Details of Fiberglass Specimen for Tension Test Parallel to Surface.

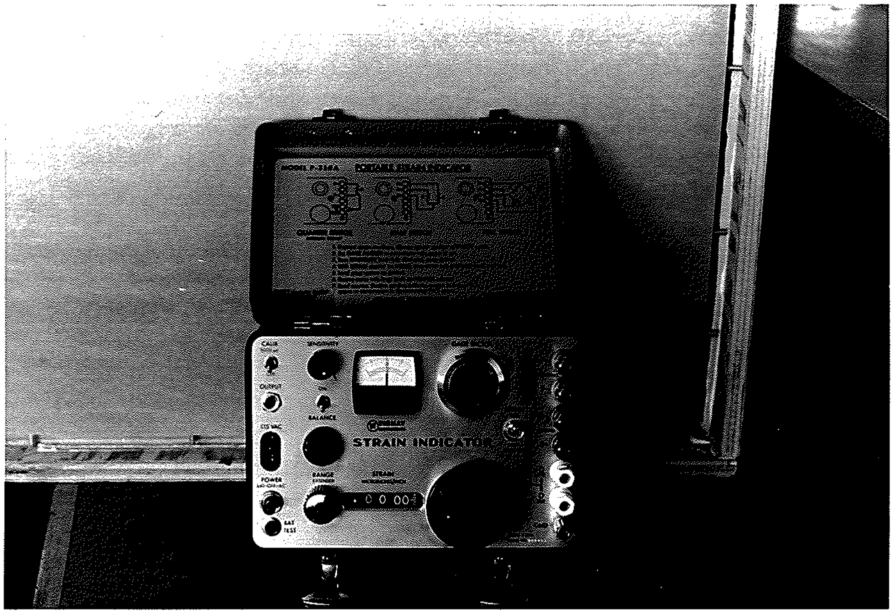


Fig. 2.2.2 - Strain Indicator

Fig. 2.2.3 - Assembly of Fiberglass Specimen for Tension Test Parallel to Surface

The load and the strain indicator readings were observed for determining stress and strain properties. The stress-strain curve was plotted and the modulus of elasticity was determined. The results are presented in Table A-2.1.

The mean value of tensile stress parallel to the surface of fiberglass was found to be 92,000 psi. with a standard deviation of 1,549 psi., and a coefficient of variation of 1.68%.

2.3 Glue

The two kinds of glues that were used were white resin and epoxy glue. The white resin glue was supplied ready to use, whereas the epoxy glue had to be mixed with a hardener before use. The white resin glue was used to bond particleboard together. Epoxy glue was used to bond fiberglass together and fiberglass to particleboard.

2.3.1 Bond Strength between Two Particleboard Pieces

The method of test was similar to the shear test parallel to the particleboard surface. Each test specimen was composed of particleboard pieces bonded together by white resin glue as shown in Fig. 2.3.1. The results are presented in Table A-3.1. It could be seen that the shear-bond strength of white resin glue was higher than the shear strength of particleboard.

The mean value of bond stress of white resin glue between two particleboard pieces was found to be 524 psi. with a standard deviation of 27.1 psi., and a coefficient of variation of 5.18%.

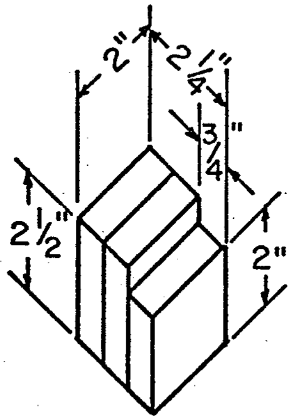


Fig. 2.3.1 Details of Specimen for Bond Strength Test Between Two Particleboard Pieces.

2.3.2 Bond Strength Between Particleboard and Fiberglass

The method of test was similar to the shear test parallel to the particleboard surface. Each test specimen was composed of particleboard pieces bonded together by white resin glue and one piece of fiberglass was glued to the particleboard by epoxy glue as shown in Fig. 2.3.2. The results are presented in Table A-3.2. It could be seen that the shear-bond strength of epoxy glue was higher than the shear strength of particleboard.

The mean value of bond stress of epoxy glue between particleboard and fiberglass was found to be 889 psi. with a standard deviation of 50.0 psi., and a coefficient of variation of 5.62%.

2.3.3 Bond Strength Between Two Fiberglass Pieces

The method of test was similar to the shear test parallel to the particleboard surface. Each test specimen was composed of fiberglass pieces bonded together by epoxy glue as shown in Fig. 2.3.3. The results are presented in Table A-3.3.

The mean value of bond stress of epoxy glue between two fiberglass pieces was found to be 504 psi. with a standard deviation of 63.4 psi., and a coefficient of variation of 12.57%.

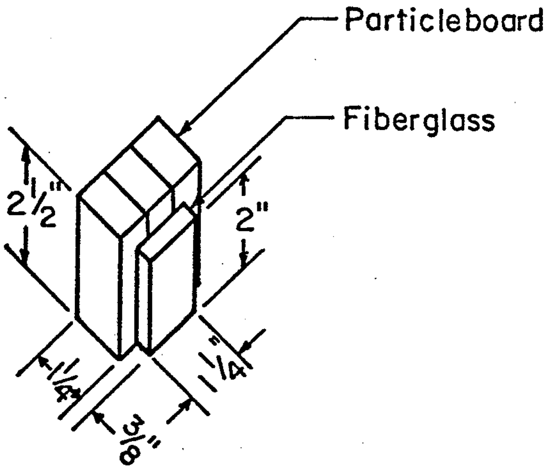


Fig. 2.3.2 Details of Specimen for Bond Strength Test Between Particleboard and Fiberglass.

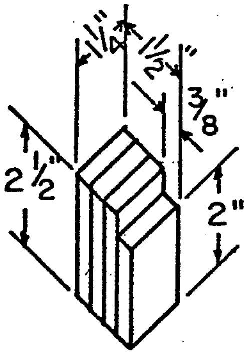


Fig. 2.3.3 Details of Specimen for Bond Strength Test Between Two Fiberglass Pieces.

TABLE 2.1.1

SUMMARY OF PRIMARY TEST RESULTS

Test	Mean Stress psi.	Standard Deviation psi.	Coefficient of Variation %
Tension parallel to surface (3/4" particleboard) long dimension of specimen parallel to long dimension of particleboard	902	82.6	9.16
Tension parallel to surface (1/2" particleboard) long dimension of specimen parallel to long dimension of particleboard	1093	77.1	7.05
Tension parallel to surface (3/4" particleboard) long dimension of specimen transverse to long dimension of particleboard	667	59.3	8.89
Tension parallel to surface (1/2" particleboard) long dimension of specimen transverse to long dimension of particleboard	816	59.6	7.30
Tension perpendicular to surface (3/4" particleboard)	46	2.1	4.57
Tension perpendicular to surface (1/2" particleboard)	103	7.8	7.57
Compression parallel to surface (3/4" particleboard) long dimension of specimen parallel to long dimension of particleboard	2008	127.4	6.34

TABLE 2.1.1 (continued)

Test	Mean Stress psi.	Standard Deviation psi.	Coefficient of Variation %
Compression parallel to surface (1/2" particleboard) long dimension of specimen parallel to long dimension of particleboard	2461	154.7	6.29
Compression parallel to surface (3/4" particleboard) long dimension of specimen transverse to long dimension of particleboard	1642	35.1	2.14
Compression parallel to surface (1/2" particleboard) long dimension of specimen transverse to long dimension of particleboard	2042	51.8	2.54
Compression perpendicular to surface (3/4" particleboard)	4556	204.6	4.49
Compression perpendicular to surface (1/2" particleboard)	7490	368.9	4.93
Shear parallel to surface (3/4" particleboard)	234	15.7	6.71
Shear parallel to surface (1/2" particleboard)	343	17.7	5.16
Shear perpendicular to surface type I (3/4" particleboard)	895	56.8	6.35

TABLE 2.1.1 (continued)

Test	Mean Stress psi.	Standard Deviation psi.	Coefficient of Variation %
Shear perpendicular to surface type I (1/2" particleboard)	1086	77.6	7.14
Shear perpendicular to surface type II (3/4" particleboard)	1138	45.6	4.01
Shear perpendicular to surface type II (1/2" particleboard)	1535	67.3	4.38
Flexure parallel to surface (3/4" particleboard) long dimension of specimen parallel to long dimension of particleboard	842	4.0	0.48
Flexure parallel to surface (1/2" particleboard) long dimension of specimen parallel to long dimension of particleboard	1104	3.0	0.27
Flexure parallel to surface (3/4" particleboard) long dimension of specimen transverse to long dimension of particleboard	699	11.0	1.57
Flexure parallel to surface (1/2" particleboard) long dimension of specimen transverse to long dimension of particleboard	844	12.2	1.44

TABLE 2.1.1 (continued)

Test	Mean Stress psi.	Standard Deviation psi.	Coefficient of Variation %
Flexure perpendicular to surface (3/4" particleboard) long dimension of specimen parallel to long dimension of particleboard	955	14.0	1.47
Flexure perpendicular to surface (1/2" particleboard) long dimension of specimen parallel to long dimension of particleboard	968	12.0	1.24
Flexure perpendicular to surface (3/4" particleboard) long dimension of specimen transverse to long dimension of particleboard	903	1.0	0.11
Flexure perpendicular to surface (1/2" particleboard) long dimension of specimen transverse to long dimension of particleboard	910	1.0	0.11
Tension parallel to surface (fiberglass)	92,000	1,549	1.68
Bond strength between two particleboard pieces	524	27.1	5.18
Bond strength between particleboard and fiberglass	889	50.0	5.62
Bond strength between two fiberglass pieces	504	63.4	12.57

CHAPTER III

DESIGN OF FLOOR SYSTEM

3.1 General Design

The structure was designed as a floor deck-joist-beam. The purpose of this design was to develop a section whose component parts that would act efficiently together; i.e. to develop composite action. All of the sections were designed following the requirements of the CSA standard 086-1970 code [2]. The average of the lowest values of ultimate strength obtained from the various tests (i.e. specimens parallel and transverse to the long dimension of the board) were divided by safety factor of 2.0 to obtain the allowable strength. The modulus of elasticity of particleboard and fiberglass were used directly from the average of the lowest values obtained from the tests. The modulus of elasticity of particleboard was 224,000 psi.,and the modulus of elasticity of fiberglass was 6,250,000 psi. The modular ratio between fiberglass and particleboard was found to be 27.9 approximately and to be conservative a value of 25 was used in the design. The average of the lowest values of ultimate strength and the allowable strength of particleboard obtained from the various tests are presented in Table 3.1.1. The ultimate tensile strength parallel to surface of fibreglass was 92,000 psi., so that the allowable tensile strength parallel to surface was 46,000 psi. The density of particleboard and fiberglass were 0.028 and 0.07 lb. per in.^{3}, respectively.

The floor deck was designed continuously over the joists which were spaced at 16 in. centers and a design live load of 100 psf. was

Table 3.1.1

Ultimate and Allowable Strength of Particleboard

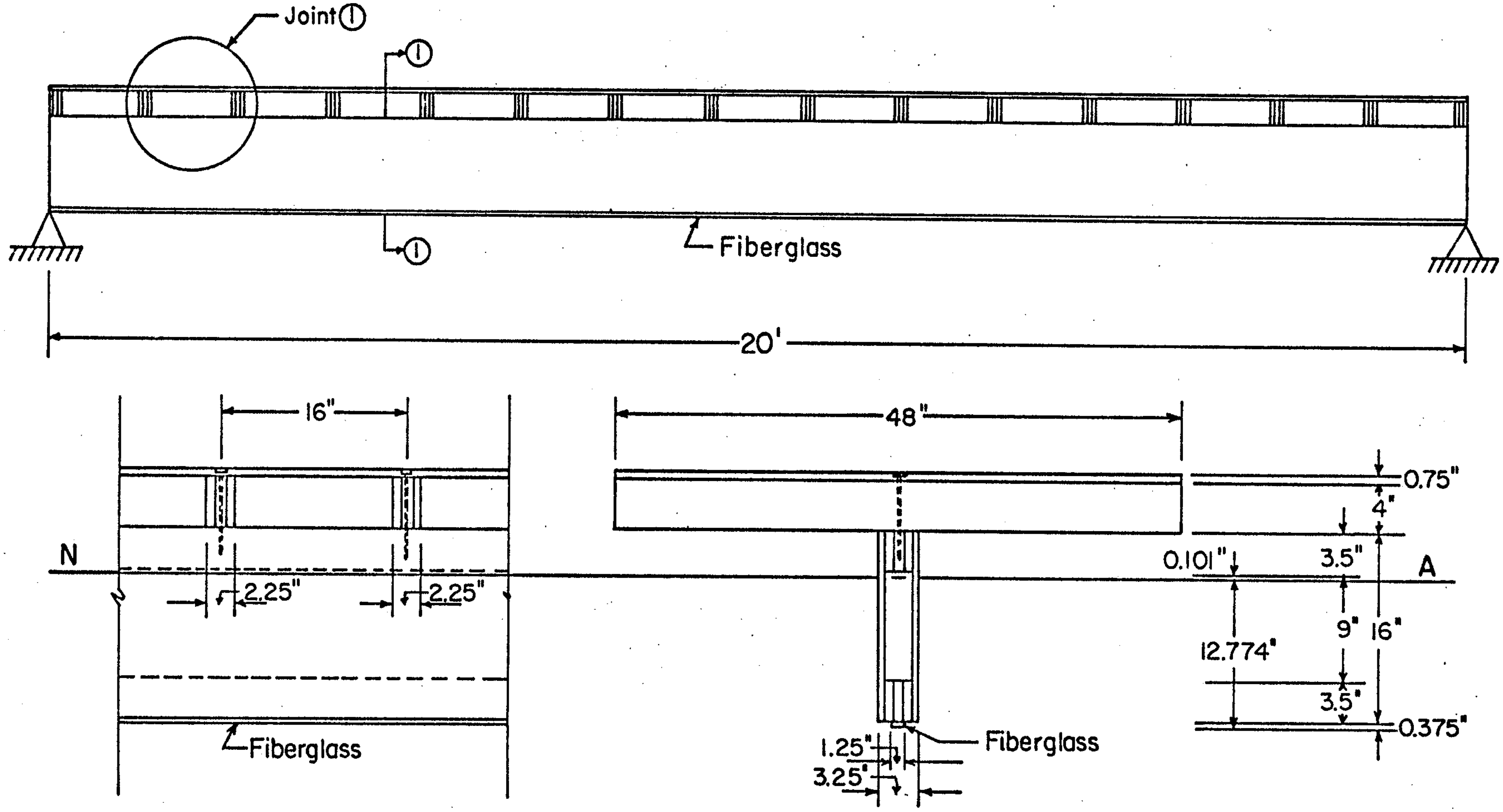
Type of Test	Ultimate Strength (psi.)	Allowable Strength (psi.)
Tension Parallel to Surface	667	333.5
Tension Perpendicular to Surface	46	23
Compression Parallel to Surface	1642	821
Compression Perpendicular to Surface	4556	2278
Shear Parallel to Surface	234	117
Shear Perpendicular to Surface	895	447.5
Flexure Parallel to Surface	699	349.5
Flexure Perpendicular to Surface	903	451.5

used. Each joist was designed simply supported over a 4 ft. span and was loaded by 1,000 lb. concentrated load over the area of 2 1/2 ft. by 2 1/2 ft. The beam was designed simply supported over a 20 ft. span and was loaded by a 50 psf. distributed live load. Composite action between the deck and the floor beam was assumed. The single unit of the floor beam section is shown in Fig. 3.1.1. Design calculations for the floor beam system are given in Appendix B.

The degree to which the deck can act as a compression flange with the beam depends on the adequacy of horizontal shear transfer at the deck-joist and joist-beam interfaces. The component parts were connected together with lag screws and the shear strength at this connection was the subject of an investigation.

3.2 Shear Test of the Deck-to-Beam Lag Screwed Connection

A double shear test was performed to find the shear strength. Each test specimen was prepared as shown in Fig. 3.2.1. Each specimen represented two sets of floor deck, joist and beam fixed together by lag screws. The dimension of each lag screw was 3/8 in. diameter by 7 in. in length. The testing machine shown in Fig. 2.1.2 was used for loading. The top platen of the testing machine was equipped with a spherical bearing to obtain uniform distribution of load over the surface of the specimen. Each specimen was assembled on the table of the testing machine and the dial gauge was placed under the fixed head of the testing machine for measuring deflection, as shown in Fig. 3.2.2. The load was applied continuously throughout the test. The load and



(a) Joint ①   (b) Section ① - ①

Fig. 3.1.1 Details of Composite Section.

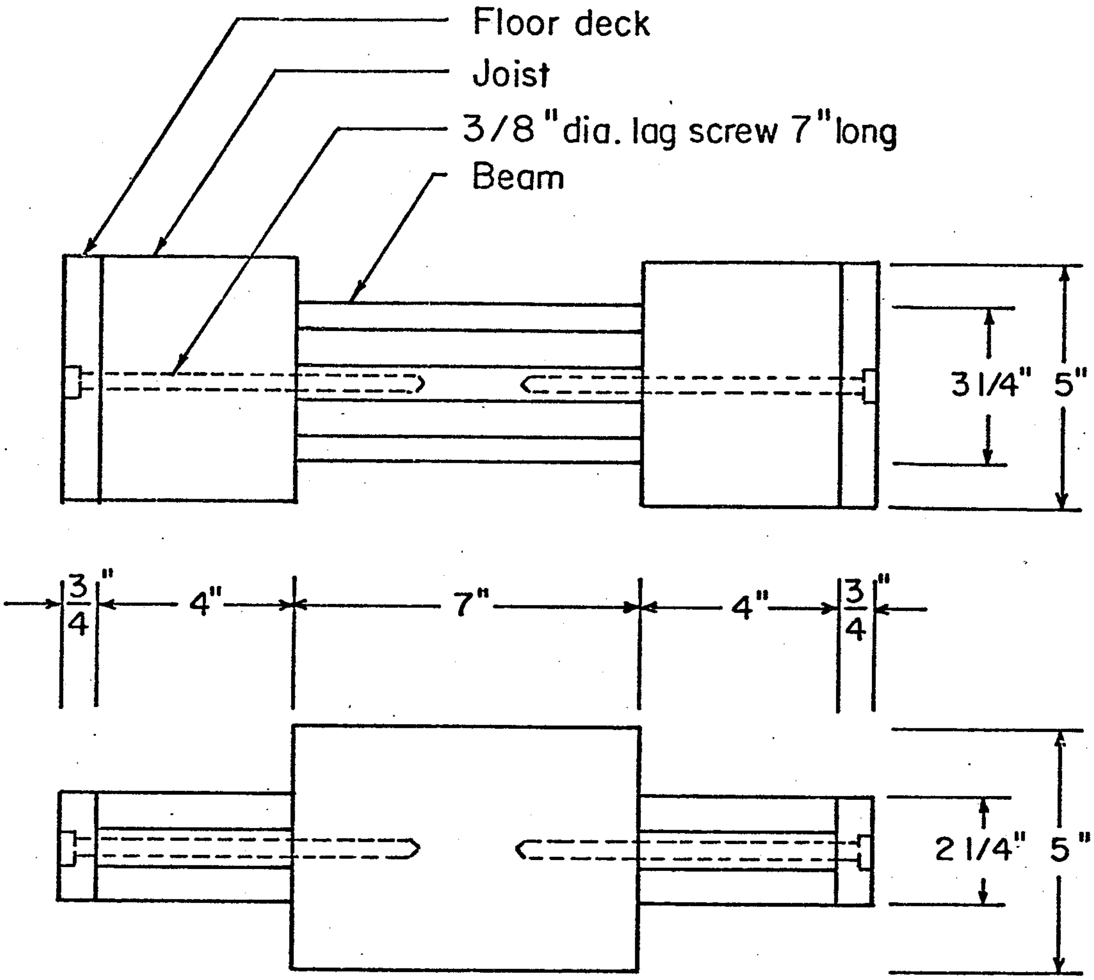


Fig. 3.2.1 Details of Specimen for Shear Test Between Particleboard and Lag Screw.

Fig. 3.2.2 - Assembly of Specimen for Shear Test Between Particleboard and Lag Screw

the dial gauge readings were observed for determining load and deflection properties. The load-deflection curve was plotted and the load at the proportional limit was determined.

The results are presented in Table B-2.1. The average value of load at the proportional limit for single shear was 640 lb. so a safety factor of 2.0 was applied. Therefore, the allowable load was 320 lb. for one lag screw.

CHAPTER IV

LOAD TEST OF FLOOR SYSTEM

4.1 Construction of the Test Structure

The structure was constructed using representative full-scale dimensions as shown in Fig. 3.1.1. 3/4 in. thick particleboard was used as the floor deck. Each joist was made of three plies of 3/4 in. thick particleboard bonded together with white resin glue. 1/2 in. thick particleboard was used for the two webs of the box beam. The top and bottom flange of the beam were made of three plies of 3/4 in. thick particleboard bonded together with white resin glue. The webs and flanges of the beam were bonded together with white resin glue. The fiberglass was bonded to the bottom flange of the beam with epoxy glue. The floor deck and each joist were glued together with epoxy glue to obtain composite section. A 3/8 in. diameter by 7 in. long lag screw was used to connect the floor, joist and beam together at each joist. Joints in the particleboard deck and webs were spliced to permit stress transfer across the joint.

Due to the shear problem between the joist and the beam, the structure was loaded with two points loads instead of uniformly distributed load. The loads were applied at one third of the span from each end to obtain zero shear in the middle third and constant maximum shear from each load to each support. The floor beam in this region of maximum shear was shown in Fig. 4.1.1. Particleboard blocking was provided between the joists to help reduce joist rotation and slip due to shear. Each block was held in place with four extra lag screws.

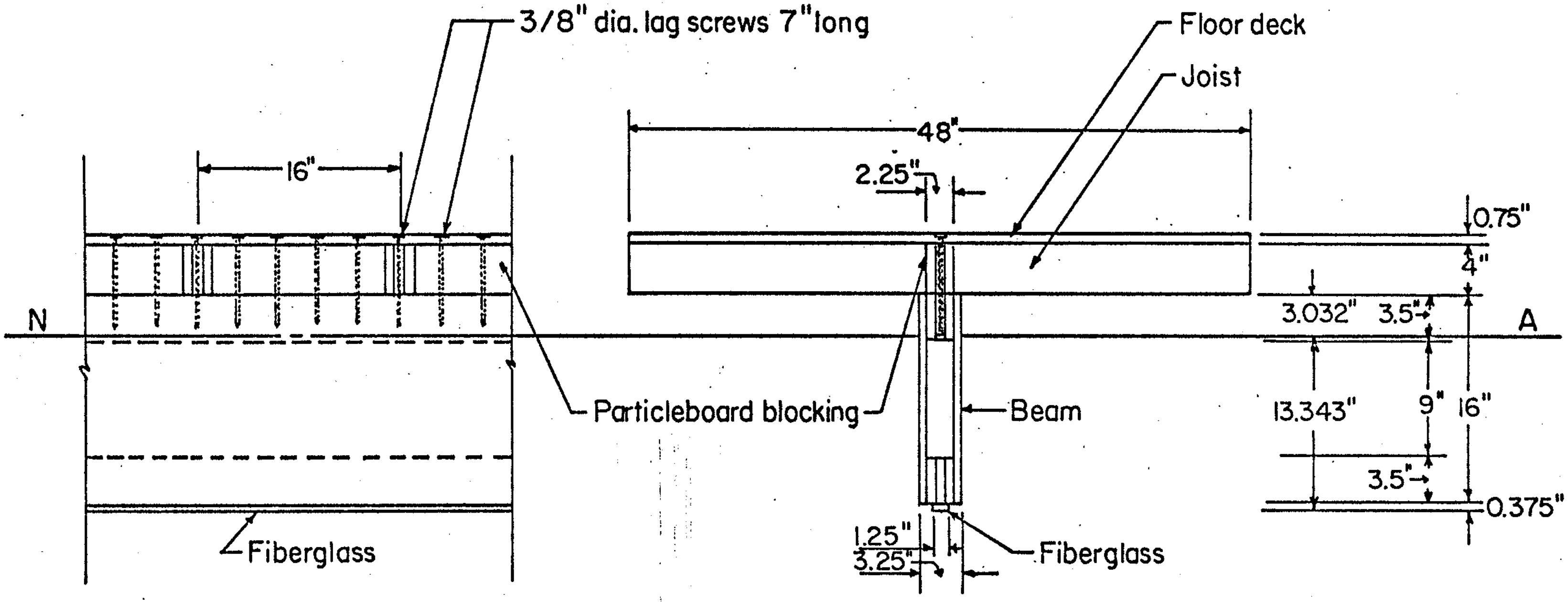


Fig. 4.1.1 Details of End Section of Test Structure from Load Point to Support.

Each block was made from three plies of 3/4 in. thick particleboard bonded together with white resin glue. The uniformly distributed load was converted to two points loads to provide the same value of bending moment. The point load value resulting in a bending moment corresponding to that due to a live load of 50 psf. was 1,700 lb.

4.2 Load Test System

The structure was tested in the inverted position to ensure stabilities during loading. The structure was set under two frames as shown in Fig. 4.2.1. Each support was hinged as shown in Fig. 4.2.2. The loads were applied at each end through load cells with hemispherical buttons using hydraulic jack loading. Each load cell was calibrated against the testing machine shown in Fig. 4.2.3. before use in the test. This calibration of the load cell transformed the strain reading to the load reading. The strain indicator shown in Fig. 2.2.2 was used with a load cell for measuring strain. The calibration chart of each load cell is presented in Fig. 4.2.4 and 4.2.5, respectively. The load cell with hemispherical button is shown in Fig. 4.2.6.

The extent to which there was composite action between deck and beam was determined from the variation of longitudinal strains across sections of the beam. The demec gauge shown in Fig. 2.1.3, was used for measuring strain. Strains were measured at seven cross-sections whose location along the beam are shown in Fig. 4.2.7. The slip between fiberglass and particleboard was checked with the demec

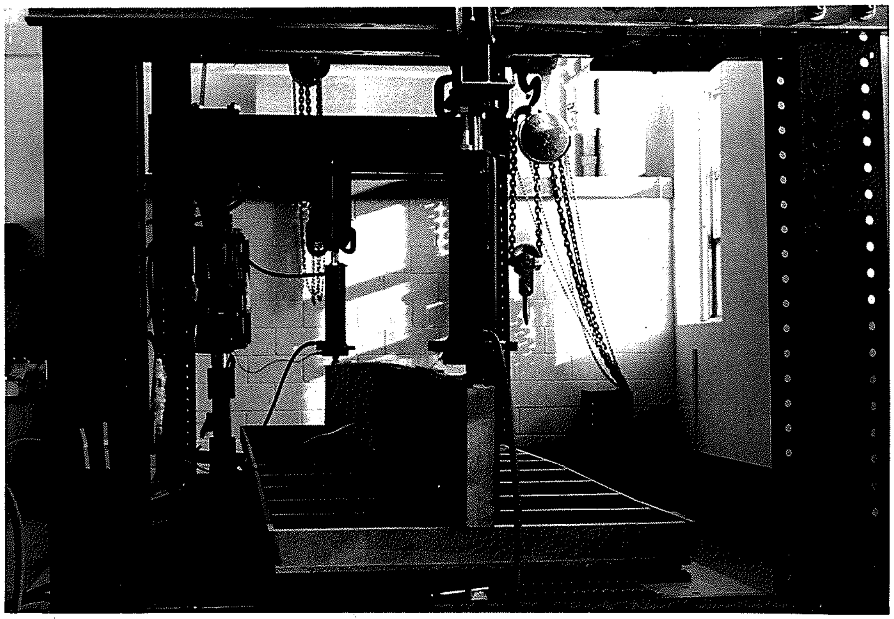


Fig. 4.2.1 - Test Structure and Loading Frame

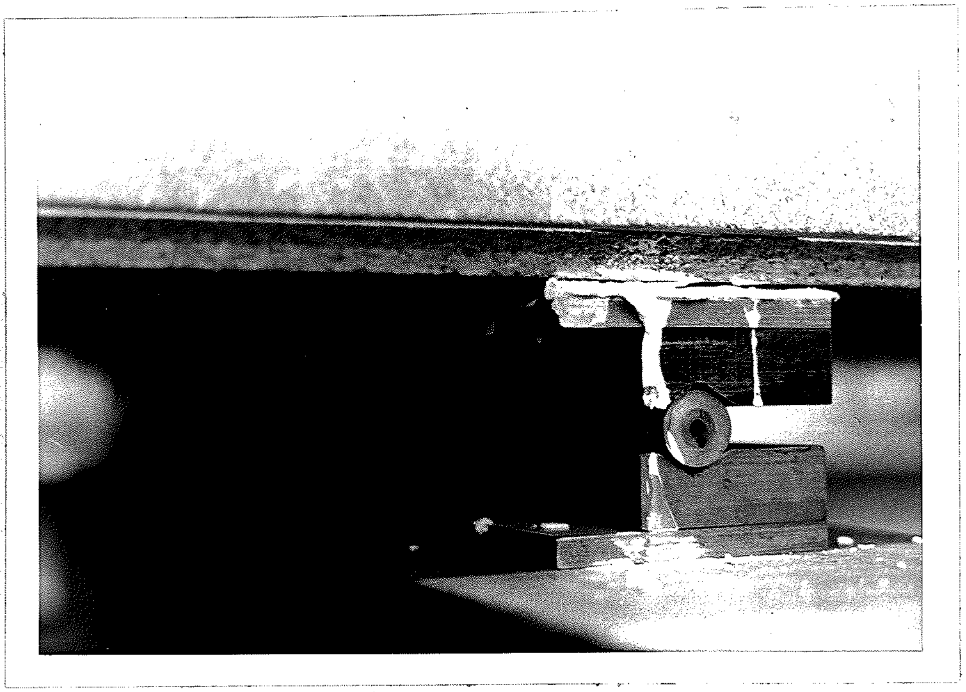


Fig. 4.2.2 - Hinge Support

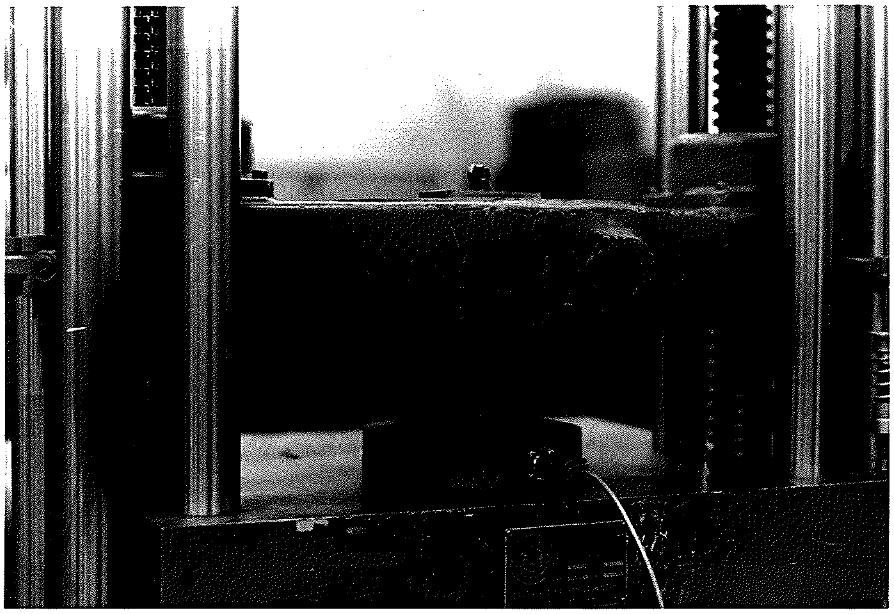


Fig. 4.2.3 - Load Cell Calibration

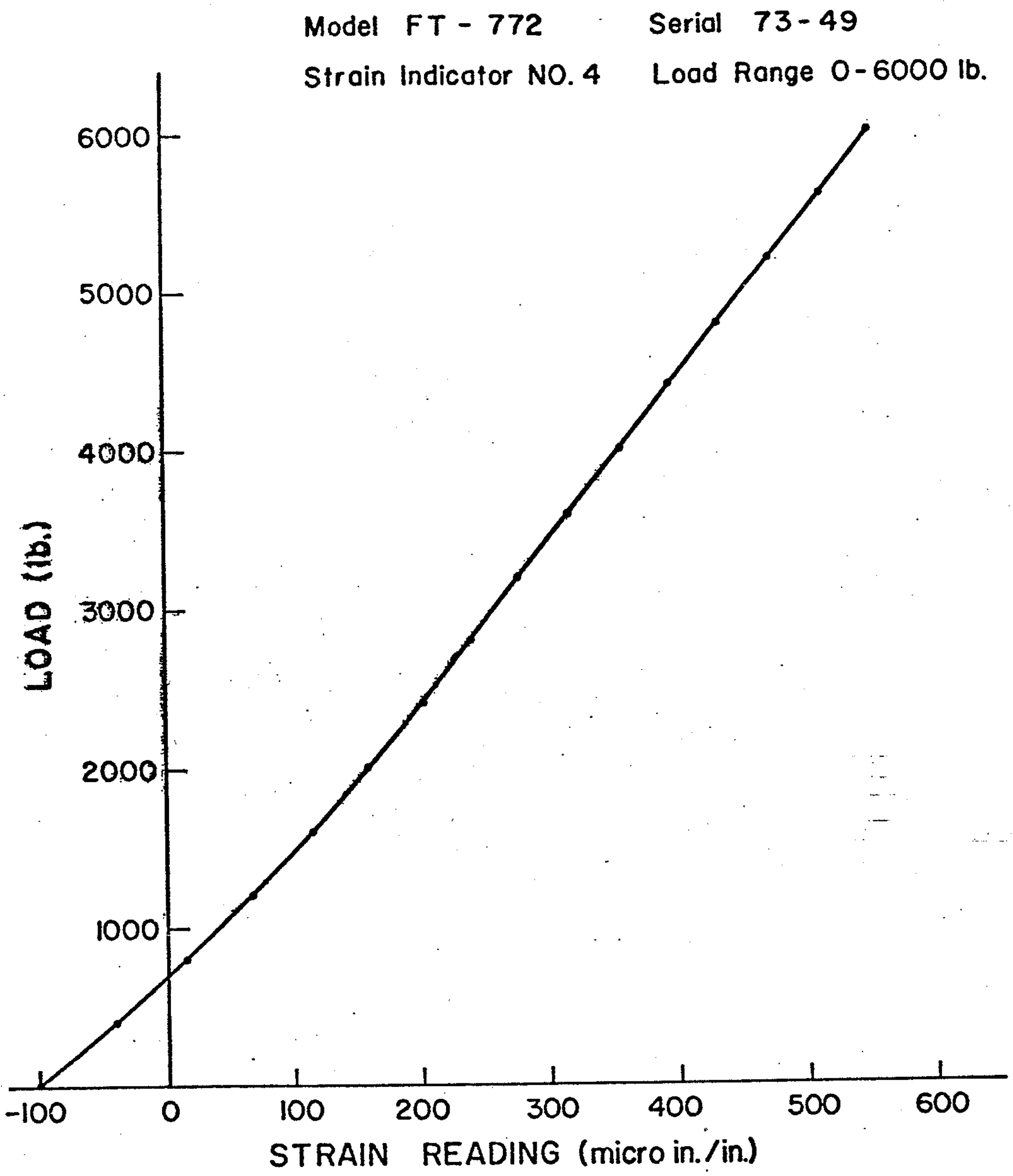


Fig. 4.2.4. CALIBRATION CHART OF LOAD CELL NO.1.

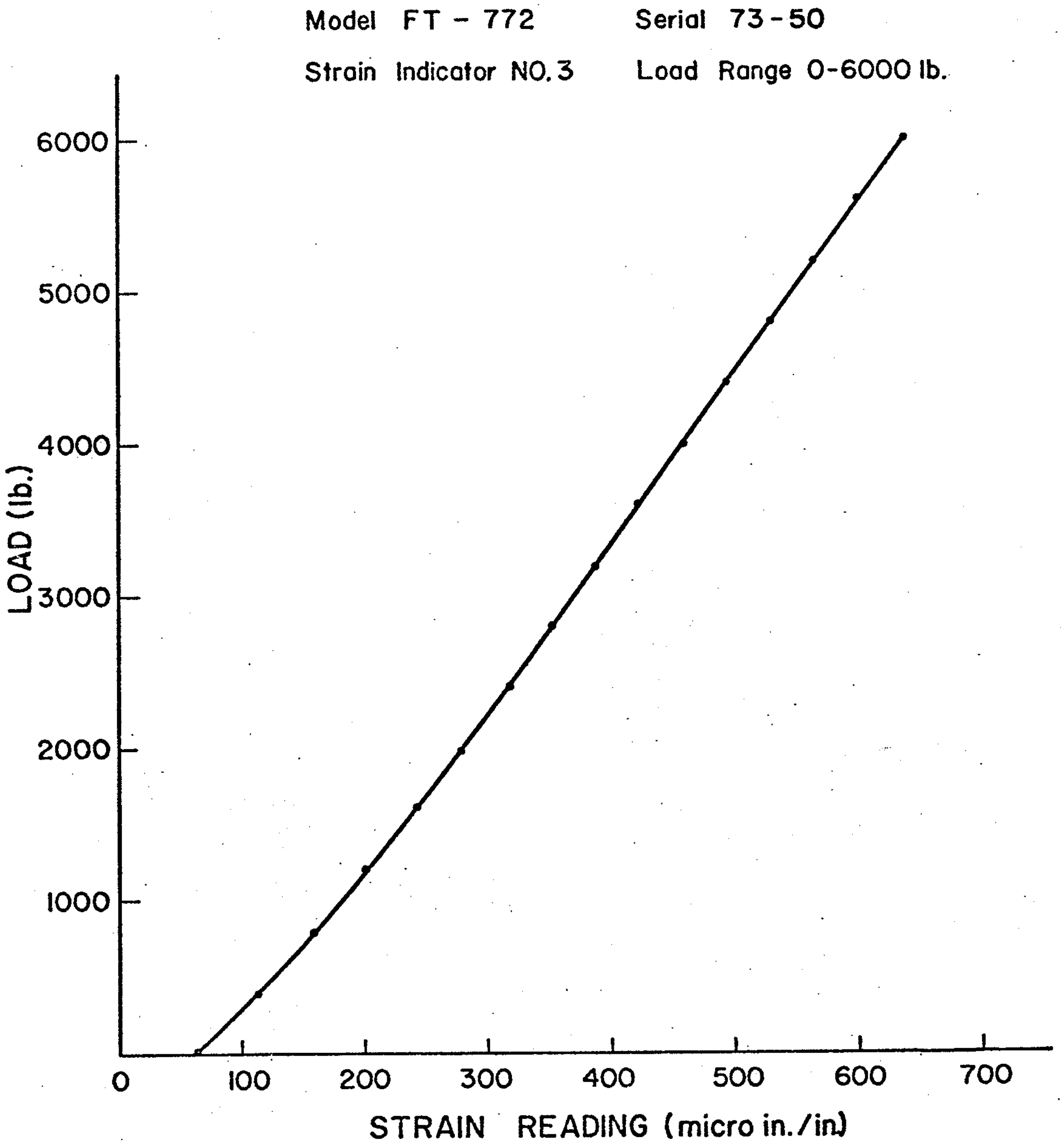


Fig. 4.2.5 CALIBRATION CHART OF LOAD CELL NO. 2.

Fig. 4.2.6 - Load Cell with Hemispherical Button

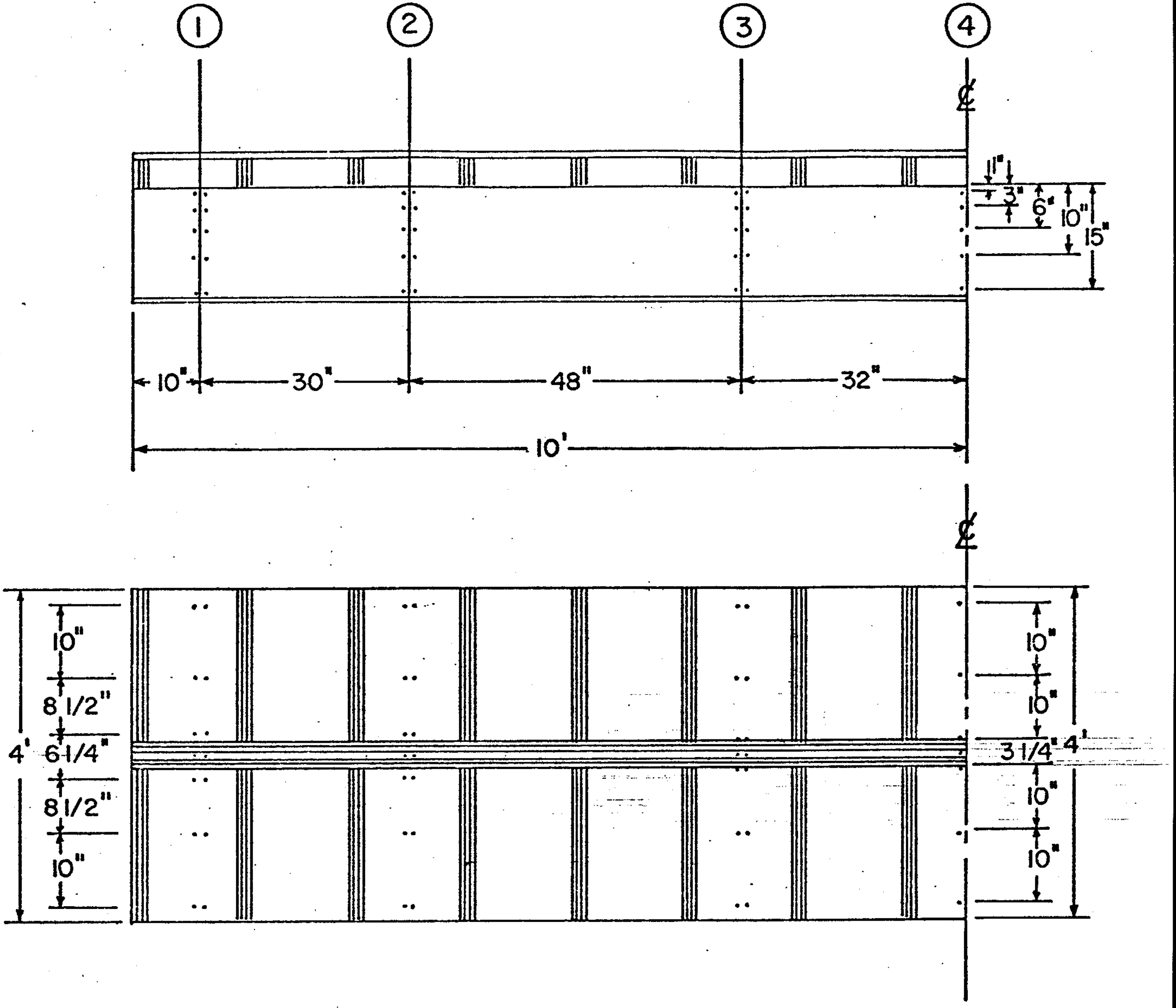


Fig. 4.2.7 Location of Strain Reading (Half Span).

gauge. The slip of the joist was also checked with the demec gauge. Dial gauges were used for measuring deflections at mid-span and at each end of the beam.

The structure was loaded in four stages. During stage I, the structure was loaded up to half of the design load (i.e. to 850 lb. at each end) and all of the gauge readings were recorded. During stage II, the load was increased to full design load (i.e. to 1,700 lbs. at each end) and all of the gauge readings were again recorded. After that, the structure was blocked in place to observe relaxation of the loads until the loading became constant at which time all of the gauge readings were again taken to determine creep in the structure. This method of determining creep behaviour from the relaxation behaviour was chosen because of the difficulty of making precise adjustments to the hydraulic jacks to keep the applied loading constant. Stage III and stage IV were similar to stage I and stage II, but the loads were increased to one and a half and two times the design load (i.e. to 2,550 lbs. and 3,400 lbs. at each end, respectively). The load was then reduced to zero and all of the gauge readings were recorded. The structure was then left unloaded for the purpose of observing the deflection recovery. When deflection recovery appeared to have ceased, all gauges were read again to determine creep recovery in the structure. The structure was then loaded to failure and only the dial gauge readings were observed.

During the early testing phase to stage II separation between joists and beam was observed at one end of the beam. At this point, the loading was removed and steel rods were used to clamp the joist and deck system together as shown in Fig. 4.2.8. The structure was then retested.

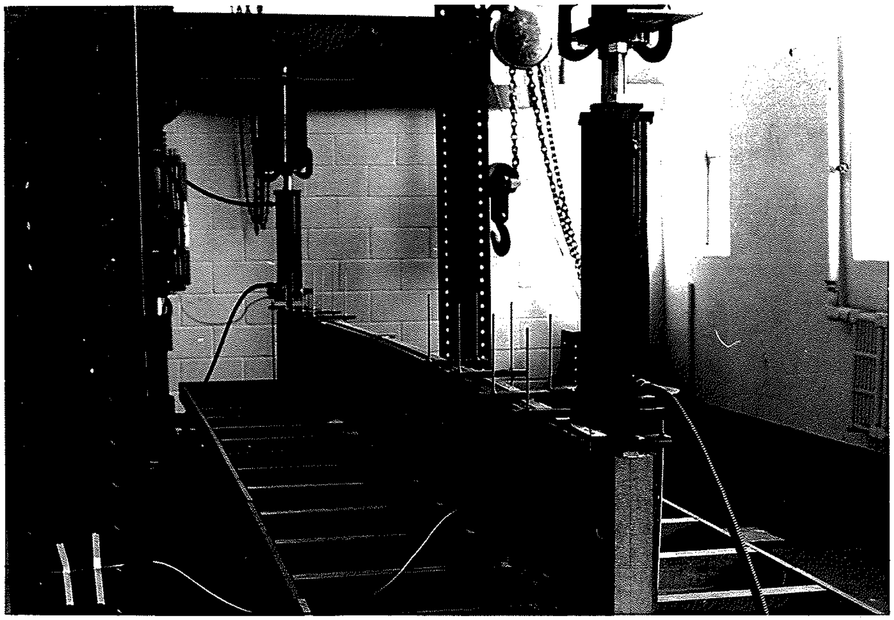


Fig. 4.2.8 - Test Structure with Extra Steel Rods and Nuts

CHAPTER V

DISCUSSION OF TEST RESULTS

5.1 Test Results

The test results presented in Chapter II are those pertaining to the appropriate properties of particleboard and fiberglass. These results led directly to the criteria used in the floor design of Chapter III and Appendix B. The test results presented in this Chapter refer to the load tests performed on the structure.

As outlined in Chapter IV, three separate load tests were performed on the structure. The first test was to full live load and the load then removed; this was for the purpose of remedial strengthening of the joist-to-beam connection. The second test was to twice the design load and the load then removed to observe creep recovery. During these two tests, strains and deflections were measured. The third test consisted of loading to failure, with deflection readings being taken during loading.

The longitudinal strain variations at the various cross-sections of the beam are plotted as shown in Fig. C-1.1 to C-1.7 inclusive for the first test and in Fig. C-2.1 to C-2.7 inclusive for the second test. Taking the neutral axis of the beam as that axis where the strain has a zero value, the variation in the location of the neutral axis along the beam is directly obtainable from the strain readings. The profiles of the neutral axis along the beam at different stages of loading are shown in Fig. 5.1.1 and 5.1.2 for the first test, and in Fig. 5.1.3 and 5.1.4 for the second test. It can be seen from a comparison of recorded

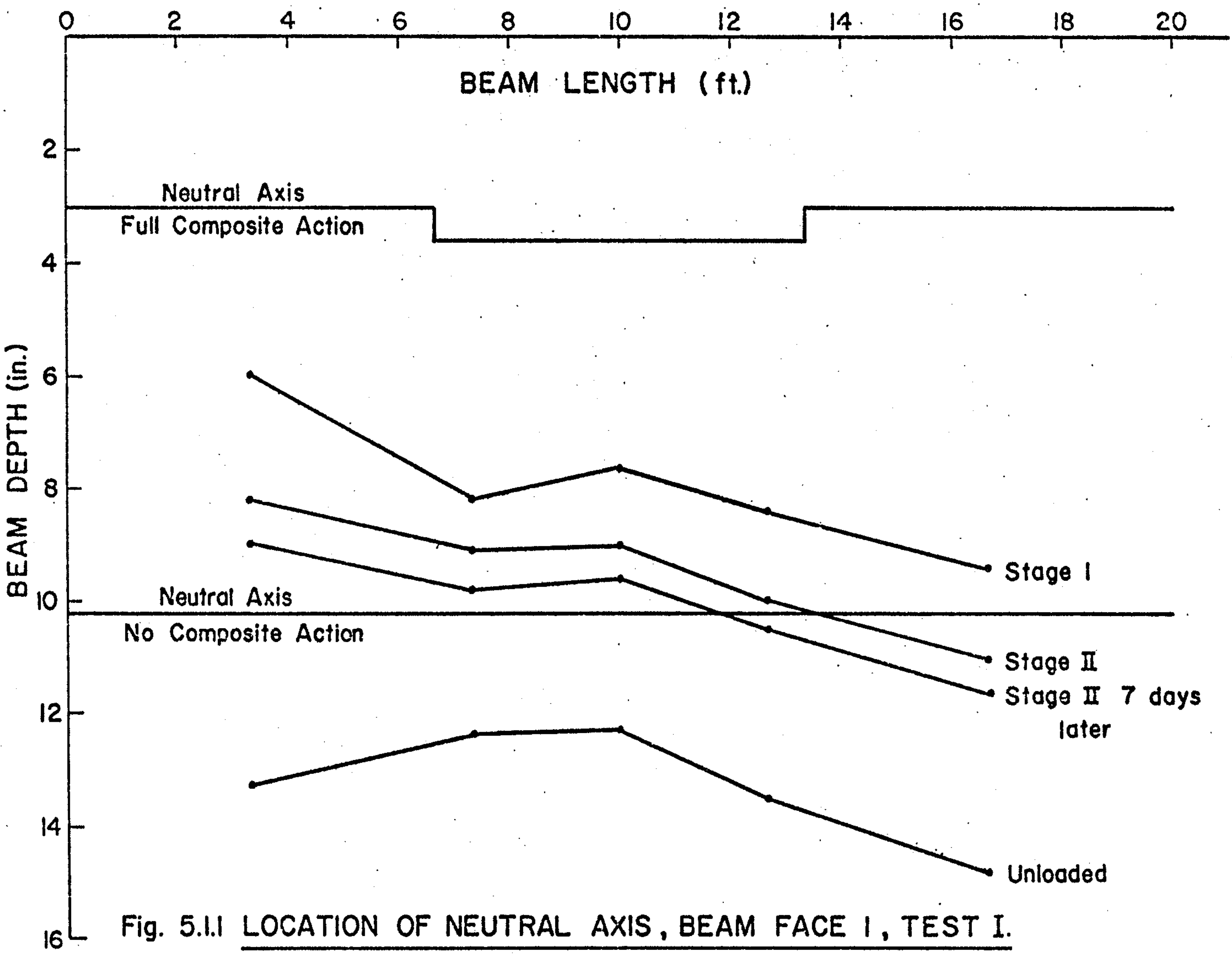


Fig. 5.1.1 LOCATION OF NEUTRAL AXIS, BEAM FACE I, TEST I.

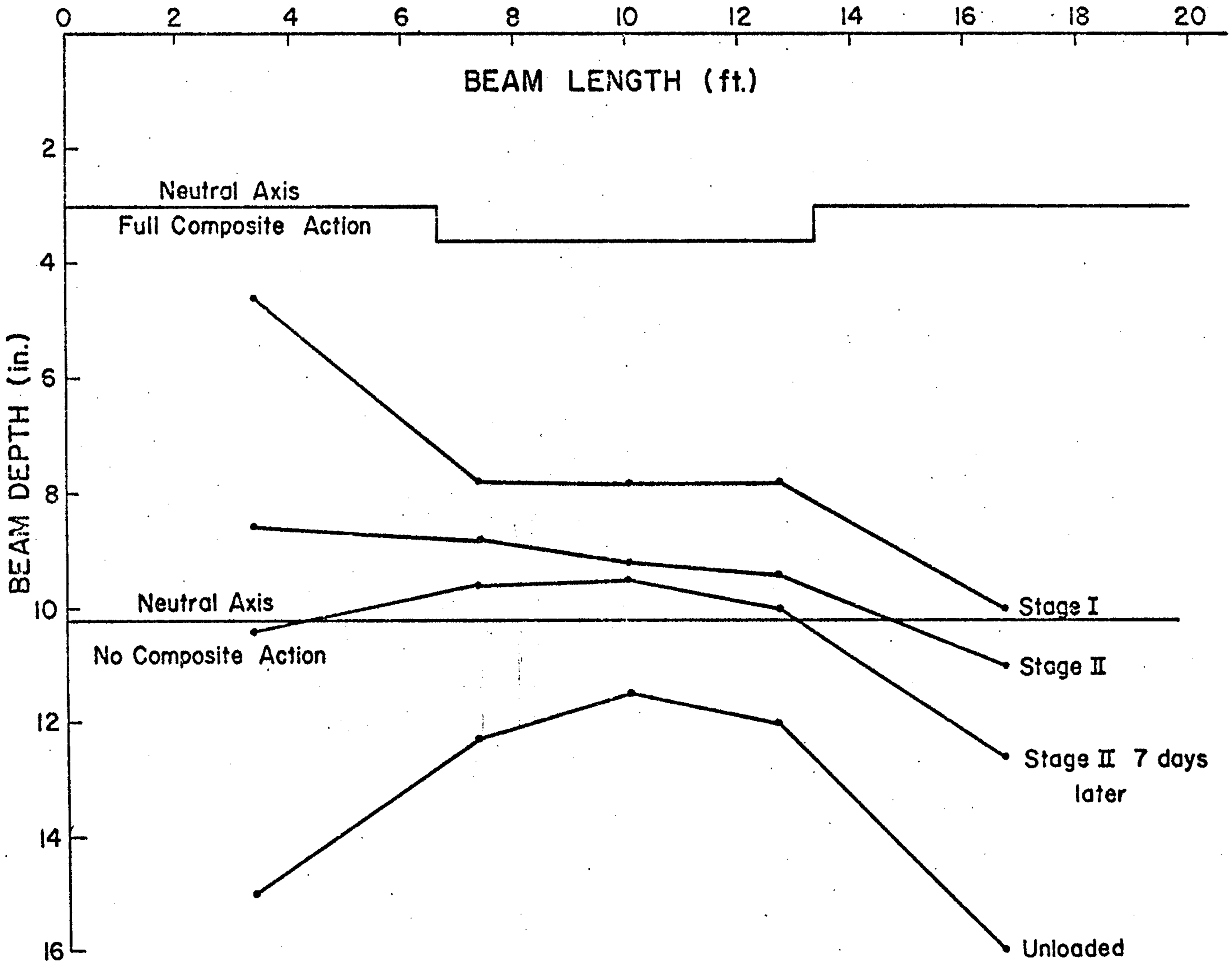


Fig. 5.1.2 LOCATION OF NEUTRAL AXIS, BEAM FACE 2, TEST I.

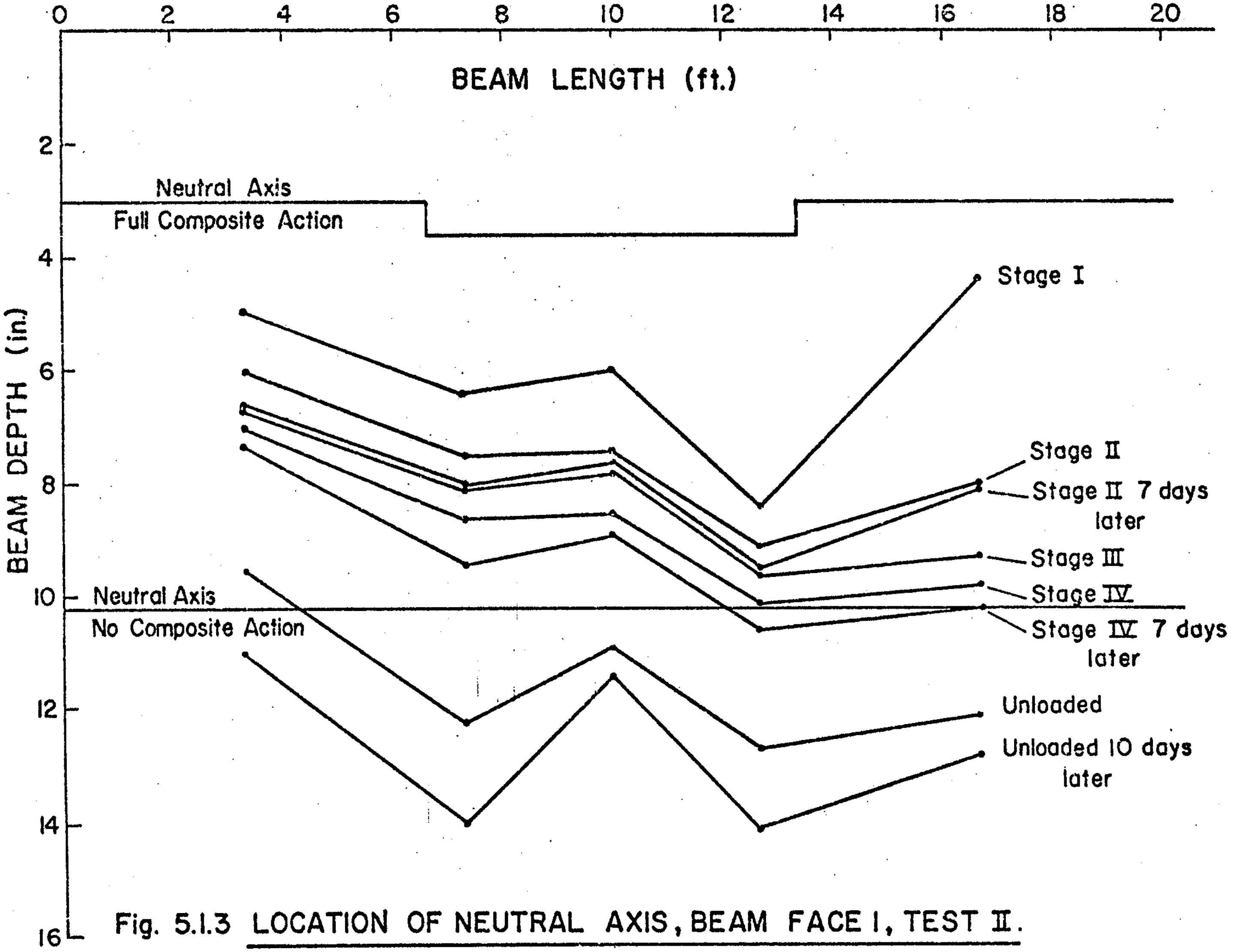


Fig. 5.1.3 LOCATION OF NEUTRAL AXIS, BEAM FACE I, TEST II.

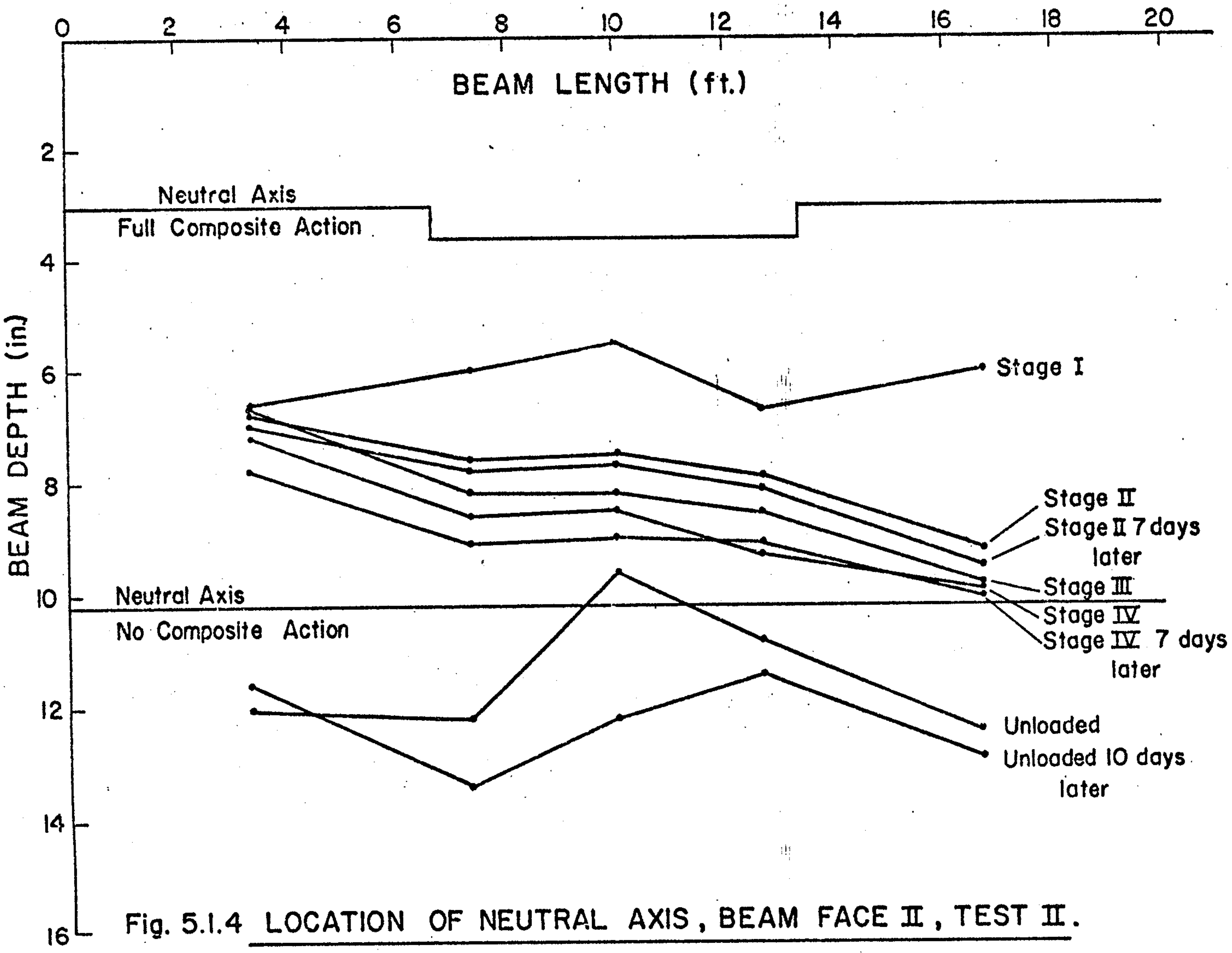


Fig. 5.1.4 LOCATION OF NEUTRAL AXIS, BEAM FACE II, TEST II.

neutral axis location with the theoretical locations for the beam with full composite action from the deck and for the beam alone that the deck did perform to some extent as a composite part of the beam. However, it is evident that the deck did not behave as a fully composite component of the beam, and moreover, the effectiveness of the deck declined with increasing load.

The amount of slip between fiberglass and particleboard was measured at a number of locations, the results being shown in Table C-1.1 for the first test, and in Table C-2.1 for the second test. Although failure during the third test initiated as a result of failure at this interface, the amount of slip registered during the first two tests was negligible.

The extent to which the deck will act as a composite structural component of the beam depends almost wholly on the integrity of the deck-to-joist connection and on the joist-to-beam connection. The extent of the slip at the joist-to-beam connection was measured at a number of selected locations and the results are presented in Tables C-1.2 and C-2.2 for the first and second tests, respectively. It can be seen that a certain amount of slip took place continuously throughout the test, a factor which is of major consideration in loss of composite deck action. The deck-to-joist connection showed no signs of slip.

As noted in Chapter IV, a study of creep under constant load was not practical for the loading arrangement used. Consequently, the relaxation of load at constant deformation was measured. The relaxation of loads for the first and second test are shown in Fig. 5.1.5 and 5.1.6, respectively. In general, the loading became constant

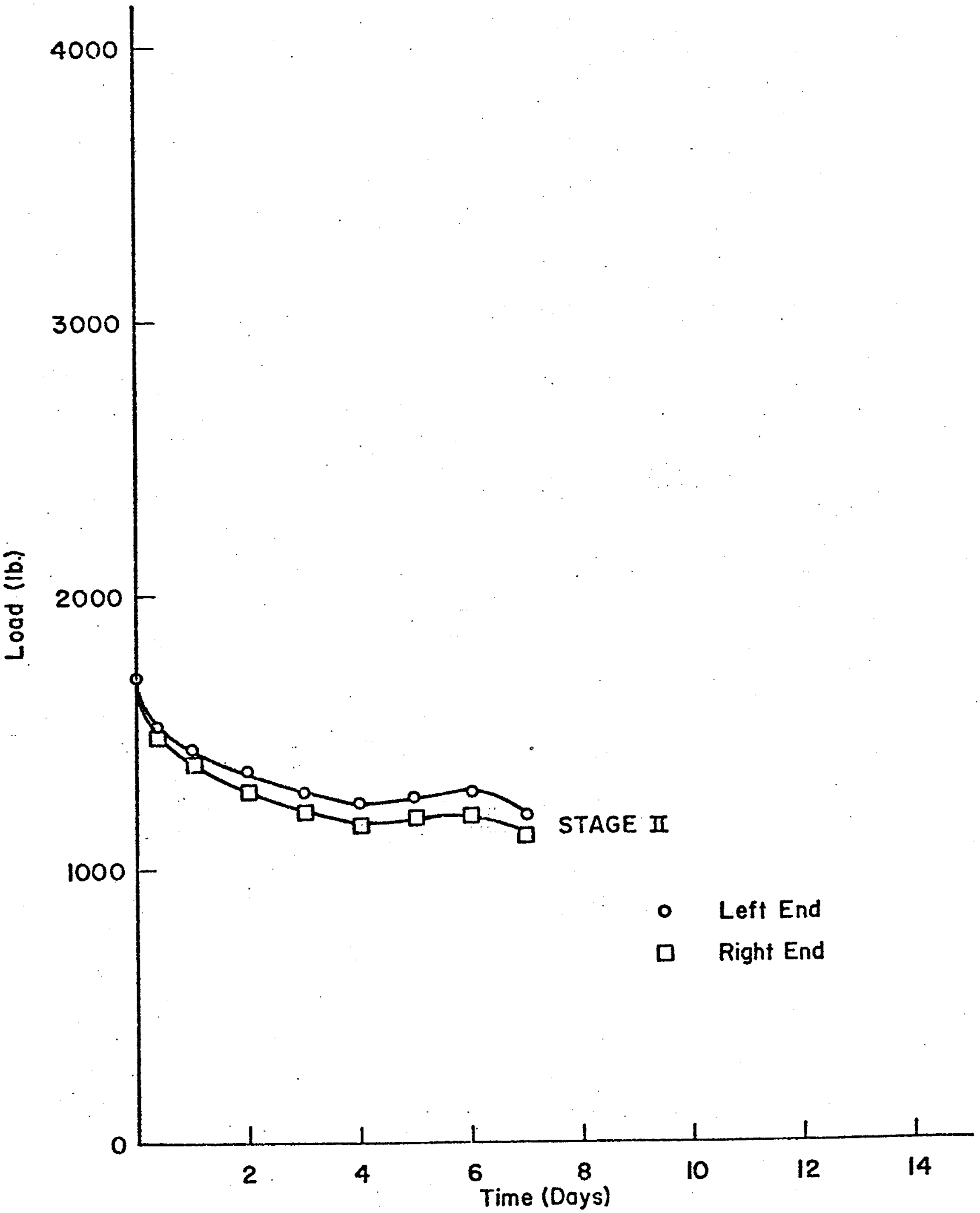


Fig. 5.1.5 Relaxation of Load, Test I.

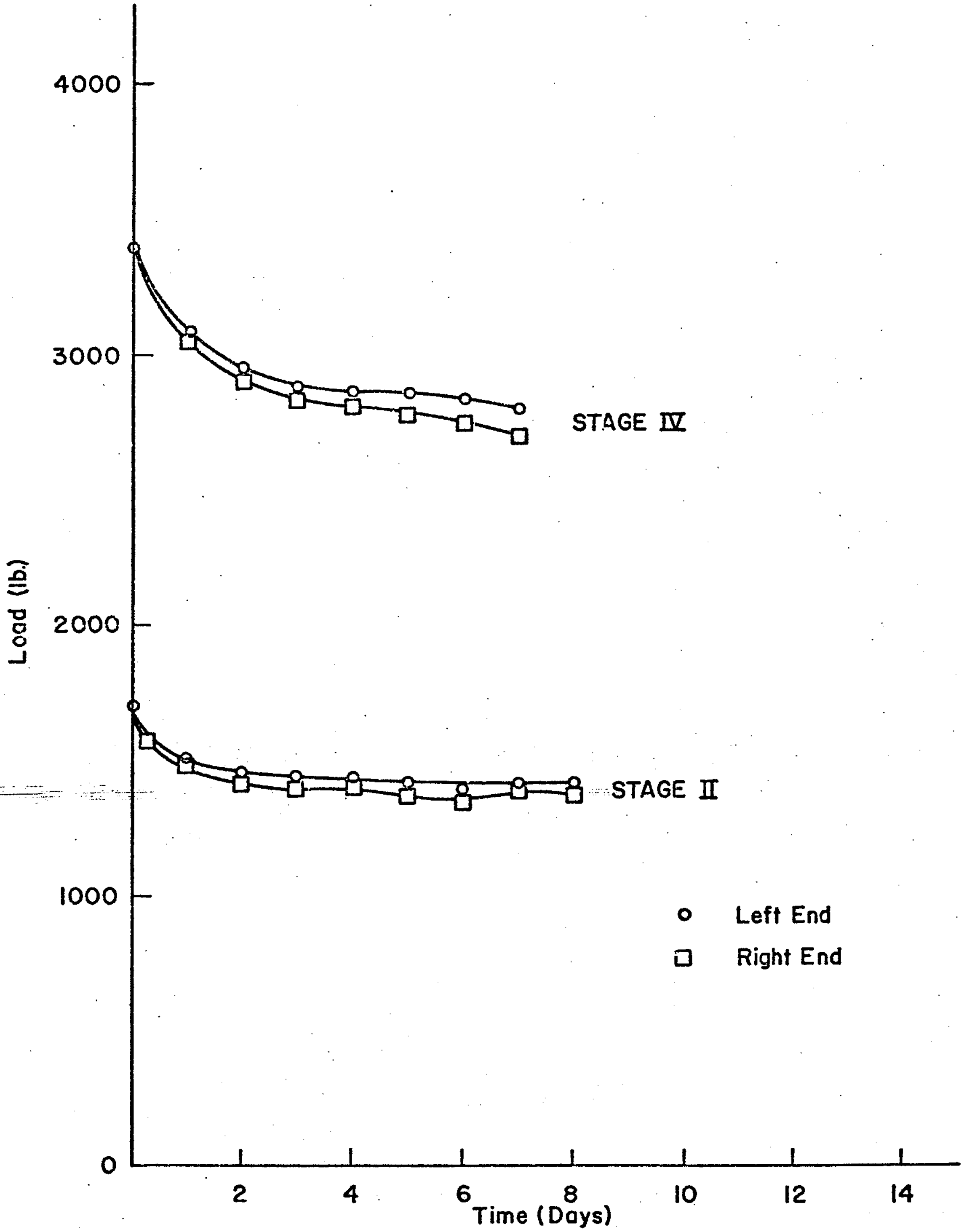


Fig. 5.1.6 Relaxation of Load, Test II.

after one week. In the first test, the relaxation at load stage II was 30% approximately. In the second test, the relaxation of load stages II and IV were 18% and 20% approximately. The first crack of the structure as shown in Fig. 5.1.7 occurred at the bottom of the particleboard beam, eight feet from the left end when the structure was loaded to stage IV in the second test. The creep recovery of the structure is shown in Fig. 5.1.8. The creep recovery was 25% approximately.

The load deflection curves of the test structure loaded continuously to failure are shown in Fig. 5.1.9. The maximum load was 2.7 times the design load approximately. The final failure of the structure is shown in Fig. 5.1.10. The structure could still carry a load of approximately 1.5 times the design load after failure.

5.2 Discussion

Having established that particleboard reinforced with fiberglass is a feasible structural medium, one of the most important factors in the development of a suitable floor system is the extent to which composite action between floor deck and beam can be relied upon. In determining the extent to which composite action is present, a number of methods are available, each of which will lead to a different assessment. The methods which can be used are as follows:

a) Taking a compressive stress in the deck of zero as 0% composite action, and a compressive stress in the deck equal to that obtained from an analysis assuming full composite action as 100%

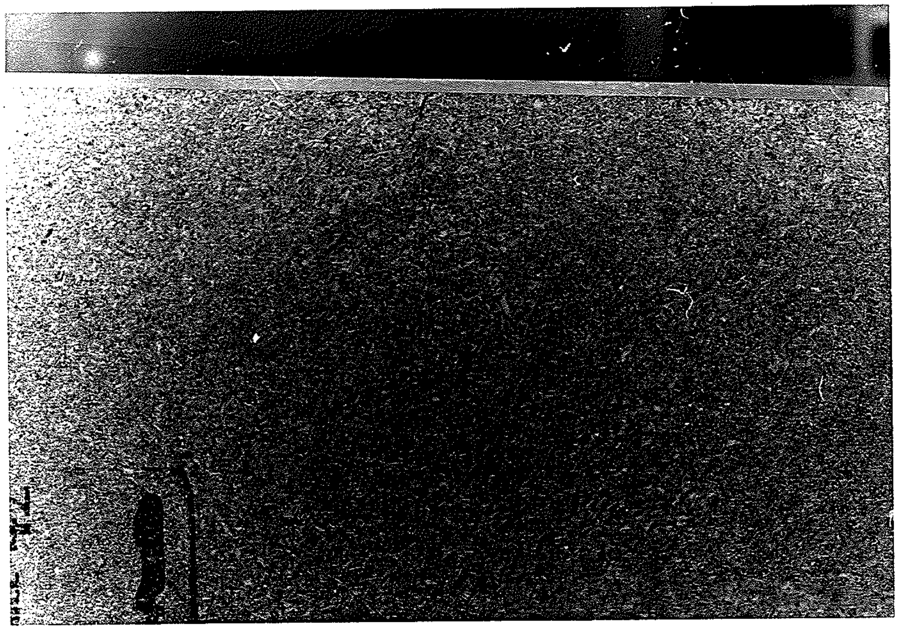


Fig. 5.1.7 - First Crack of Test Structure

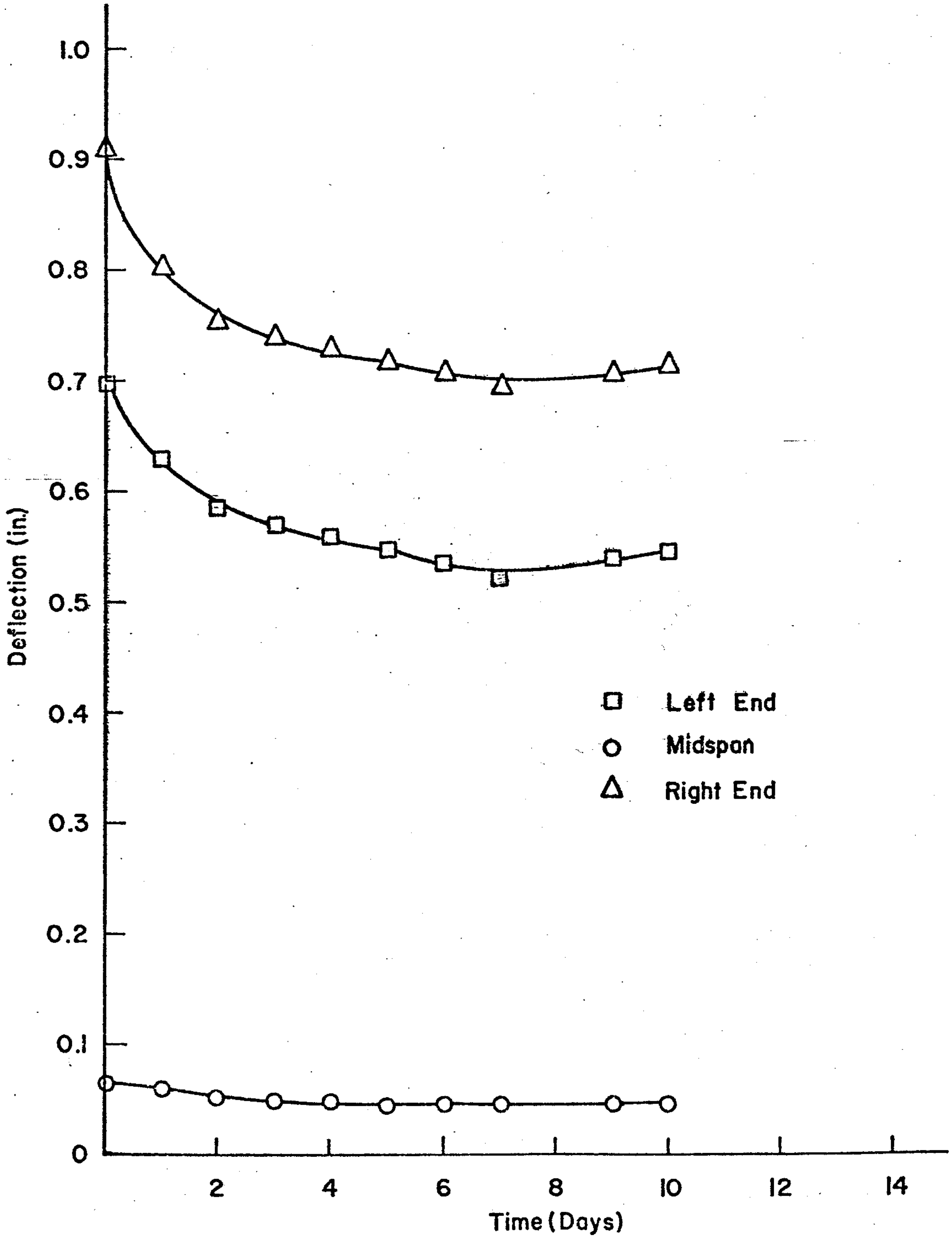


Fig. 5.1.8 Creep Recovery of Unloaded Test Structure.

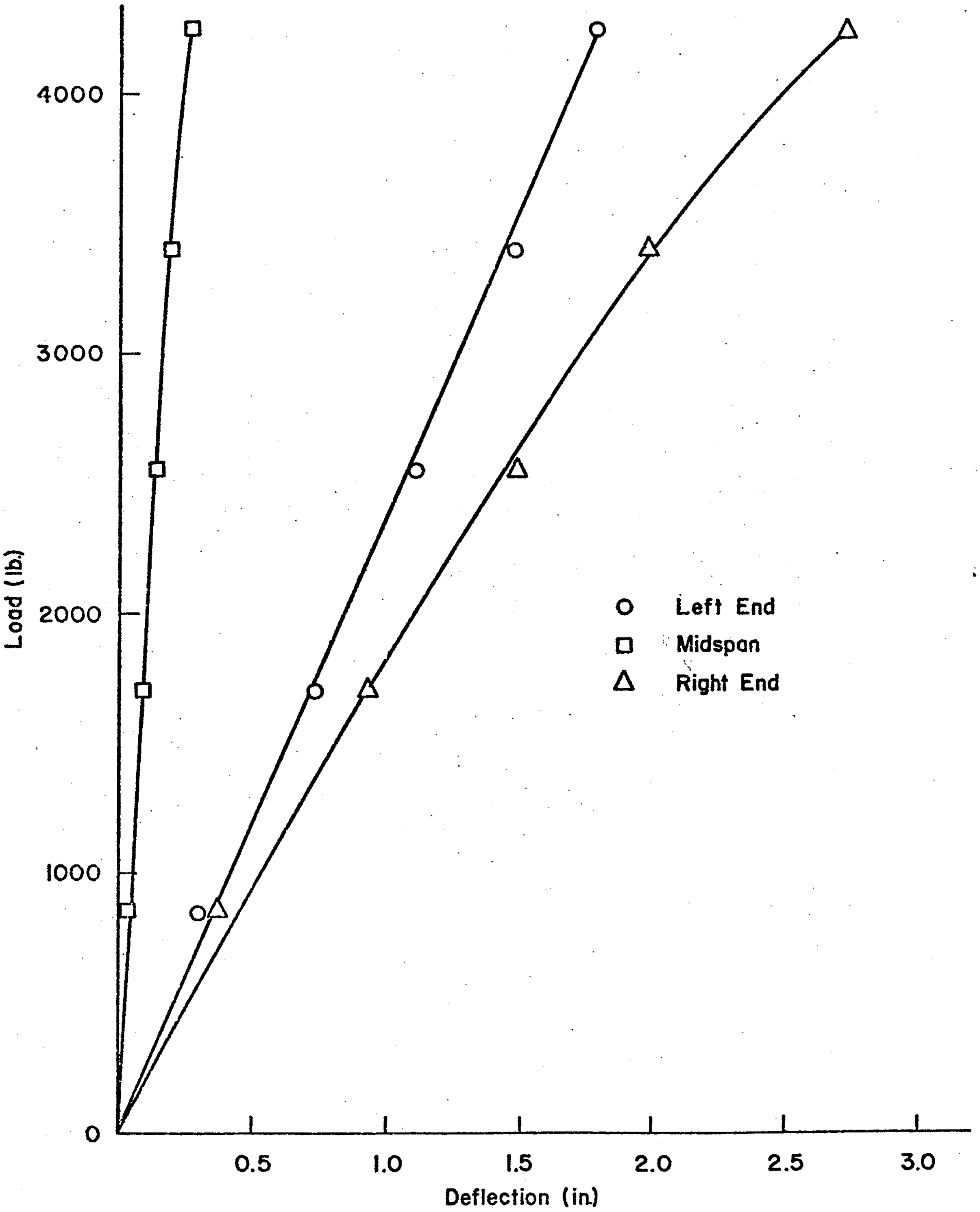


Fig. 5.1.9 Load - Deflection Curves of Test Structure.

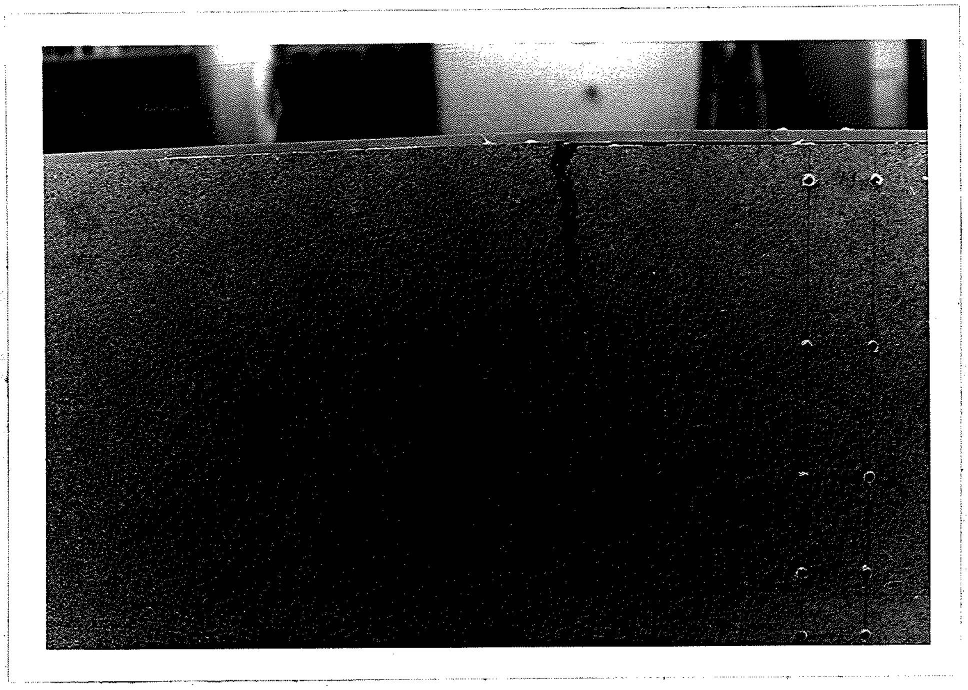


Fig. 5.1.10 - Failure of Test Structure

composite action, a determination of deck stress based on strain readings and the stress-strain diagram will lead, by interpolation, to an assessment of the precentage composite action available.

b) The contribution of the deck to the ultimate moment of resistance compared with that for a fully composite beam would also provide an assessment of the degree to which composite action was being achieved.

c) A deflection analysis can be made to assess the contribution of the deck to the stiffness of the beam. Taking composite action as 100% when the actual deflection was equal to the theoretical deflection of the fully composite floor deck and beam section, and taking composite action as zero when the actual deflection was equal to the theoretical deflection of the beam alone, the percentage of composite action can be assessed from actual deflection readings.

The first method gives an assessment of composite action based on stress considerations and is therefore related to the strength of the structure. The percentage contribution of the deck can be assessed at any load level and at a number of locations along the beam. An analysis of the test results were found to be as follows: In the first test at the left end of the beam the percentage of composite action available from the deck was 66% and 55% for loading stages I and II, respectively, while at the right hand side it was found to be 45% and 22%, and 66% and 40% at mid-span. In the second test at the left end of the beam the percentage of composite action available from the deck was 66%, 60%, 58% and 55% for loading stages I, II, III and IV, respectively, while at the right hand side it was found to be 66%, 44%, 37% and 33%, and 66%, 55%, 46% and 40% at mid-span.

The second method gives an assessment of the composite action available to resist ultimate moment. Whereas a theoretical assessment can be made of the values of the ultimate moment for the beam alone, and for the fully composite beam and deck system, it is not possible in the present investigation to make an accurate assessment of the composite action. This is because the failure was precipitated prematurely by a fiberglass-to-epoxy bond failure, and a true ultimate moment was not obtainable. An estimate of the ultimate moment of the beam alone is 21 ft.-kips. and that for the fully composite section is 26 ft.-kips. The actual failure moment was 23 ft.-kips. This leads to an assessment of 50% composite action, but the assessment is probably low.

The last method outlined above is based on deflection behaviour. As the modulus of elasticity of particleboard is considerably less than that of timber, deflections become a significant factor in the design of particleboard floor systems. Any evaluation of the percentage composite action available from the floor deck is therefore based on serviceability (as measured by deflection performance) rather than on strength. Based on this method of evaluation the percentages of composite action were found to be as follows: In the first test, the percentages composite action at load stages I and II were about 85% and 60% respectively. In the second test, the percentages of composite action at load stages I, II, III and IV were about 90%, 80%, 70% and 65%, respectively.

The choice of which method to use in design would depend upon whether strength or deflection were being considered. The most suitable solution to this dilemma, of course, it the development of a non-slip joist-to-beam connection permitting 100% composite action.

The movement of the location of the neutral axis under increasing load can be explained as follows: It can be seen from stress-strain curves of particleboard and fiberglass that the proportional limit range of particleboard is considerably less than the proportional limit range of fiberglass. In the structure, when the stress in the particleboard has just reached the proportional limit, the stress in the fiberglass is still well within the proportional limit. The modulus of elasticity of particleboard is reduced, but the modulus of elasticity of fiberglass remains constant as the load is increased. Consequently, the fiberglass becomes a more significant structural component as the load increases. For this reason, the neutral axis shown in Fig. 5.1.1 to 5.1.4 shifts lower in the beam with increasing load. After unloading, the neutral axis moved almost to the level of fiberglass because of creep which had taken place in the particleboard. That is, deflection recovery was much greater in the fiberglass than the particleboard, as the stress level in the fiberglass was still below the proportional limit. As expected, it was found from the strain readings that the particleboard creep was considerable whereas fiberglass creep was not detectable.

The particleboard cracked when the load reached stage IV in the second test. The crack occurred at the location of a particleboard joint in the bottom flange because it was the weakest point in the beam. The value of the stress at this particular location obtained from the strain reading was in the order of 700 psi. The value of stress obtained from a calculation assuming full composite action was about 600 psi. The actual stress is somewhat greater than the theoretical stress as full composite action is not available.

The load-deflection curves of the structure were quite linear because failure was due to a sudden slip of the fiberglass. The fiberglass used in the investigation contained a releasing agent which did not exhibit good bonding properties with the epoxy glue. The structure could therefore carry a greater load than the maximum load obtained from the test, if fiberglass slip had not taken place. The failure of the structure might be a buckling of the deck at the maximum moment portion or shear along the webs of the beam.

While the test structure behaved as an adequate structural unit during loading, the stresses and deflections were greater than anticipated by simple beam theory. As discussed earlier, this is due to the fact that the deck was not fully effective as a structural component acting compositely with the beam. It is recommended that structural design can be performed based on simple beam theory, but that a precise amount of composite deck-beam action cannot be relied upon. The solution to this dilemma would be to develop a sound joist-to-beam connection capable of transferring shear without slip or joist rotation. Until that time, the beam and deck should be considered as separate structural elements. In any design, of course, it is necessary to establish the values of working stress to be used for the particular materials employed in the design. This would necessitate an adequate testing programme to establish the working stress values for a wide range of particleboard types and fiberglass types.

Simple beam theory is based on the assumption of plane sections remaining plane during bending, and on the assumption that the materials involved obey Hooke's law. The validity of the first assumption is apparent from the diagram of strain distribution, from which the effect of joist-to-beam slip can also be seen. The validity of Hooke's law up to the design stresses can be seen from the stress-strain diagram of the particleboard and fiberglass. Using the mid-span strain distribution at design load, Fig. C-2.4, and the modulus of elasticity of the materials based on the stress-strain tests, the value of the internal moment of resistance was calculated to 134,400 lb.-in. The actual mid-span moment at the design load was 136,000 lb.-in. This close agreement is further evidence of the applicability of simple beam theory.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1 Conclusions

An experimental study to determine the structural integrity of a beam and floor deck system constructed from particleboard reinforced with fiberglass was undertaken following a study of the material properties. These latter tests on particleboard indicated that the values of the various properties were dependent on the orientation of the test specimen in the particleboard sheet, and on the density of the specimen. However, the values of the appropriate engineering properties of particleboard and fiberglass obtained from these tests indicated that a reasonable structural design could be performed.

The floor system designed behaved reasonably well under load, although stress levels and deflections were greater than predicted by simple beam theory assuming one structural unit consisting of deck, joist and beam acting together. It was evident both from the strain readings and the deflection readings that the deck did not form a fully composite component of the structural system. However, in general, simple beam theory is applicable as discussed in Chapter V. The lag screws used as the joist-to-beam connection were found to be an unsuitable medium for providing an adequate shear connection. During test the deck separated from the beam and the load had to be removed while the deck and floor were clamped together with steel rods. The extent to which the deck behaved as a composite part of the structure varied from 22% to 66% based on a consideration of stress levels, and from 60% to

90% based on a consideration of deflection behaviour. Generally, composite action reduced with increasing load.

Creep, which took place primarily in the particleboard, was evident in the structure at all stages of loading and was evaluated by a consideration of load relaxation at constant deflection. Creep was found to be in the order of 18% of normal design load, and in the order of 20% at twice the design load. Upon load removed creep recovery was 25%.

Although final failure was precipatated prematurely by a slip of the fiberglass, the structure was still able to carry 2.7 times the design load before failure, and after failure could still sustain a load of 1.5 times the design load.

The structure tested proved to be a very adequate load-carrying system of potential use in house construction. Further refinements of fabrication technique, analysis and design would result in improved structural behaviour and economy.

6.2 Recommendations for Future Work

As the particleboard and fiberglass composite action represents a new structural medium, there are many topics requiring investigation. Some topics on consequence are:

i) A classification of the various types of particleboard or chipboard, and a comprehensive investigation into the material properties. Also, some additional information on the properties of the various types of fiberglass.

ii) An investigation of the joist-beam interface and the development of a suitable shear-transfer connection.

iii) The development of particleboard wall panels for house construction.

iv) The use of fiberglass as a medium for providing continuity in particleboard rigid frame construction.

v) The fire resistance of particleboard structural elements reinforced with fiberglass.

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APPENDIX A

PRELIMINARY TEST RESULTS

A-1 Particleboard

TABLE A-1.1

Tension Parallel to Surface (3/4" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	f_{tp}//ult. psi.	ε ult. in./in.	E_p 1000 psi.
1	0.02853	1010	0.004308	287
2	0.02704	847	0.003730	290
3	0.02803	952	0.004208	320
4	0.02793	824	0.003287	318
5	0.02712	882	0.002714	364
6	0.02745	766	0.002689	300
7	0.02763	970	0.003785	325
8	0.02737	870	0.003785	300
9	0.02754	947	0.003685	356
10	0.02795	944	0.003924	312
11	0.02785	783	0.003013	324
12	0.02831	1029	0.003969	340
Average	0.02773	902	0.003591	320

TABLE A-1.2

Tension Parallel to Surface (1/2" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	f_{tp}//ult. psi.	ε ult. in./in.	E_p 1000 psi.
1	0.02825	1124	0.004567	335
2	0.02869	1165	0.004856	360
3	0.02730	966	0.003735	360
4	0.02862	1067	0.003745	400
5	0.02868	1192	0.004532	400
6	0.02833	1064	0.003093	410
7	0.02816	1167	0.004059	410
8	0.02828	1001	0.004522	335
Average	0.02829	1093	0.004139	376

TABLE A-1.3

Tension Parallel to Surface (3/4" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

Specimen No.	D $lb./in.^3$	$f_{tp\parallel}$ ult. psi.	ε ult. in./in.	E_p 1000 psi.
1	0.02672	727	0.003546	246
2	0.02696	697	0.004532	200
3	0.02655	727	0.004233	215
4	0.02660	665	0.003320	250
5	0.02729	699	0.002988	270
6	0.02690	581	0.003088	195
7	0.02639	585	0.003217	230
8	0.02650	596	0.003536	210
9	0.02692	725	0.004313	235
Average	0.02676	667	0.003641	228

TABLE A-1.4

Tension Parallel to Surface (1/2" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{tp\parallel}$ ult. psi.	ε ult. in./in.	E_p 1000 psi.
1	0.02674	870	0.003320	330
2	0.02697	845	0.003411	380
3	0.02716	733	0.002448	380
Average	0.02696	816	0.003060	363

TABLE A-1.5

Tension Perpendicular to Surface (3/4" Particleboard)

Specimen No.	Weight gm.	$f_{tp\perp}$ ult. psi.
1	106	48
2	110	44
3	110	50
4	107	44
5	107	48
6	108	44
7	111	45
8	114	49
9	111	46
10	112	46
Average		46

TABLE A-1.6

Tension Perpendicular to Surface (1/2" Particleboard)

Specimen No.	Weight gm.	$f_{tp\perp}$ ult. psi.
1	106	112
2	96	100
3	102	98
4	98	116
5	100	97
6	97	96
Average		103

TABLE A-1.7

Compression Parallel to Surface (3/4" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{cp//}$ ult. psi.	ε ult. in./in.	E_p 1,000 psi.
1	0.02748	2074	0.017131	250
2	0.02684	2050	0.016235	280
3	0.02721	2033	0.015687	310
4	0.02710	1844	0.012550*	300
5	0.02672	1809	0.017181	245
6	0.02729	1877	0.018302	300
7	0.02767	2079	0.018277	285
8	0.02646	1854	0.012649*	280
9	0.02782	2160	0.017679	252
10	0.02815	2246	0.016185*	335
11	0.02812	2071	0.010956*	340
12	0.02810	2070	0.014392*	335
13	0.02679	1870	0.014069	310
14	0.02686	1997	0.017953	300
15	0.02794	2172	0.011752*	320
16	0.02729	1925	0.018376	315
Average	0.02737	2008	0.015586	297

* Failures outside gauge length

TABLE A-1.8

Compression Parallel to Surface (1/2" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{cp\parallel}$ ult. psi.	ε ult. in./in.	E_p 1000 psi.
1	0.02871	2526	0.015563*	342
2	0.02799	2406	0.014442*	340
3	0.02930	2749	0.019396	400
4	0.02816	2193	0.011006*	360
5	0.02817	2406	0.017330*	315
6	0.02855	2506	0.019396	330
7	0.02901	2439	0.017628	380
Average	0.02856	2461	0.016394	352

*Failures outside gauge length

TABLE A-1.9

Compression Parallel to Surface (3/4" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{cp//}$ ult. psi.	ε ult. in./in.	E_p 1000 psi.
1	0.02712	1634	0.009818*	260
2	0.02679	1666	0.013296*	240
3	0.02673	1679	0.016583	210
4	0.02623	1588	0.016557	210
Average	0.02672	1642	0.014064	230

* Failures outside gauge length

TABLE A-1.10

Compression Parallel to Surface (1/2" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{cp\parallel}$ ult. psi.	ε ult. in./in.	E_p 1000 psi.
1	0.02690	2055	0.011428*	332
2	0.02734	1987	0.008021*	335
3	0.02706	1975	0.008872*	335
4	0.02705	2099	0.018300	300
5	0.02733	2092	0.008491*	330
Average	0.02714	2042	0.011022	326

* Failures outside gauge length

TABLE A-1.11

Compression Perpendicular to Surface (3/4" Particleboard)

Specimen No.	D lb./in.^{3}	$f_{cp\perp}$ ult. psi.
1	0.02656	4514
2	0.02675	4518
3	0.02674	4805
4	0.02646	4368
5	0.02612	4509
6	0.02499	4204
7	0.02643	4549
8	0.02727	4872
9	0.02531	4405
10	0.02617	4819
Average	0.02628	4556

TABLE A-1.12

Compression Perpendicular to Surface (1/2" Particleboard)

Specimen No.	D lb./in.^{3}	$f_{cp\perp}$ ult. psi.
1	0.02710	6979
2	0.02851	8097
3	0.02822	7282
4	0.02703	7517
5	0.02700	7573
Average	0.02757	7490

TABLE A-1.13

Shear Parallel to Surface (3/4" Particleboard)

Specimen No.	Weight gm.	$f_{vp\parallel}$ ult. psi.
1	124	205
2	132	237
3	128	211
4	130	236
5	129	232
6	129	237
7	127	224
8	134	260
9	127	211
10	122	260
11	132	252
12	123	234
13	122	248
14	127	222
15	131	237
16	125	226
17	118	218
18	130	232
19	129	258
20	130	231
Average		234

TABLE A-1.14

Shear Parallel to Surface (1/2" Particleboard)

Specimen No.	Weight gm.	$f_{vp/\!/}$ ult. psi.
1	121	365
2	124	338
3	119	347
4	120	355
5	124	352
6	121	314
7	114	335
8	118	327
9	117	343
10	123	313
11	121	350
12	116	373
Average		343

TABLE A-1.15

Shear Perpendicular to Surface Type I (3/4" Particleboard)

Specimen No.	Weight gm.	$f_{vp\perp}$ ult. psi.
1	102	841
2	104	927
3	107	987
4	100	884
5	100	835
Average		895

TABLE A-1.16

Shear Perpendicular to Surface Type I (1/2" Particleboard)

Specimen No.	Weight gm.	$f_{vp\perp}$ ult. psi.
1	124	986
2	120	1175
3	125	1097
Average		1086

TABLE A-1.17

Shear Perpendicular to Surface Type II (3/4" Particleboard)

Specimen No.	Weight gm.	$f_{vp\perp}$ ult. psi.
1	129	1073
2	130	1193
3	128	1106
4	130	1136
5	129	1184
Average		1138

TABLE A-1.18

Shear Perpendicular to Surface Type II (1/2" Particleboard)

Specimen No.	Weight gm.	$f_{vp\perp}$ ult. psi.
1	119	1584
2	118	1633
3	117	1450
4	118	1529
5	117	1477
Average		1535

TABLE A-1.19

Flexure Parallel to Surface (3/4" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{bp\parallel}$ PL. psi.	$f_{bp\parallel}$ ult. psi.	E_p 1,000 psi.
1	0.02694	846	1652	273
2	0.02736	838	1548	269
Average	0.02715	842	1600	271

TABLE A-1.20

Flexure Parallel to Surface (1/2" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{bp\parallel}$ PL. psi.	$f_{bp\parallel}$ ult. psi.	E_p 1,000 psi.
1	0.02714	1107	1826	313
2	0.02691	1101	1803	305
Average	0.02703	1104	1814	309

TABLE A-1.21

Flexure Parallel to Surface (3/4" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{bp//}$ PL. psi.	$f_{bp//}$ ult. psi.	E_p 1,000 psi.
1	0.02646	710	1318	222
2	0.02616	688	1248	227
Average	0.02631	699	1283	224

TABLE A-1.22

Flexure Parallel to Surface (1/2" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{bp//}$ PL. psi.	$f_{bp//}$ ult. psi.	E_p 1,000 psi.
1	0.02617	830	1467	239
2	0.02642	858	1549	249
Average	0.02630	844	1508	244

TABLE A-1.23

Flexure Perpendicular to Surface (3/4" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{bp\perp}$ PL. psi.	$f_{bp\perp}$ ult. psi.	E_p 1,000 psi.
1	0.02669	969	1912	363
2	0.02667	941	1830	375
Average	0.02668	955	1871	369

TABLE A-1.24

Flexure Perpendicular to Surface (1/2" Particleboard)

Long Dimension of Specimen Parallel to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{bp\perp}$ PL. psi.	$f_{bp\perp}$ ult. psi.	E_p 1,000 psi.
1	0.02729	980	2043	439
2	0.02668	956	1967	401
Average	0.02699	968	2005	420

TABLE A-1.25

Flexure Perpendicular to Surface (3/4" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

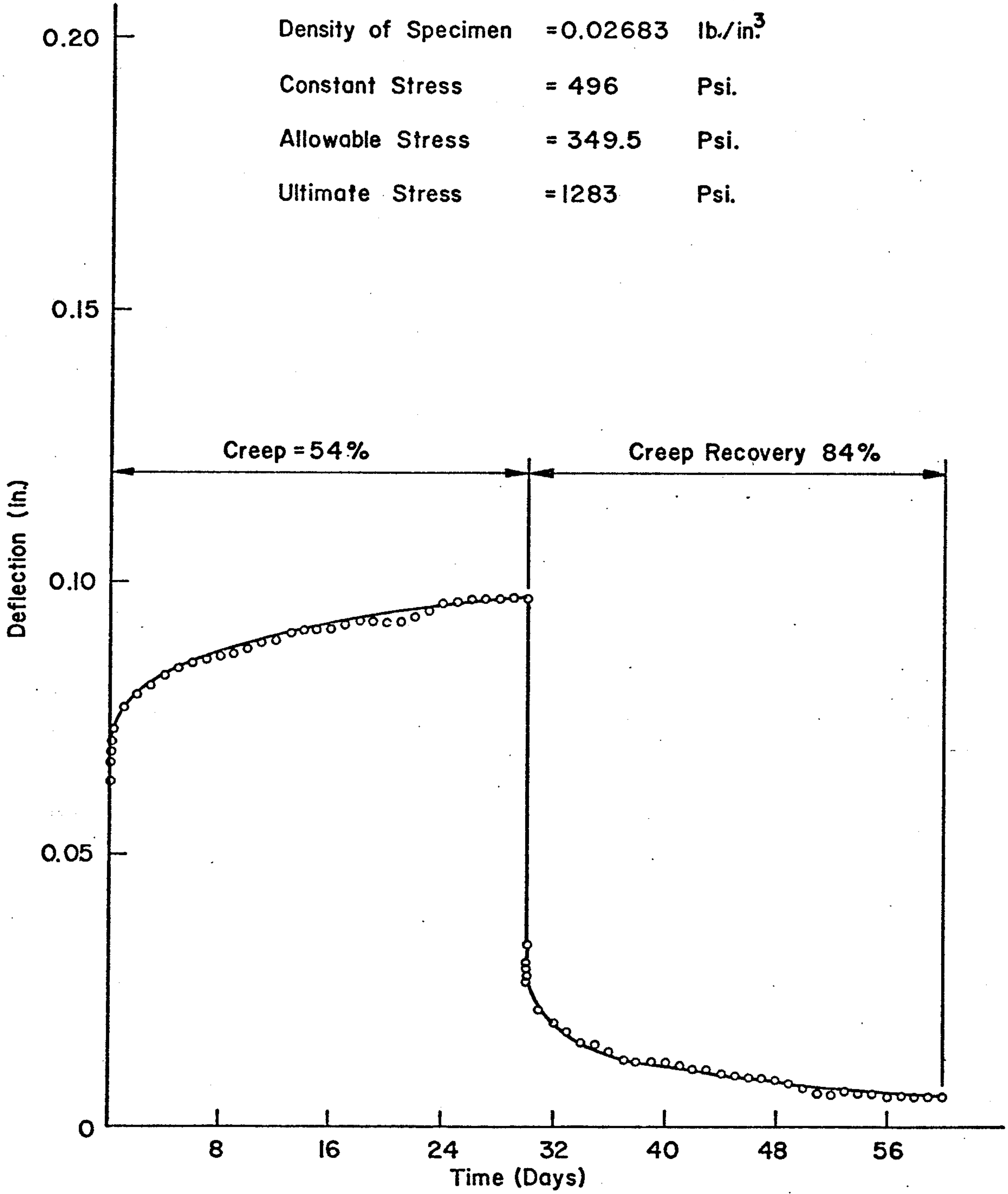
Specimen No.	D lb./in.^{3}	$f_{bp\perp}$ PL. psi.	$f_{bp\perp}$ ult. psi.	E_p 1,000 psi.
1	0.02655	904	1782	345
2	0.02680	902	1804	343
Average	0.02668	903	1793	344

TABLE A-1.26

Flexure Perpendicular to Surface (1/2" Particleboard)

Long Dimension of Specimen Transverse to Long Dimension of Particleboard

Specimen No.	D lb./in.^{3}	$f_{bp\perp}$ PL. psi.	$f_{bp\perp}$ ult. psi.	E_p 1,000 psi.
1	0.02645	911	1794	353
2	0.02632	909	1764	367
Average	0.02639	910	1779	360



Density of Specimen =0.02683 lb./in.^{3}

Constant Stress = 496 Psi.

Allowable Stress = 349.5 Psi.

Ultimate Stress =1283 Psi.

Fig. A-1.1 Creep Parallel to Surface (3/4" Particleboard).

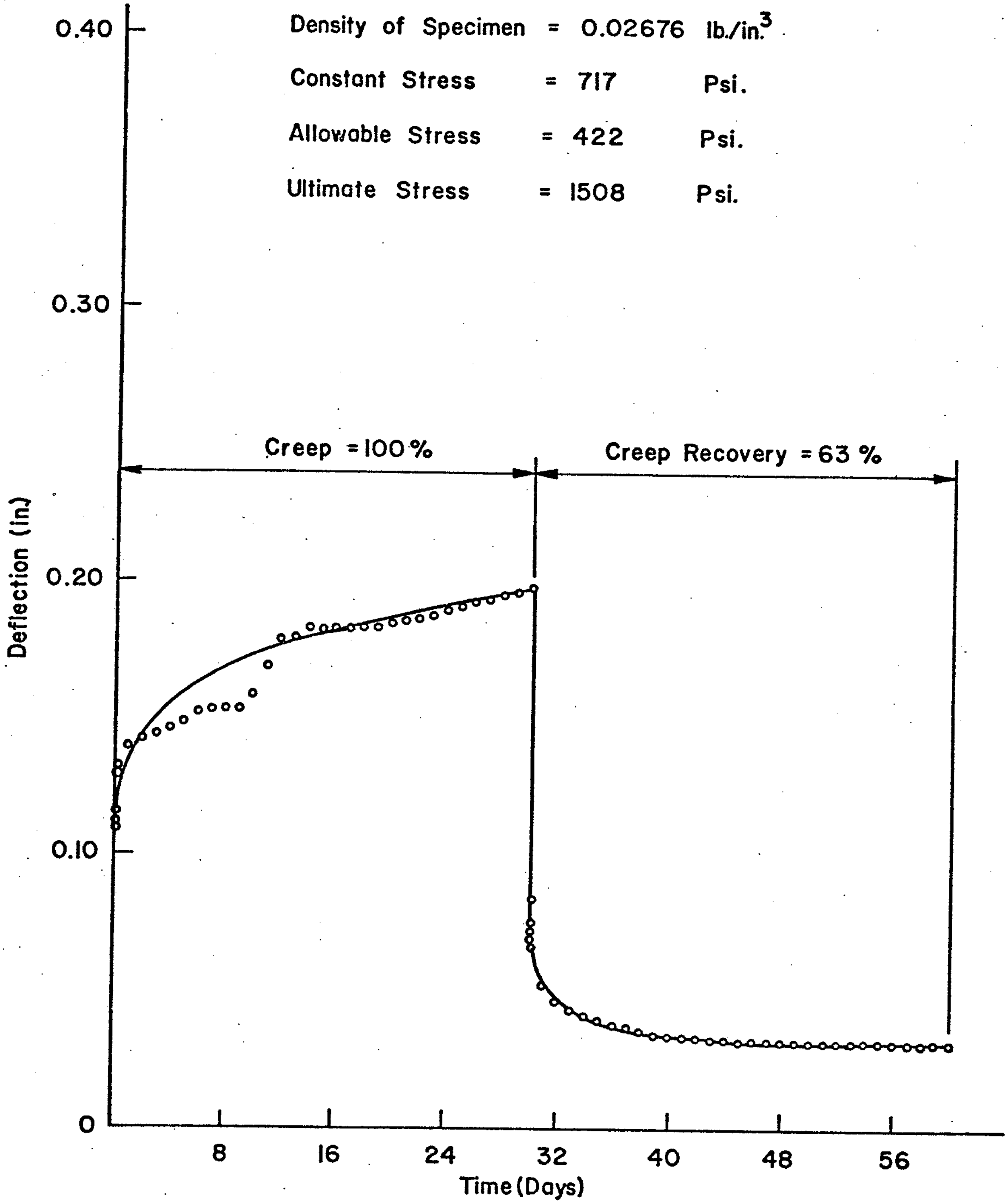


Fig. A-1.2 Creep Parallel to Surface (½" Particleboard).

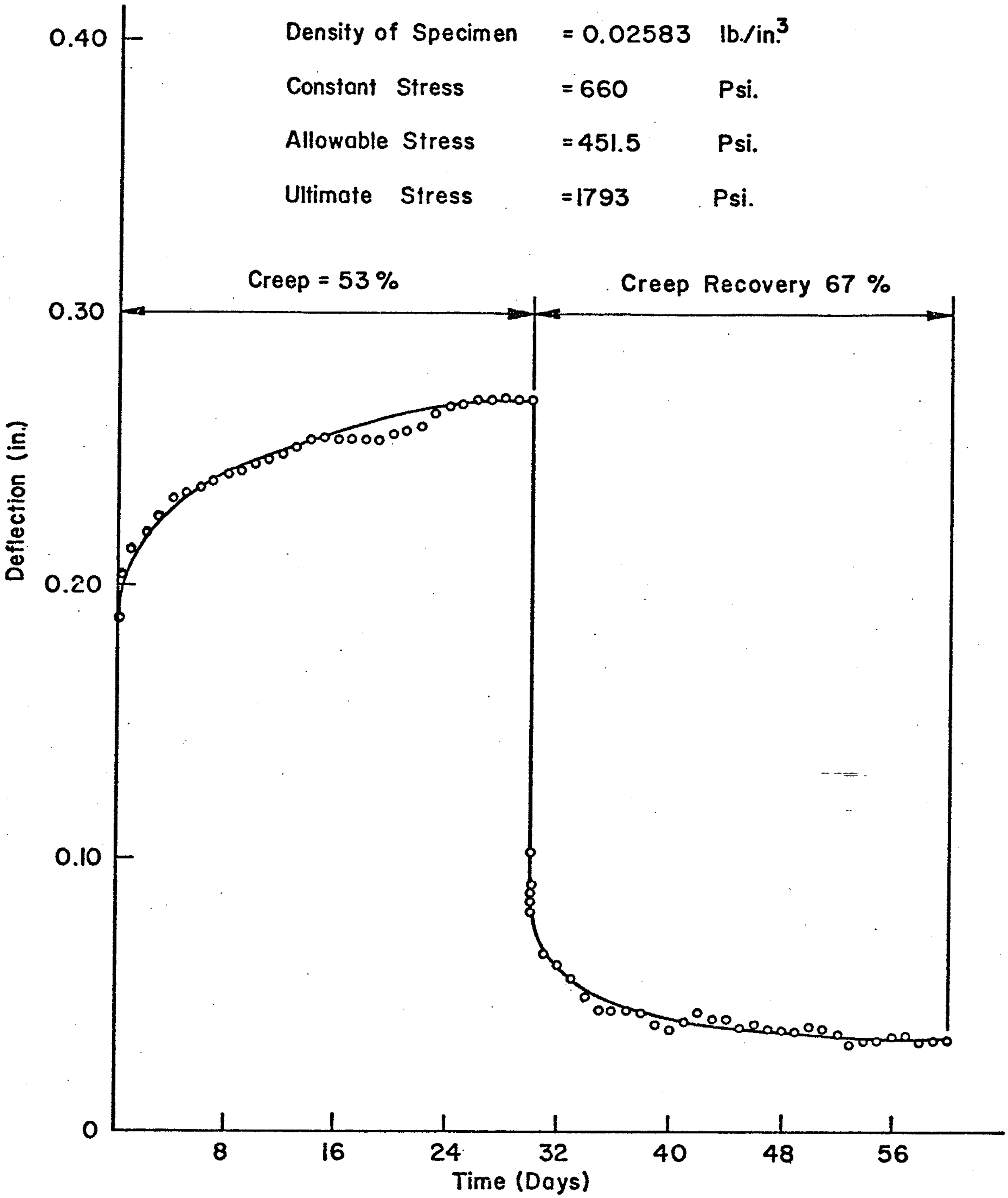


Fig. A-1.3 Creep Perpendicular to Surface (3/4" Particleboard).

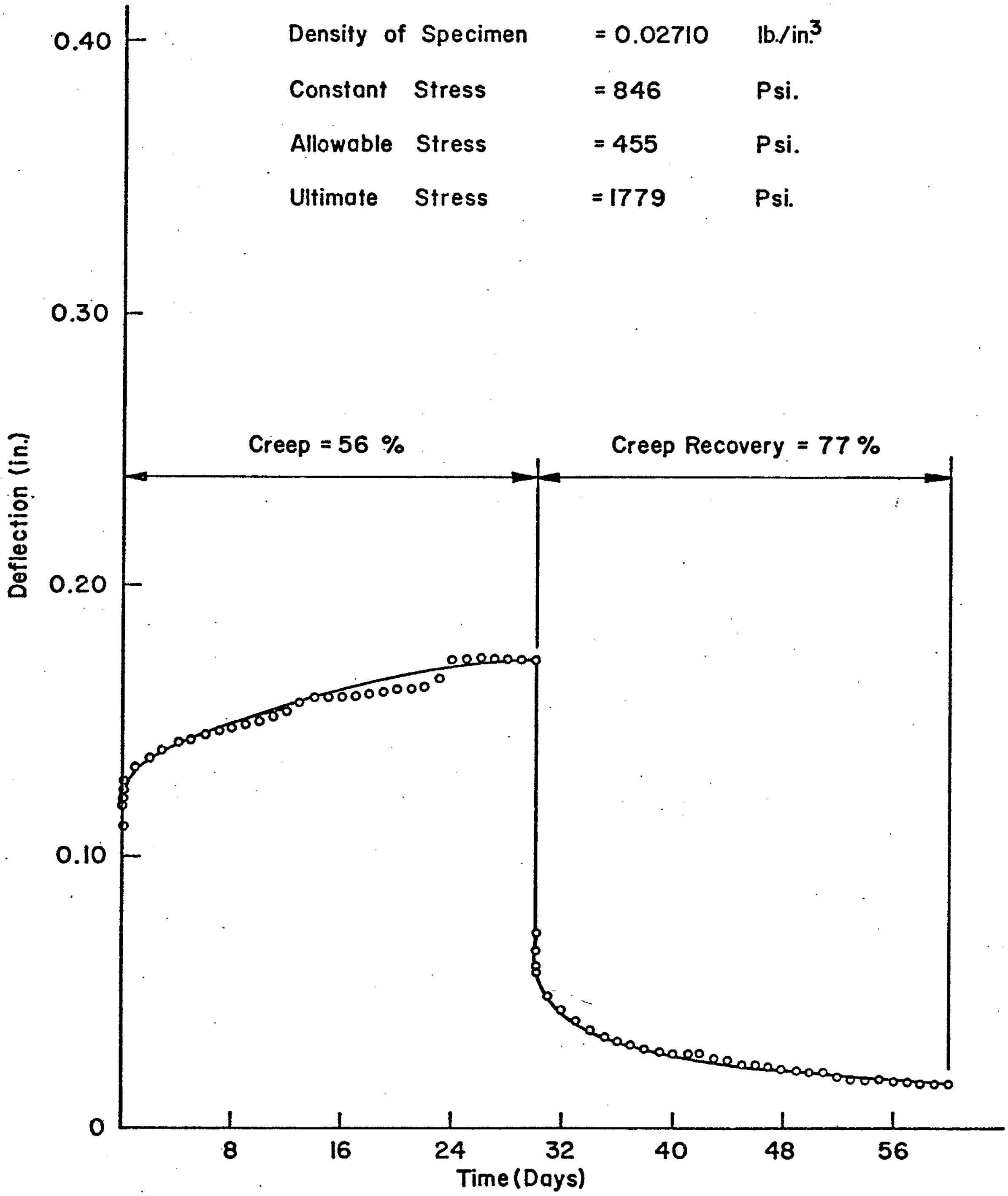


Fig. A—1.4 Creep Perpendicular to Surface ($\frac{1}{2}$" Particleboard).

A-2 Fiberglass

TABLE A-2.1

Tension Parallel to Surface

Specimen No.	$f_{tf\parallel}$ ult. 1,000 psi.	E_f 10,000 psi.
1	92	635
2	93	625
3	91	620
4	91	625
5	95	620
Average	92	625

A.3 Glue

TABLE A-3.1

Bond Strength Between Two Particleboard Pieces

Specimen No.	U_{pp} ult. psi.
1	556
2	522
3	492
4	496
5	553
Average	524

TABLE A-3.2

Bond Strength Between Particleboard and Fiberglass

Specimen No.	U_{pf} ult. psi.
1	953
2	911
3	806
4	910
5	865
Average	889

TABLE A-3.3

Bond Strength Between Two Fiberglass Pieces

Specimen No.	U_{ff} ult. psi.
1	570
2	580
3	432
4	435
5	502
Average	504

APPENDIX B

STRUCTURAL PROPERTIES

B-1 Section Design

The dead load and live load that used were as follows:

Live load on floor deck = 100 psf.

Live load on joist section = 1,000 lb. over an area of 2 1/2 x 2 1/2 ft^2.

Live load on floor-beam system = 50 psf.

Dead load of particleboard = 0.028 pcf.

Dead load of fiberglass = 0.07 pcf.

The span length and size of the various sections were assumed as follows:

Spacing of joists = 16 in.

Span length of joists = 4 ft.

Span length of beam = 20 ft.

Thickness of floor deck = 0.75 in.

Section of joists = 2.25 x 4 in^2.

Section of Beam = 3.25 x 16 in^2.

Floor deck design

$$DL. = 0.028 \times 0.75 \times 48 = 1.0 \text{ lb./in.}$$

$$LL. = \frac{100 \times 48}{144} = 33.4 \text{ lb./in.}$$

$$\text{Total Load} = 34.4 \text{ lb./in.}$$

$$I_{NA} = \frac{48 \times 0.75^3}{12} = 1.688 \text{ in}^4.$$

$$S_m = \frac{48 \times 0.75^2}{6} = 4.5 \text{ in}^3.$$

$$Q_{NA} = 0.375 \times 48 \times 0.1875 = 3.375 \text{ in}^3.$$

$$M_{max.} = \frac{34.4 \times 16^2}{10} = 880.64 \text{ lb.-in.}$$

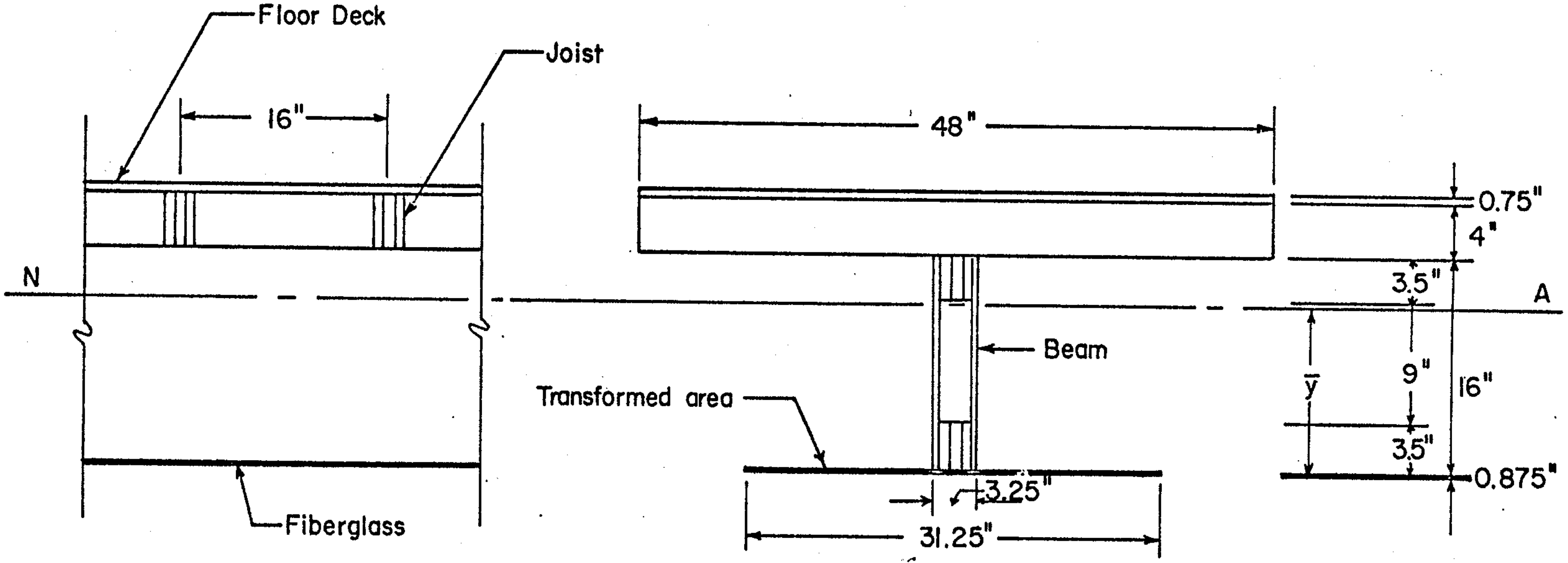


Fig. B-1.1 Floor - Beam Design Section.

$$f_b\text{max.} = \frac{880.64}{4.5} = 195.7 \text{ psi} < f_b\text{all.} = 349.5 \text{ psi.}$$

$$V \text{ max.} = 1.1 \times 33.4 \times 16 = 587.84 \text{ lb.}$$

$$f_v \text{ max.} = \frac{587.84 \times 3.375}{1.688 \times 48} = 24.5 \text{ psi.} < f_v\text{all.} = 117 \text{ psi.}$$

$$\Delta \text{ max.} = \frac{0.0069 \times 34.4 \times 16^4}{224{,}000 \times 1.688} = 0.041 \text{ in.}$$

$$\Delta \text{ all.} = \frac{16}{360} = 0.044 \text{ in.}$$

Section is O.K.

Joist design

DL. = 0.59 lb./in.

LL. = 17.78 lb./in.

Total load = 18.37 lb./in.

$$\bar{y} = \frac{(16 \times 0.75 \times 4.375) + (2.25 \times 4 \times 2)}{21} = 3.357 \text{ in.}$$

$$I_{NA} = \left[\left(\frac{16 \times 0.75^3}{12}\right) + (16 \times 0.75 \times 1.018^2)\right] + \left[\left(\frac{2.25 \times 4^3}{12}\right) + (2.25 \times 4 \times 1.357^2)\right] = 41.571 \text{ in.}^4$$

$$M \text{ max.} = 275.55 \left(8 + \frac{275.55}{2 \times 18.37}\right) = 4271.025 \text{ lb.-in.}$$

$$f_b \text{ max.} = \frac{4271.025 \times 3.357}{41.571} = 344.9 \text{ psi} < f_b\text{all.} = 349.5 \text{ psi.}$$

$$V \text{ max.} = \frac{18.37 \times 30}{2} = 275.55 \text{ lb.}$$

$$f_v \text{ max.} = \frac{275.55 \times 12.678}{41.571 \times 2.25} = 37.4 \text{ psi.} < f_v\text{all.} = 117 \text{ psi.}$$

$$\Delta \text{ max.} = \frac{889119.394}{224{,}000 \times 41.571} = 0.096 \text{ in.}$$

$$\Delta \text{ all.} = \frac{48}{360} = 0.13 \text{ in.}$$

Section is O.K.

Floor-beam design

DL. = 2.1 lb./in.

LL. = 16.67 lb./in.

Total load = 18.77 lb./in.

TABLE B-1.1

Section Properties

Section	A in.^{2}	y in.	Ay in.^{3}	I in.^{4}	y_1 in.	Ay_1^2 in.^{4}
Top floor	36	20.75	747	1.6875	7.976	2290.197
Top flange	7.875	14.625	115.172	8.039	1.851	26.981
Bottom flange	7.875	2.125	16.734	8.039	10.649	893.034
Webs	16	8.375	134	341.333	4.399	309.619
Fiberglass	11.719	0.1875	2.197	0.1373	12.5865	1856.524
Total	79.469		1015.103	359.236		5376.355

$$\bar{y} = \frac{1015.103}{79.469} = 12.774 \text{ in.}$$

$$I_{NA} = 359.236 + 5376.355 = 5735.591 \text{ in.}^4$$

$$Q_{NA} = (36 \times 7.976) + (7.875 \times 1.851) + (3.601 \times 1.8005)$$

$$= 308.196 \text{ in.}^3$$

$$M \text{ max.} = \frac{18.77 \times (20 \times 12)^2}{8} = 135144 \text{ lb.-in.}$$

$$\text{Equivalent point load} = \frac{135144}{80} = 1689.3 \simeq 1700 \text{ lb.}$$

$$M \text{ max.} = 1700 \times 80 = 136000 \text{ lb.-in.}$$

$$f_b \text{ max.} = \frac{136000 \times 12.399}{5735.591} = 294 \text{ psi (in particleboard)}$$

$$f_b \text{ all.} = 349.5 \text{ psi.}$$

$$f_b \text{ max.} = \frac{136000 \times 12.774 \times 25}{5735.591} = 7572.3 \text{ psi. (in fiberglass)}$$

V max. = 1700 lb.

$$f_V \text{ NA} = \frac{1700 \times 308.196}{5735.591 \times 1} = 91.4 \text{ psi} < f_v\text{all.} = 117 \text{ psi.}$$

$$\Delta \text{ max.} = \frac{23 \times 1700 \times (20 \times 12)^3}{648 \times 224000 \times 5735.591} = 0.649 \text{ in.}$$

$$\Delta \text{ all.} = \frac{20 \times 12}{360} = 0.667 \text{ in.}$$

Section in O.K.

Horizontal shear force at interface between joist and beam

$$\text{H max.} = \frac{1700 \times 287.136 \times 16}{5735.591} = 1361.69 \text{ lb. at each joist}$$

Use lag screws 3/8" dia. 7 in. long

$$\text{No. of lag screws} = \frac{1361.69}{320} = 4.26$$

Use one lag screw at each joist and use four extra lag screws between joists in the maximum shear portion.

B-2 Lag Screw

TABLE B-2.1

Single Shear Between Lag Screw and Particleboard

Specimen No.	PL. Load (lb.)	Ult. Load (lb.)
1	650	1137
2	625	1110
3	650	1112
4	650	1232
5	625	1162
Average	640	1150

APPENDIX C

STRUCTURAL TEST RESULTS

C-1 Test I

TABLE C-1.1

Slip Between Fiberglass and Particleboard Beam

Loading Condition	Left End (in.)	Midspan (in.)	Right End (in.)
No Load	0	0	0
Stage I	0.0001	0.0009	0.0003
Stage II	0.0004	0.0023	0.0007
Stage II after 6 days	0.0004	0.0020	0.0008
Unloaded	0.0001	0.0003	0.0004

TABLE C-1.2

Slip Between Joist and Beam

Loading Condition	Left End (in.)	Right End (in.)
No load	0	0
Stage I	0.0144	0.0589
Stage II	0.0469	0.3184
Stage II after 6 days	0.0482	0.3184
Unloaded	0.0252	0.1484

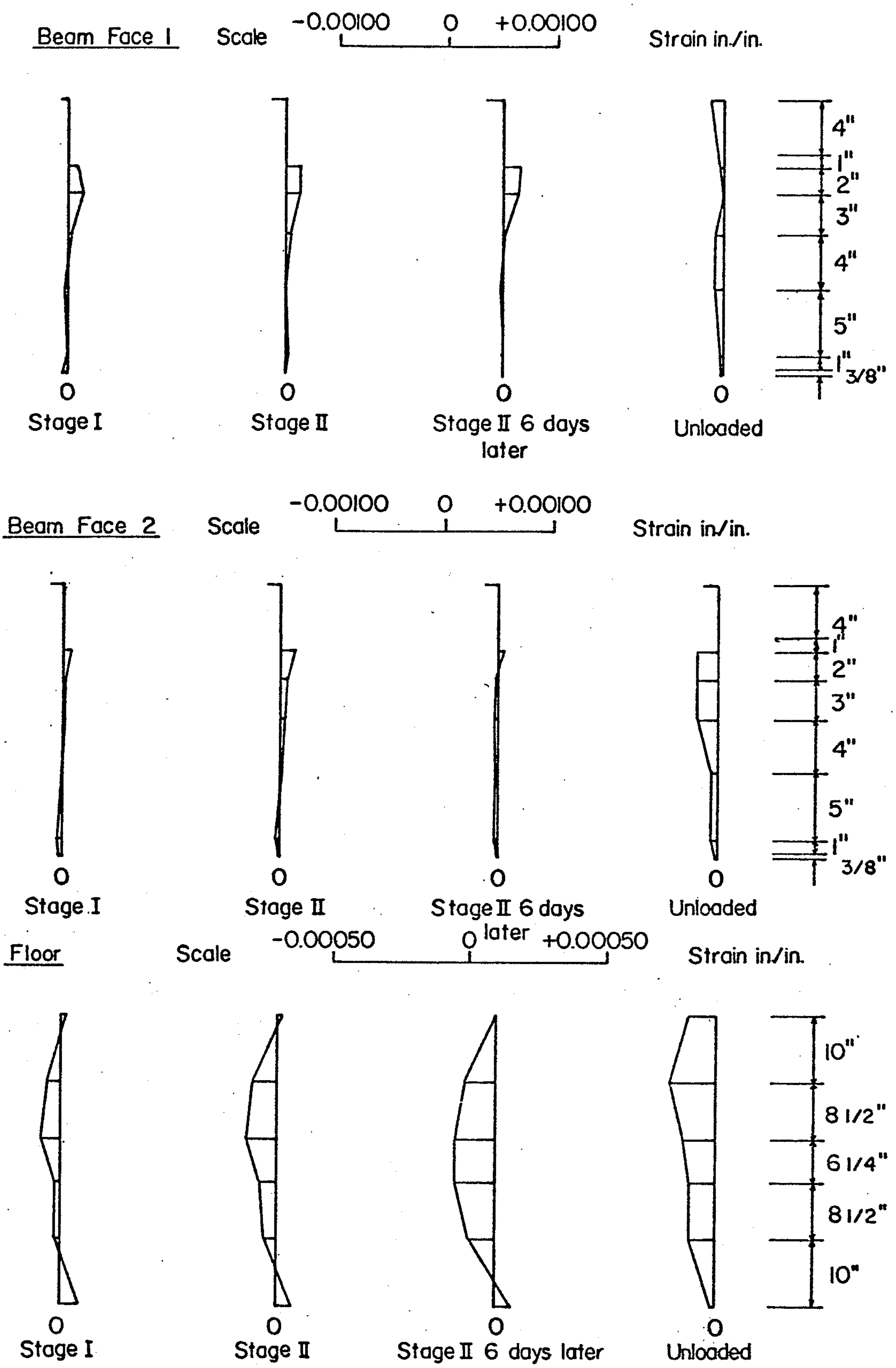


Fig. C-1.1 STRAIN VARIATION AT LOCATION I.

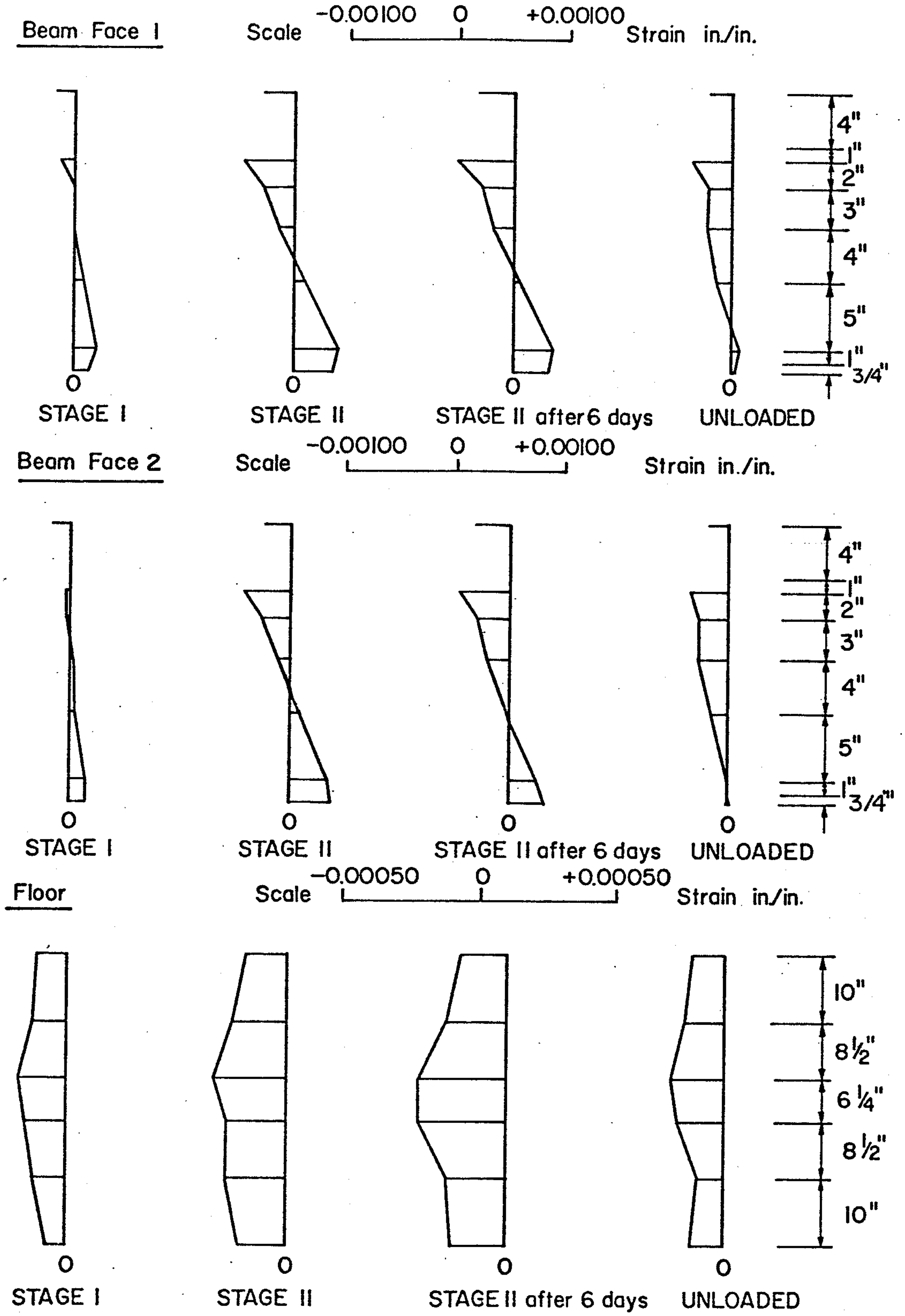
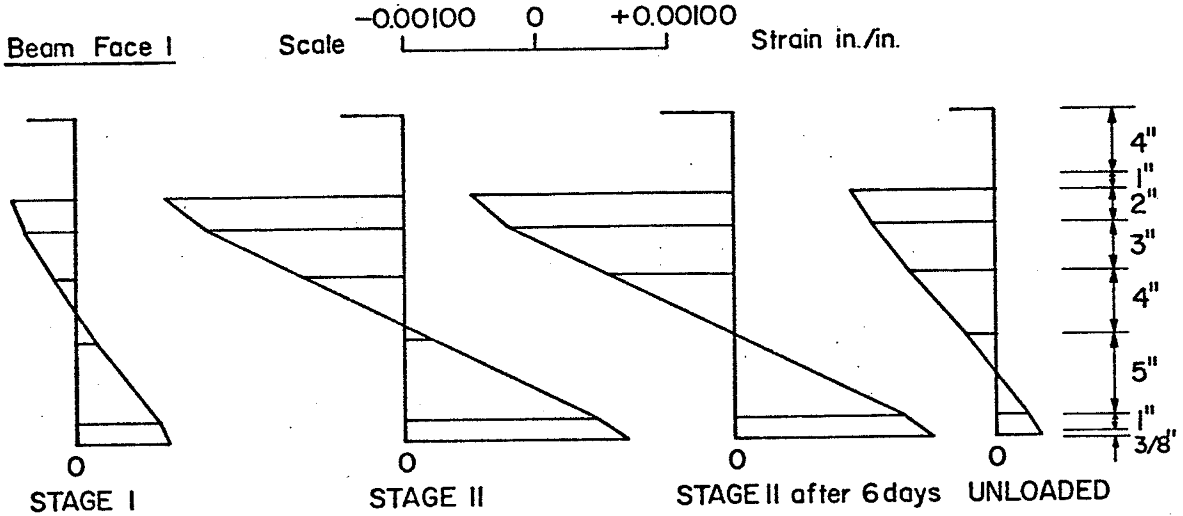
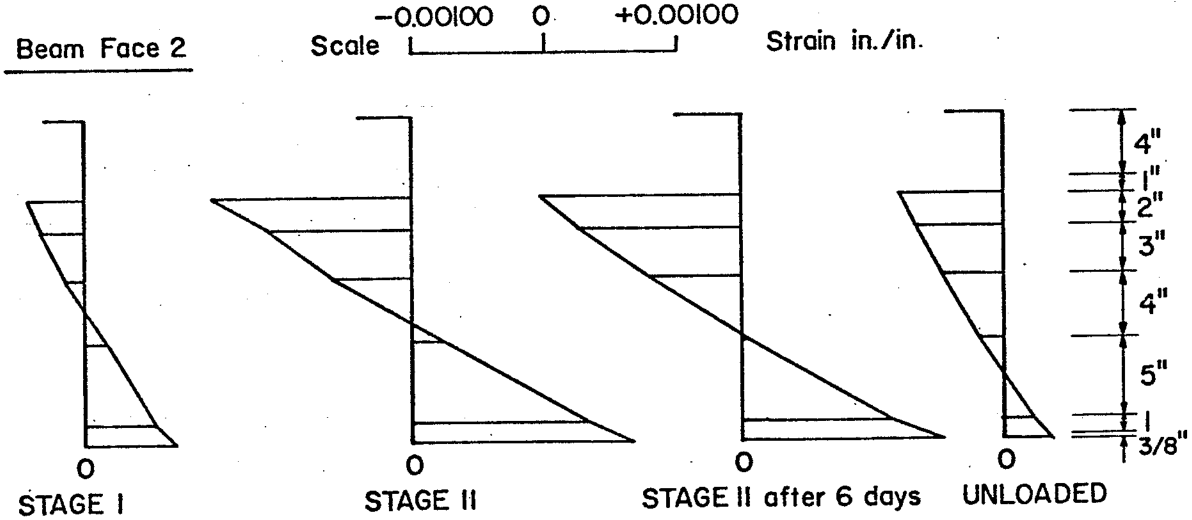


Fig. C-1.2 Strain Variation at Location 2.

Beam Face 1



Beam Face 2



Floor

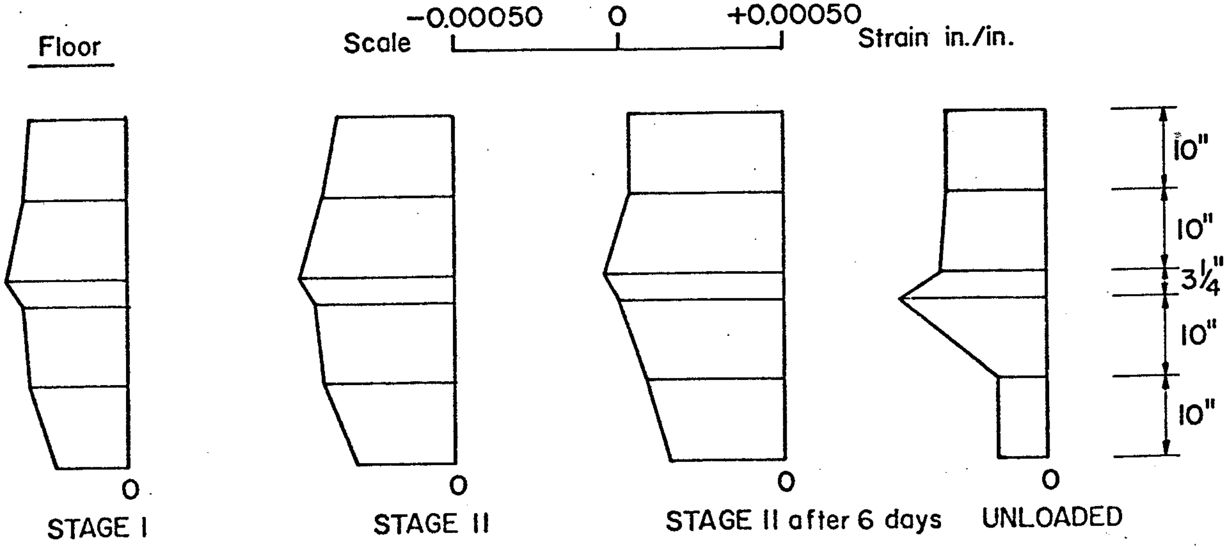


Fig. C-1.3 Strain Variation at Location 3.

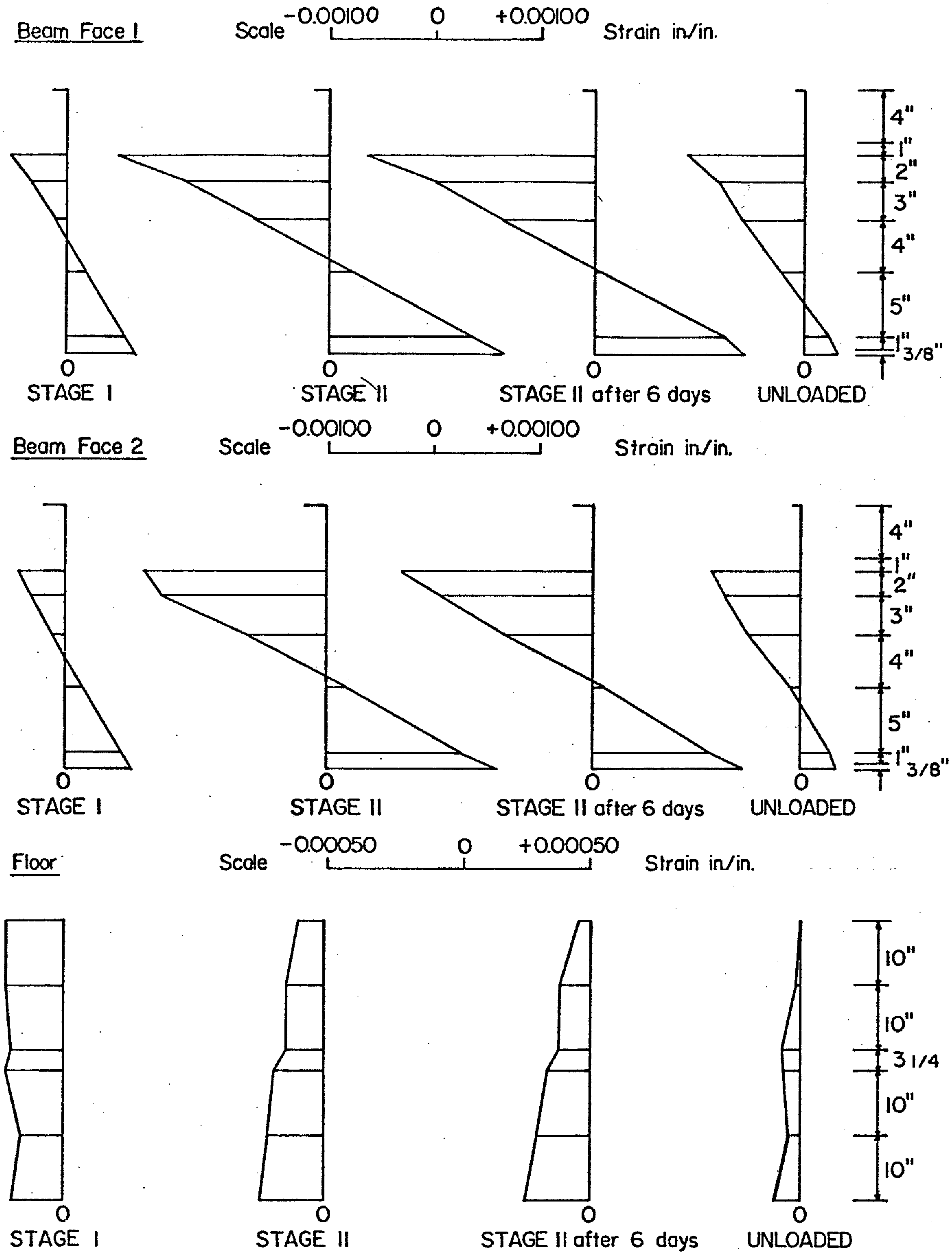


Fig. C-1.4 Strain Variation at Location 4.

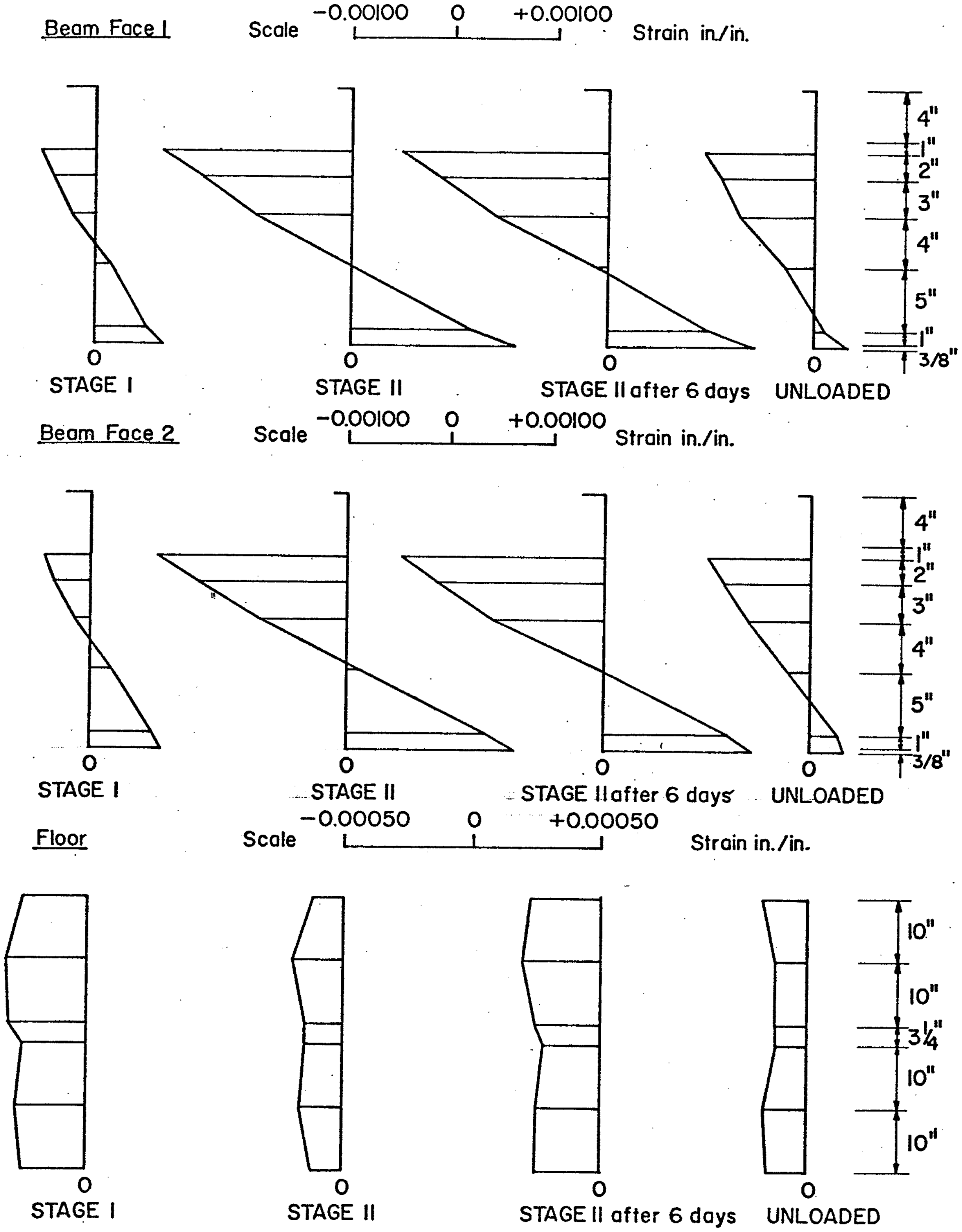
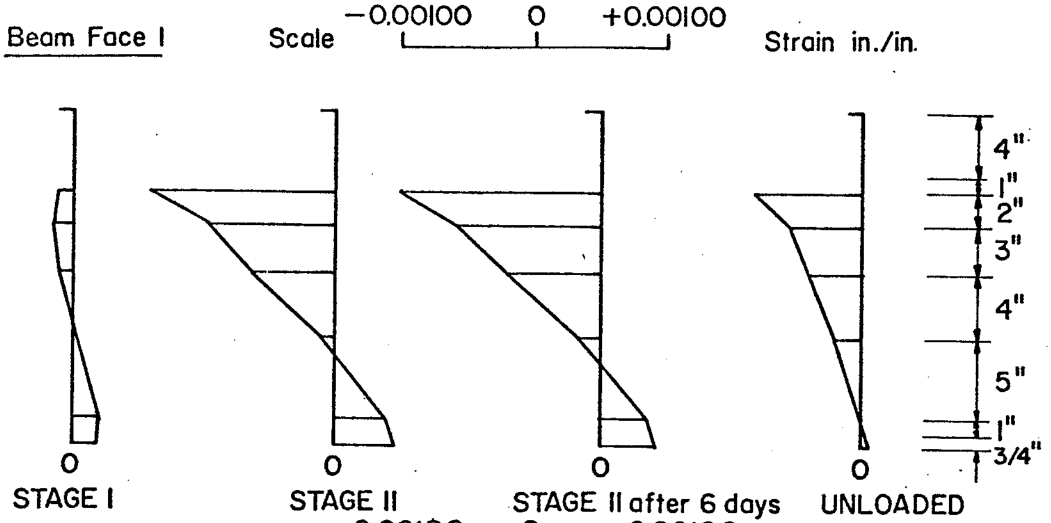
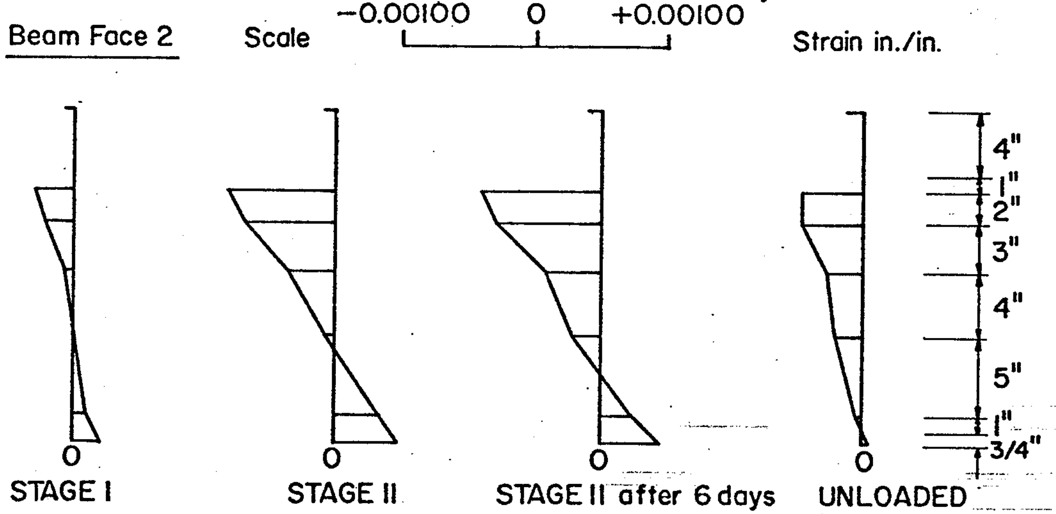


Fig. C–1.5 Strain Variation at Location 5.

Beam Face 1



Beam Face 2



Floor

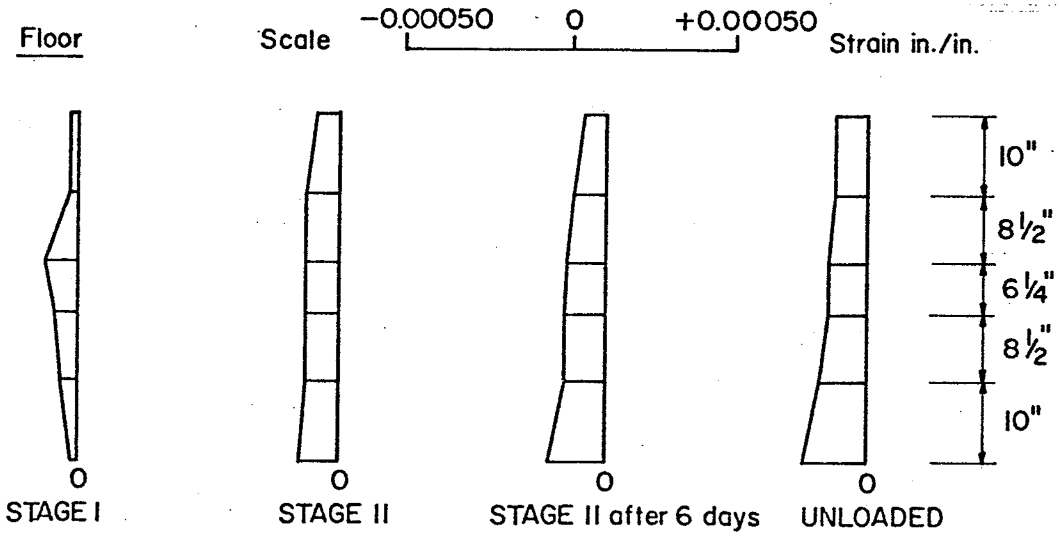


Fig. C-1.6 Strain Variation at Location 6.

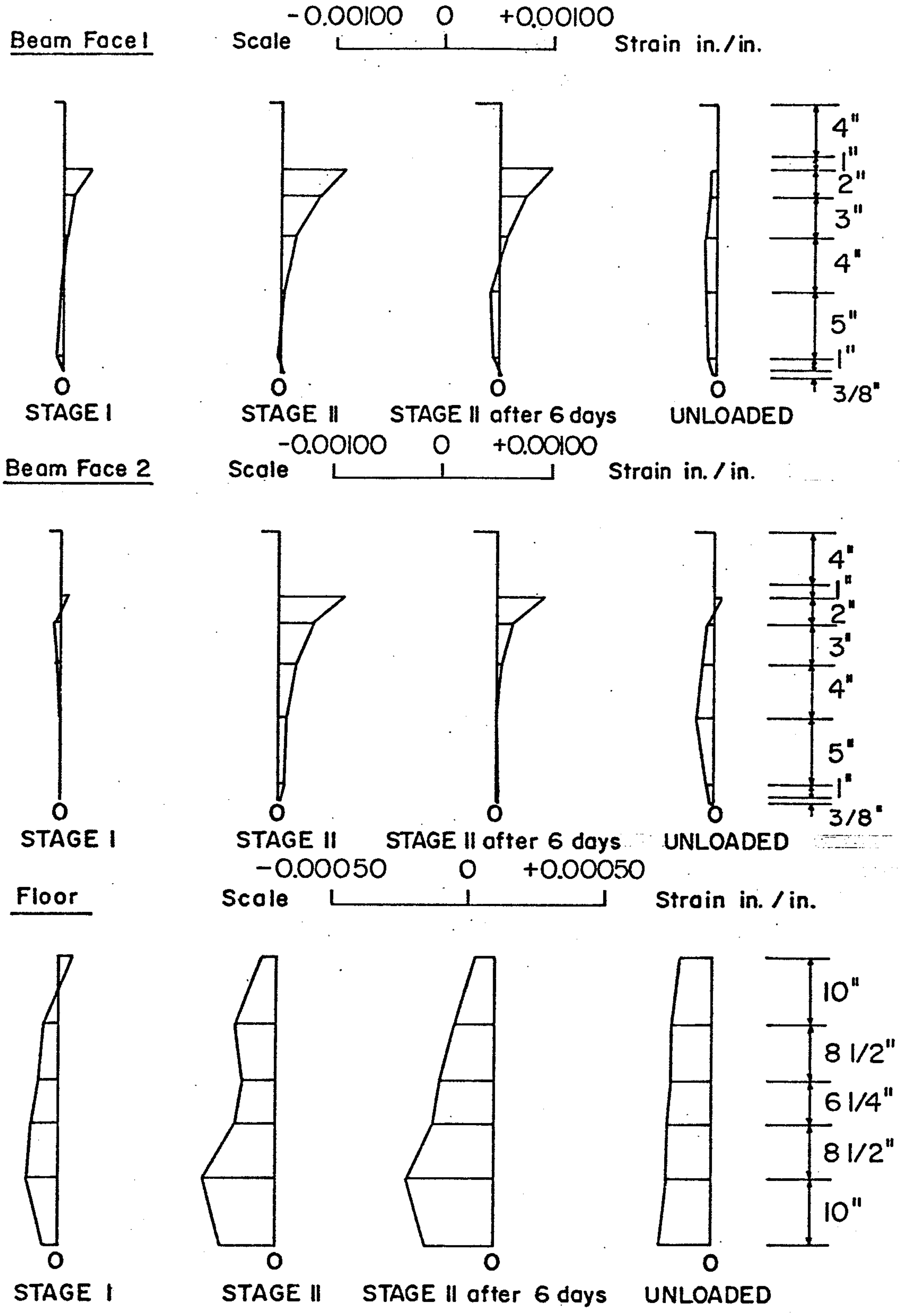


Fig. C-1.7 Strain Variation at Location 7.

C-2 Test II

TABLE C-2.1

Slip Between Fiberglass and Particleboard Beam

Loading Condition	Left End (in.)	Midspan (in.)	Right End (in.)
No load	0	0	0
Stage I	0.0002	0.0011	0.0002
Stage II	0.0004	0.0021	0.0007
Stage II after 8 days	0.0004	0.0020	0.0008
Stage III	0.0006	0.0035	0.0011
Stage IV	0.0008	0.0057	0.0015
Stage IV after 7 days	0.0009	0.0074	0.0015
unloaded	0.0002	0.0025	0.0008
unloaded after 10 days	0	0.0016	0.0006

TABLE C-2.2

Slip Between Joist and Beam

Loading Condition	Left End (in.)	Right End (in.)
No load	0	0
Stage I	0.0080	0.0300
Stage II	0.0307	0.1500
Stage II after 8 days	0.0320	0.1500
Stage III	0.0572	0.3500
Stage IV	0.1092	0.5600
Stage IV after 7 days	0.1092	0.5700
unloaded	0.0692	0.2600
unloaded after 10 days	0.0692	0.2200

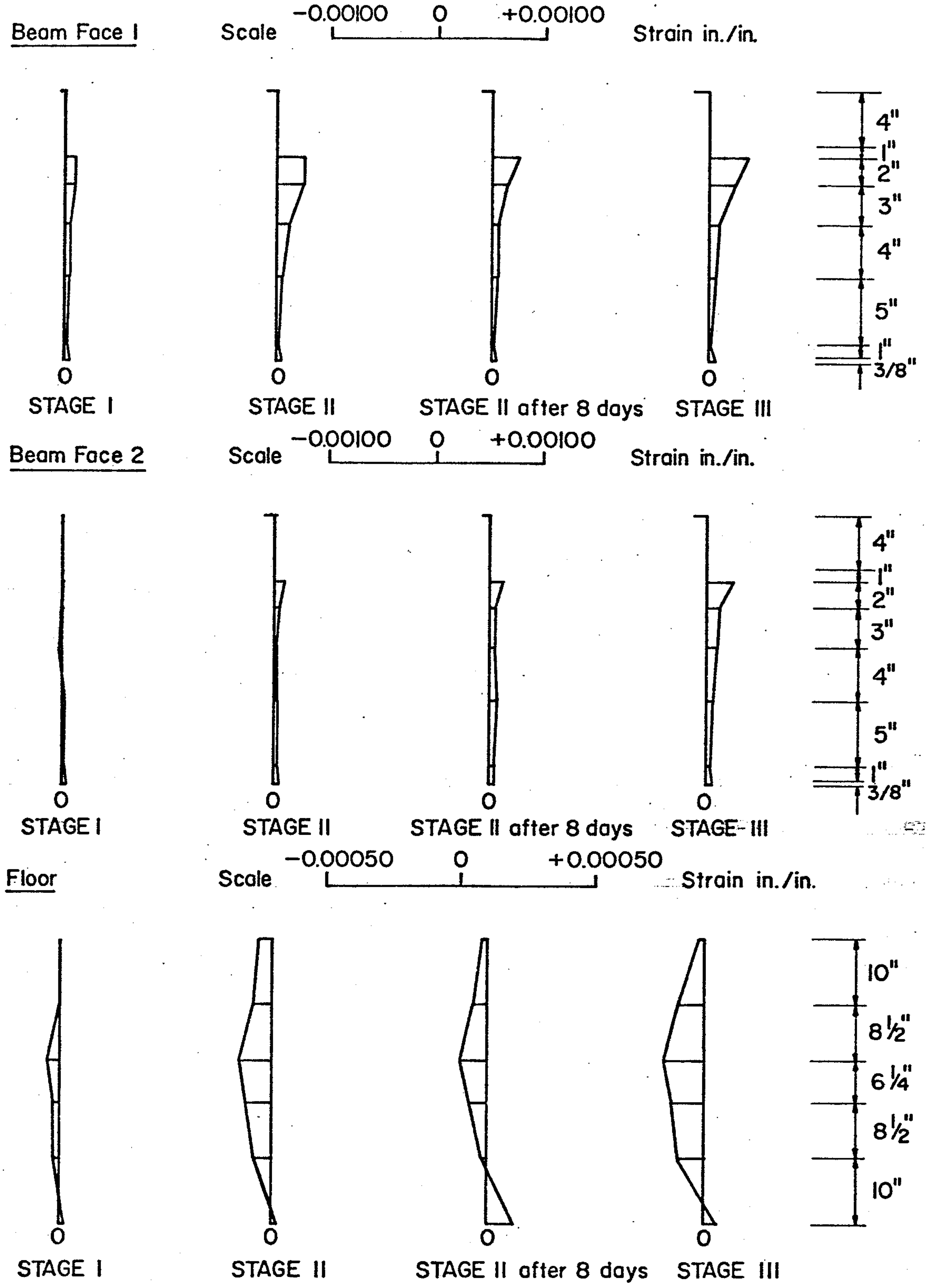


Fig. C−2.1 Strain Variation at Location I.

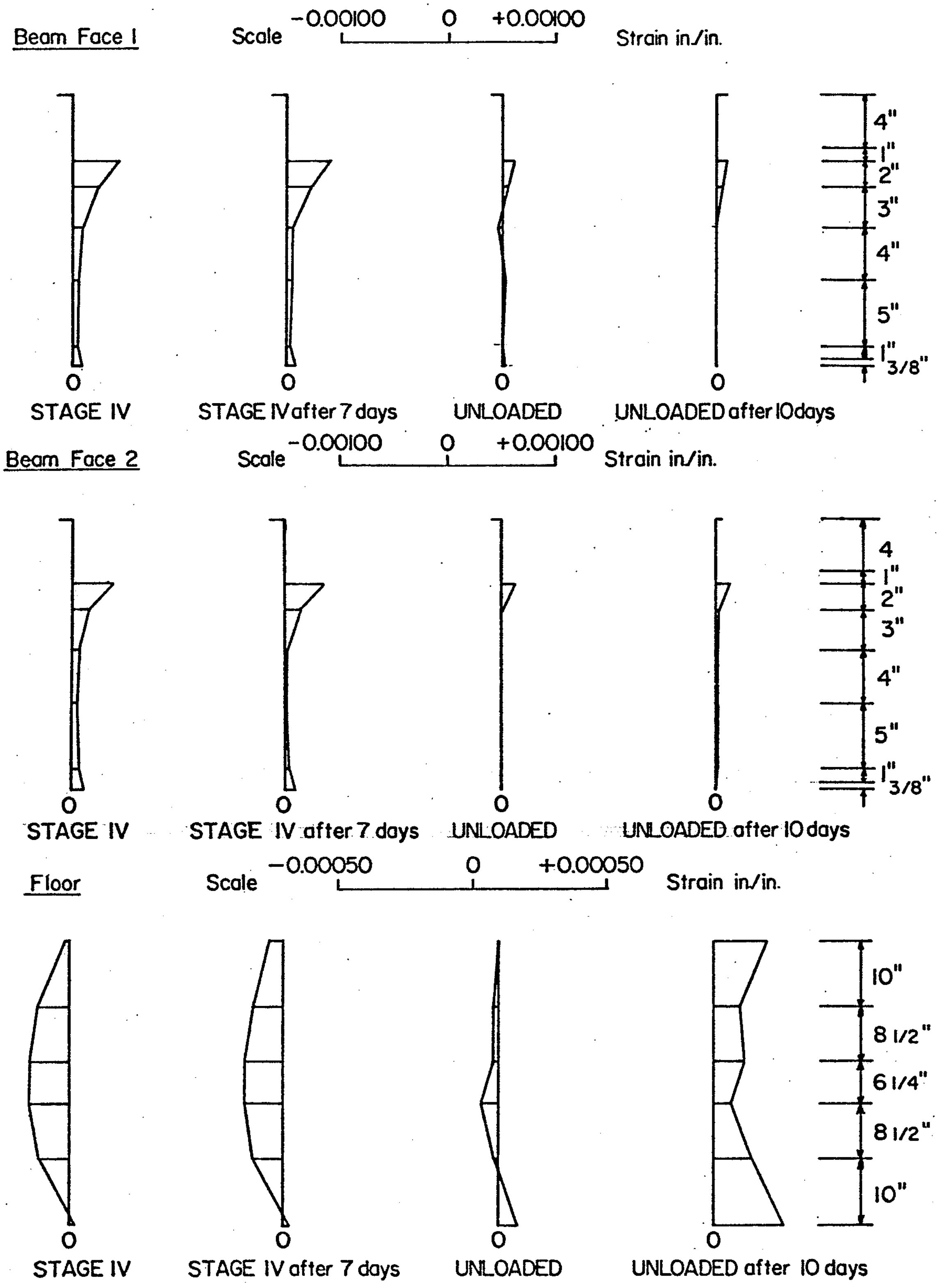


Fig. C-2.1 Strain Variation at Location I. (continued).

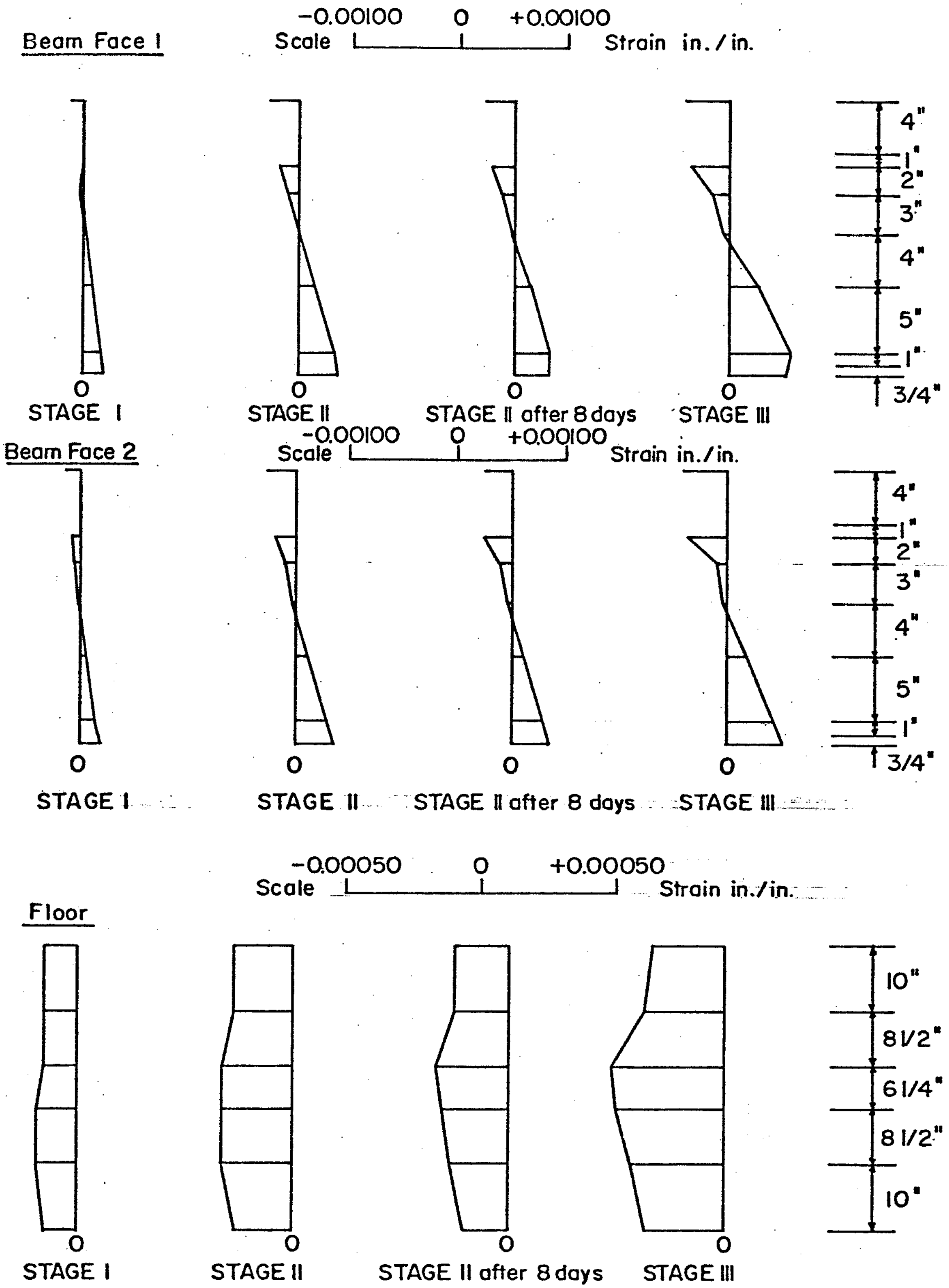


Fig. C-2.2 Strain Variation at Location 2.

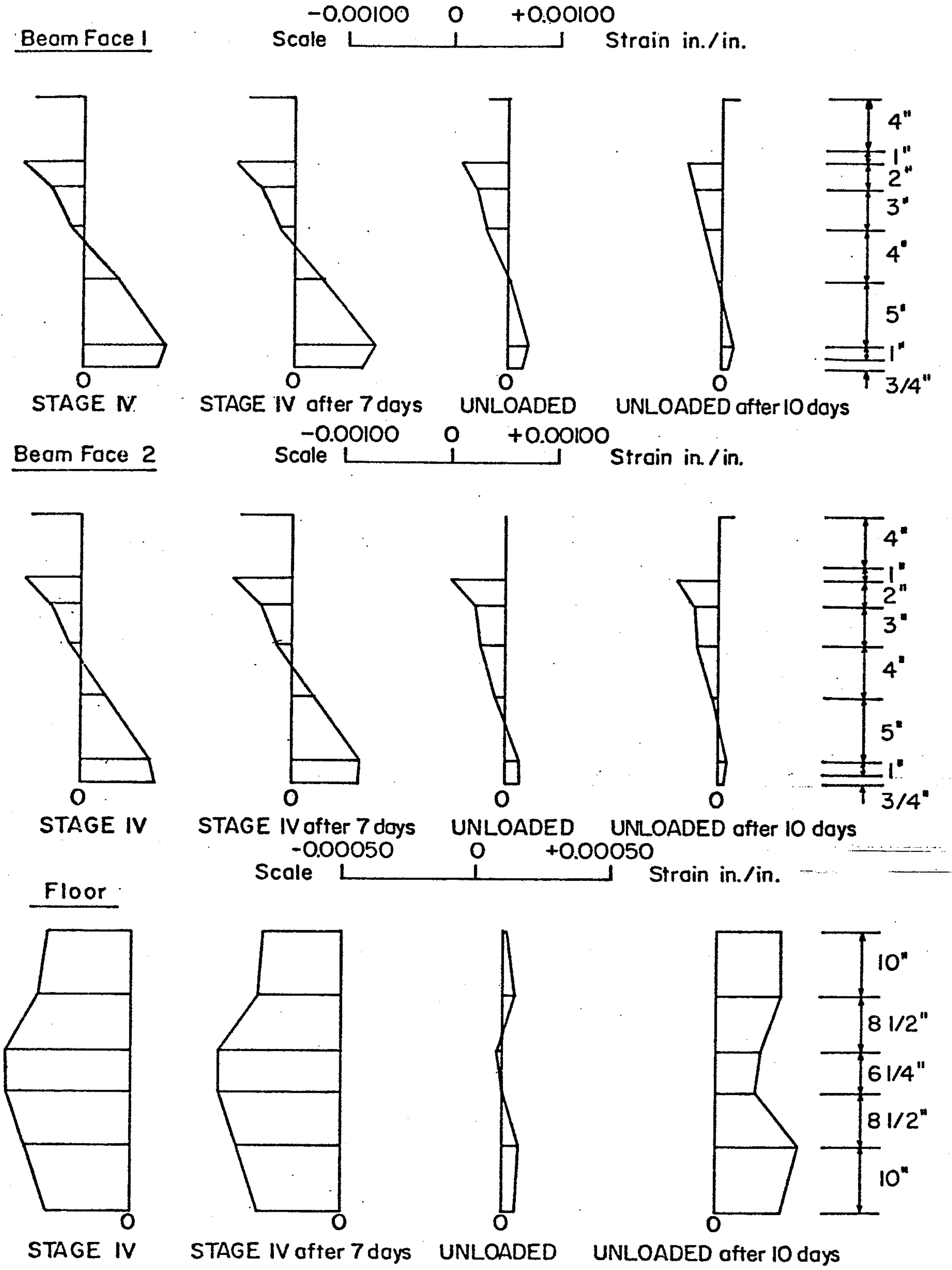


Fig. C-2.2 Strain Variation at Location 2 (Continued).

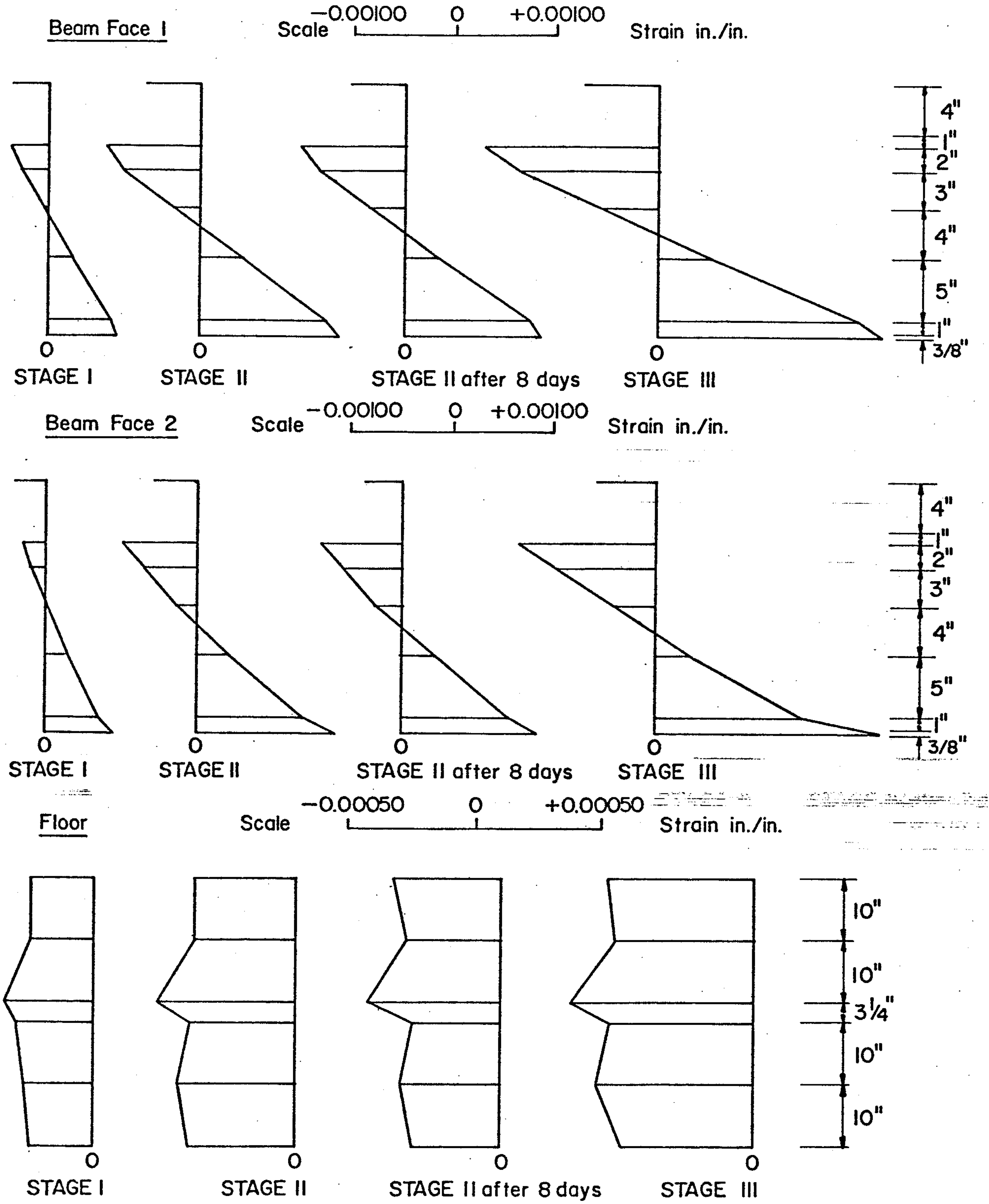


Fig. C-2.3 Strain Variation at Location 3.

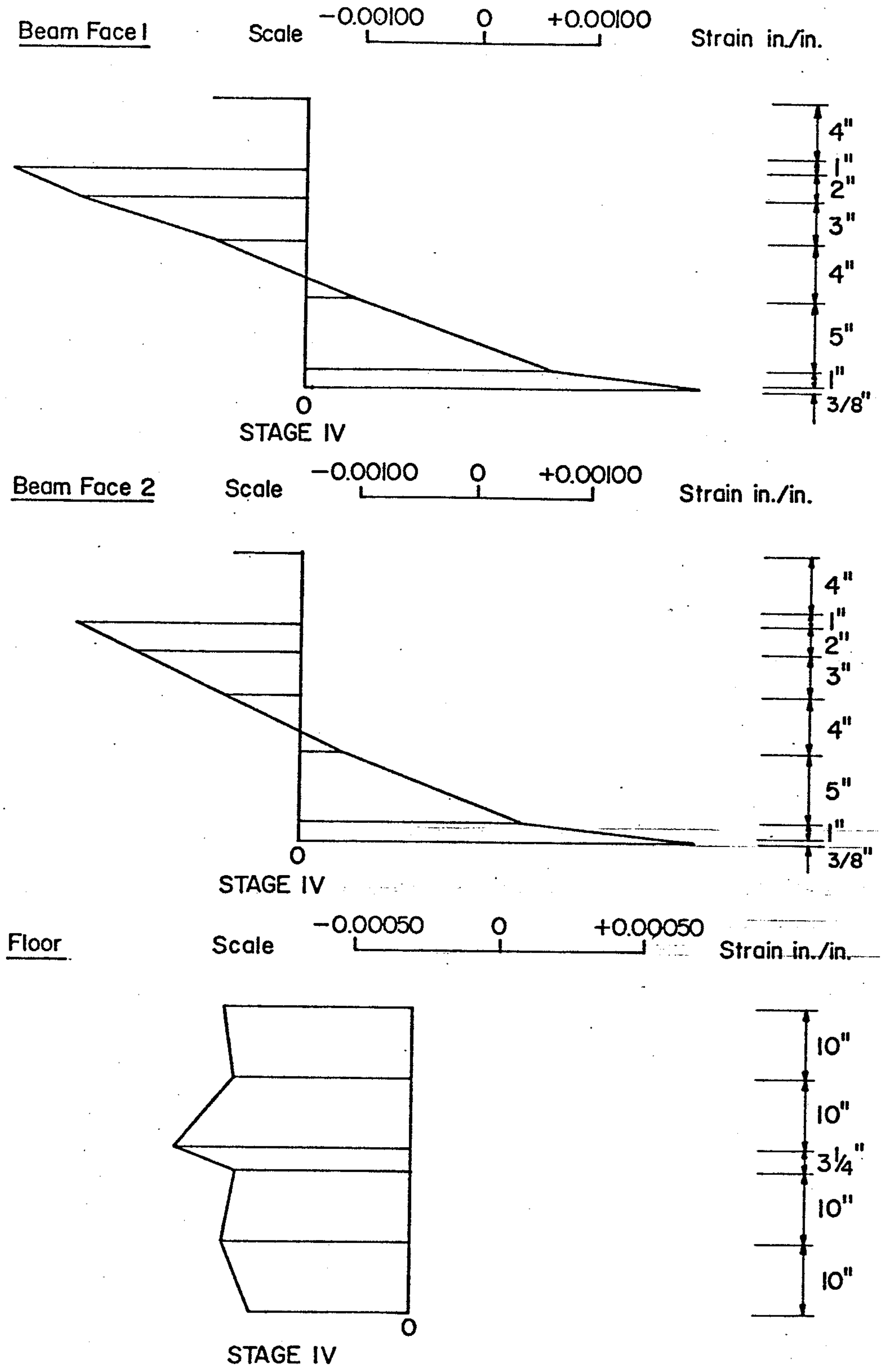
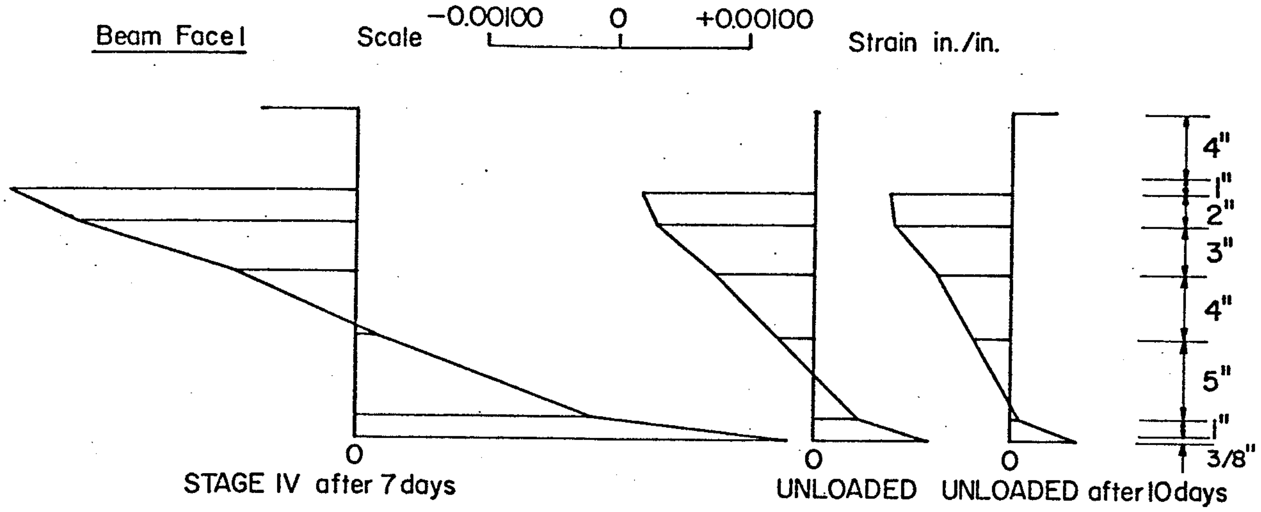
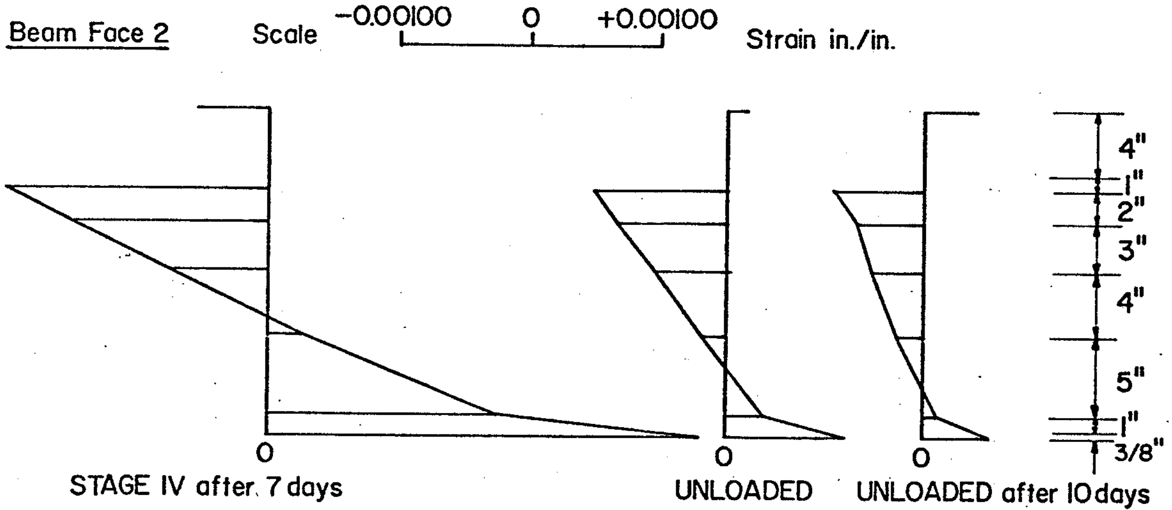


Fig. C-2.3 Strain Variation at Location 3 (Continued).





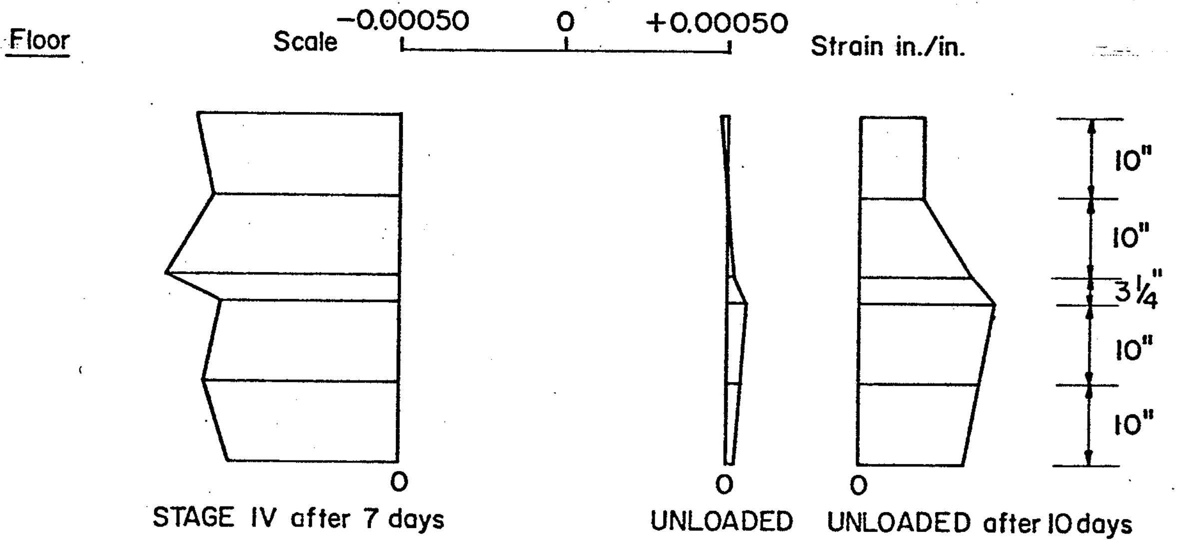


Fig. C–2.3 Strain Variation at Location 3 (Continued).

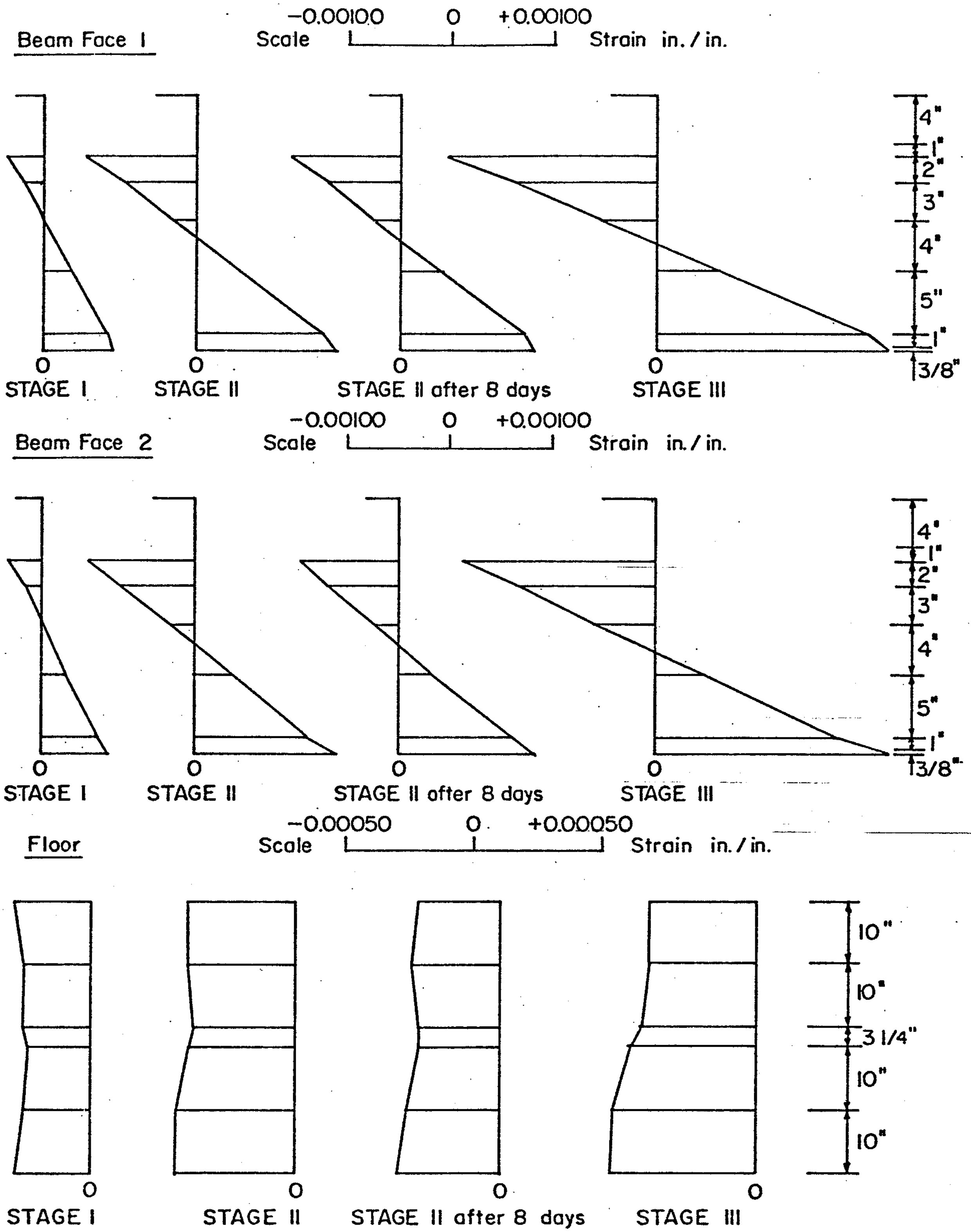


Fig. C-2.4 Strain Variation at Location 4.

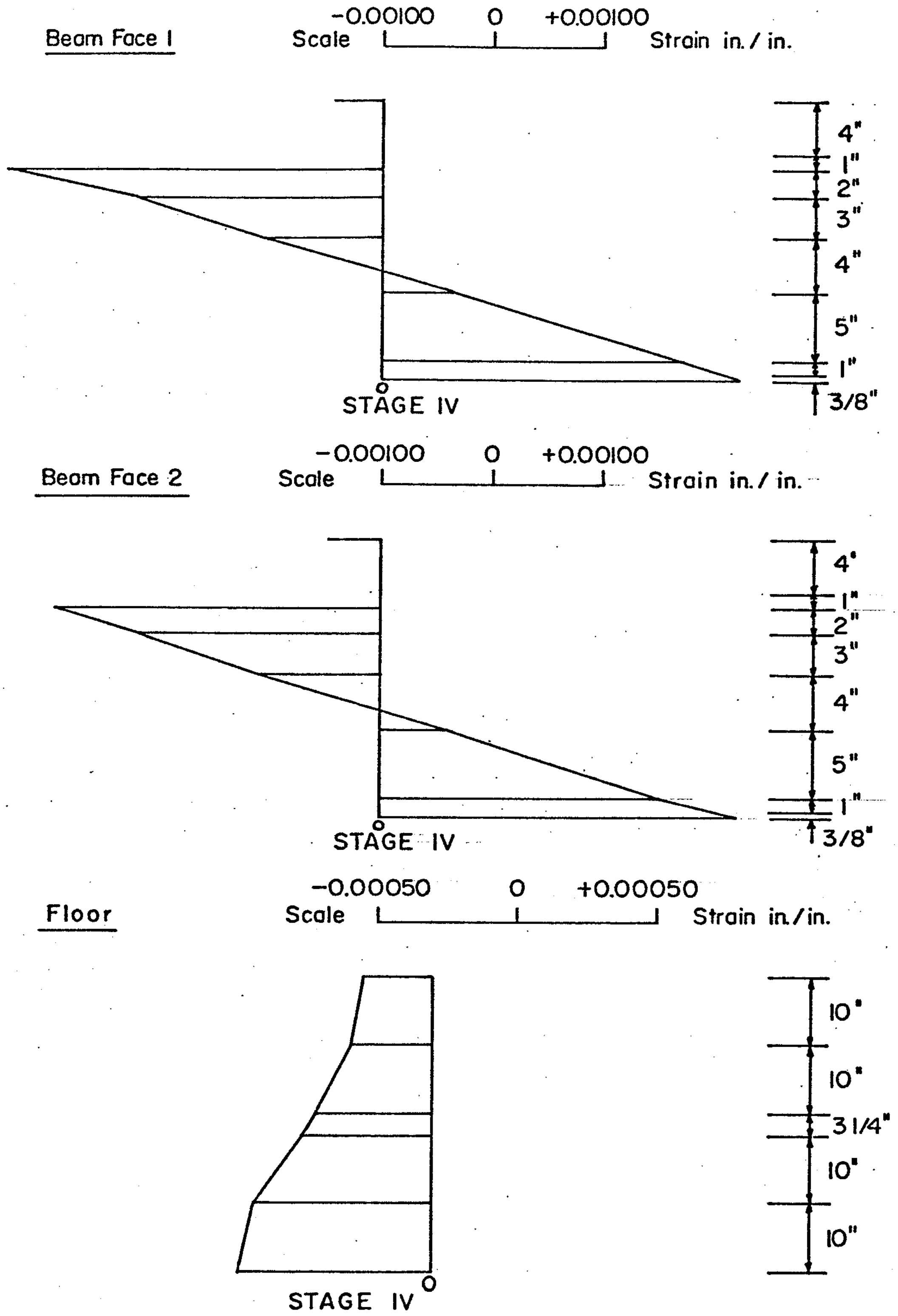
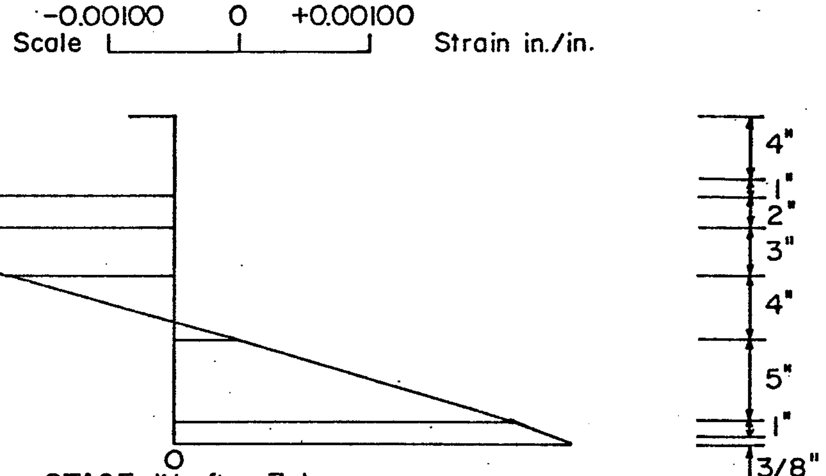


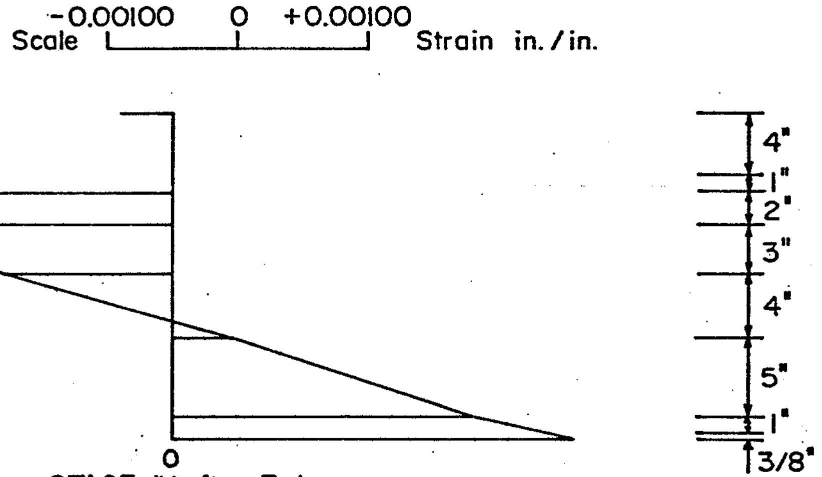
Fig. C-2.4 Strain Variation at Location 4 (Continued).

Beam Face I



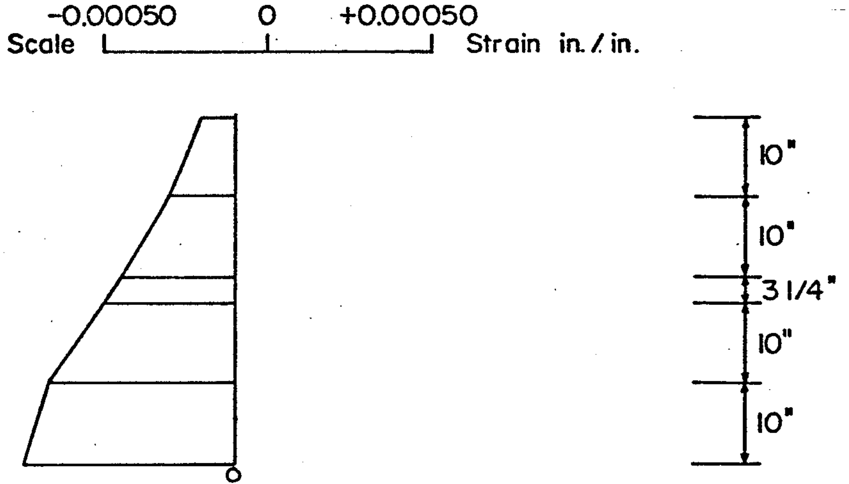
STAGE IV after 7 days

Beam Face 2



STAGE IV after 7 days

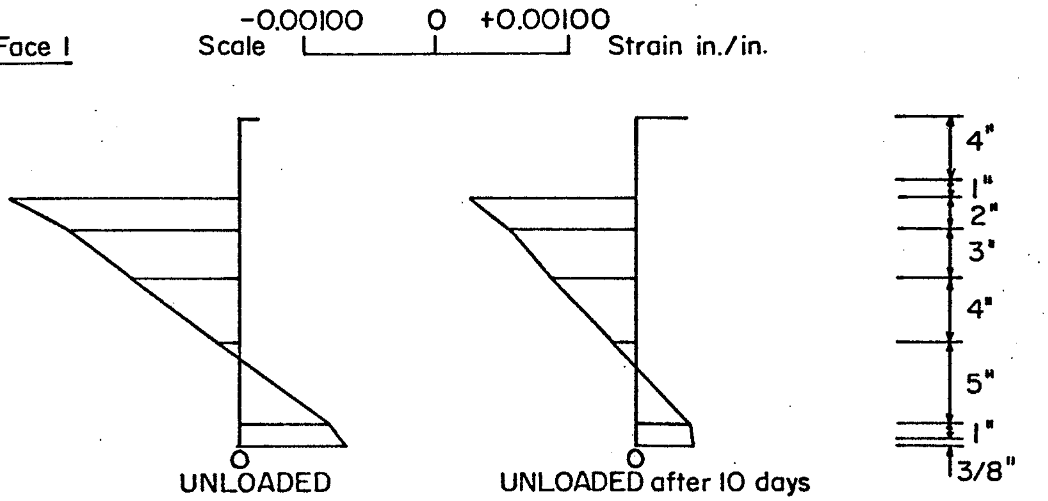
Floor



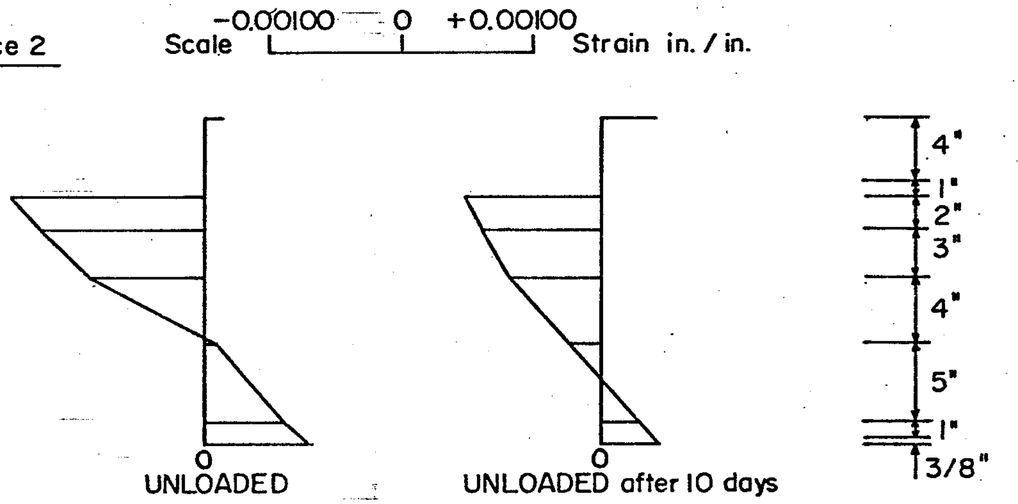
STAGE IV after 7 days

Fig. C-2.4 Strain Variation at Location 4 (Continued).

Beam Face I



Beam Face 2



Floor

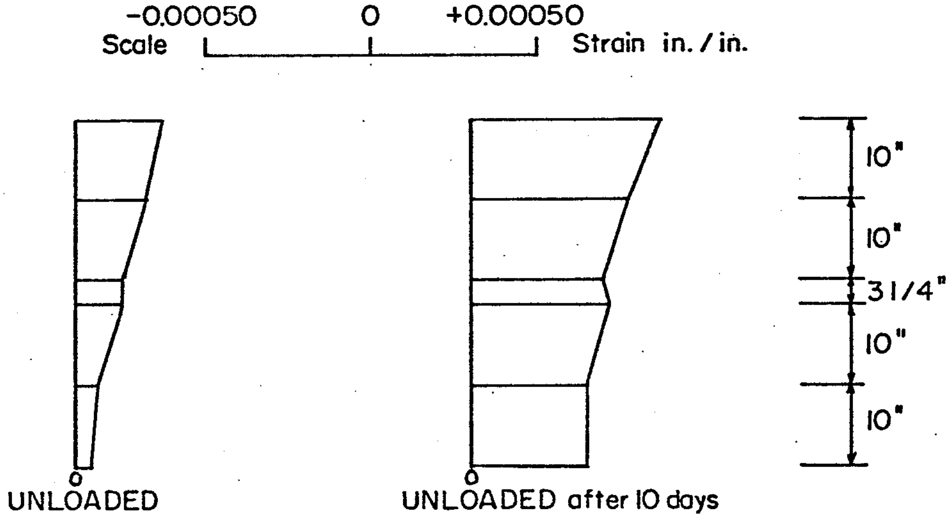


Fig. C-2.4 Strain Variation at Location 4 (Continued).

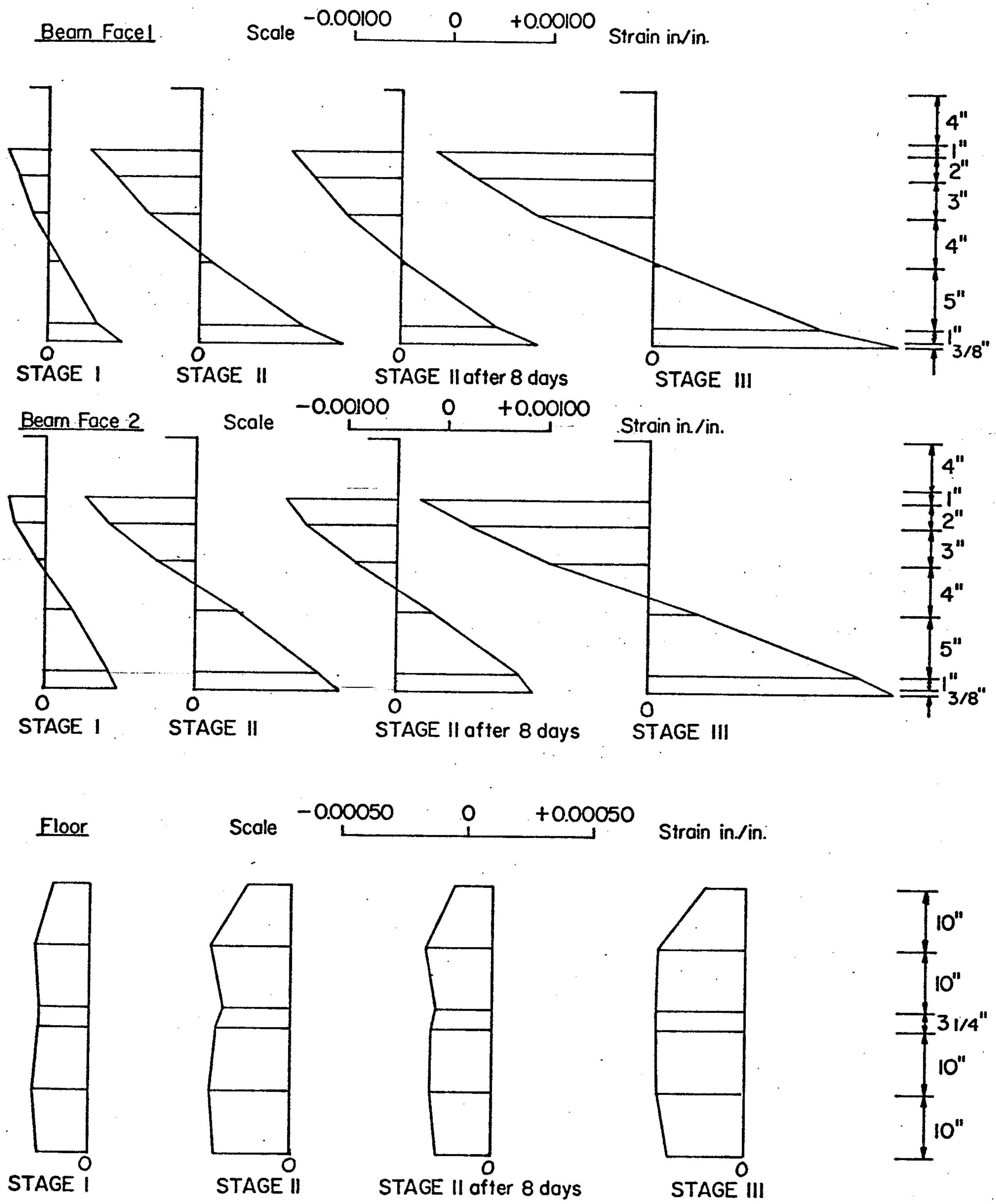
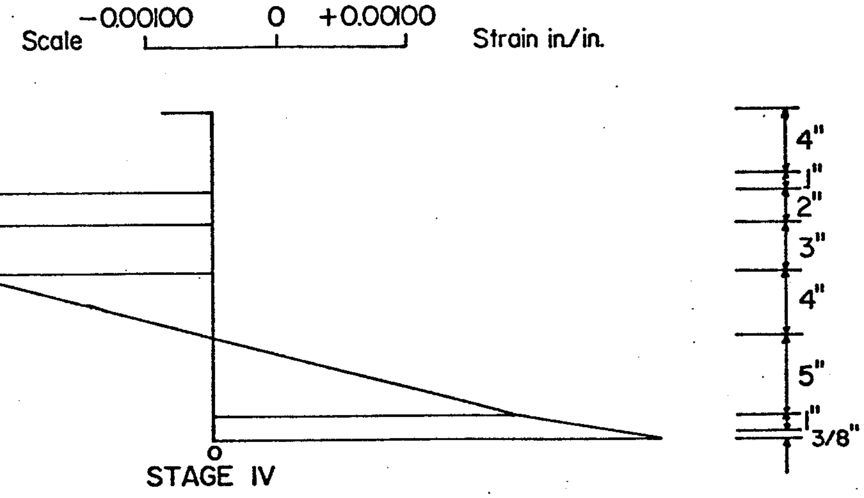
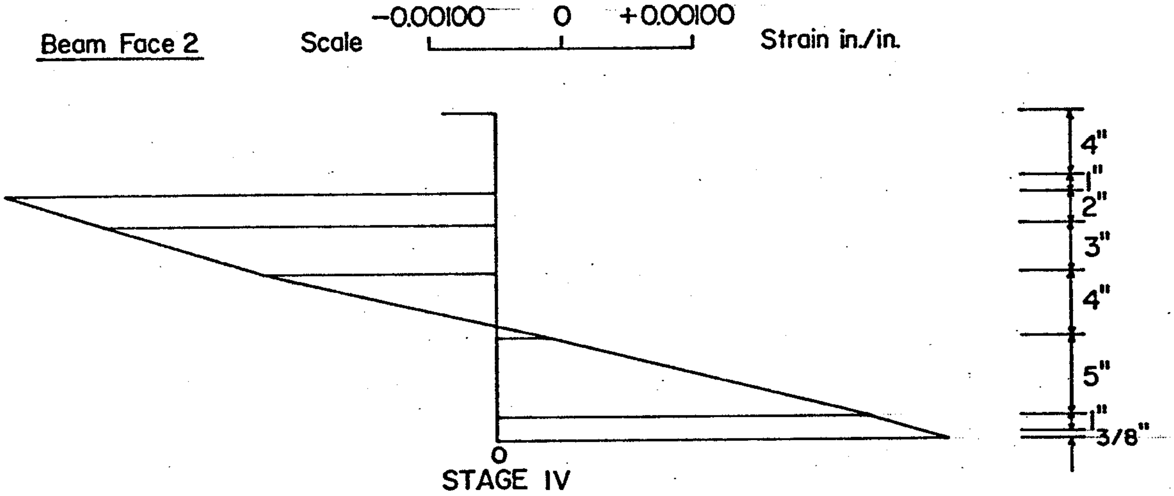


Fig. C-2.5 Strain Variation at Location 5.

Beam Face 1



Beam Face 2



Floor

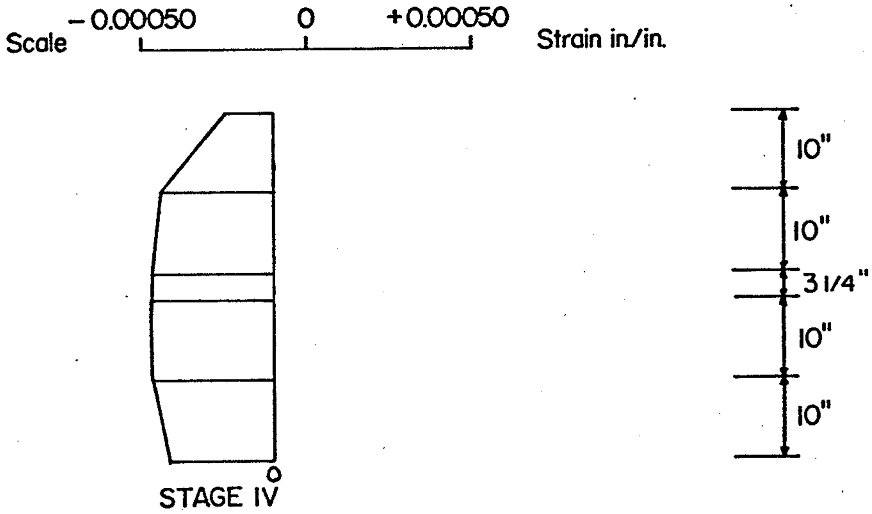


Fig. C-2.5 Strain Variation at Location 5. (continued).

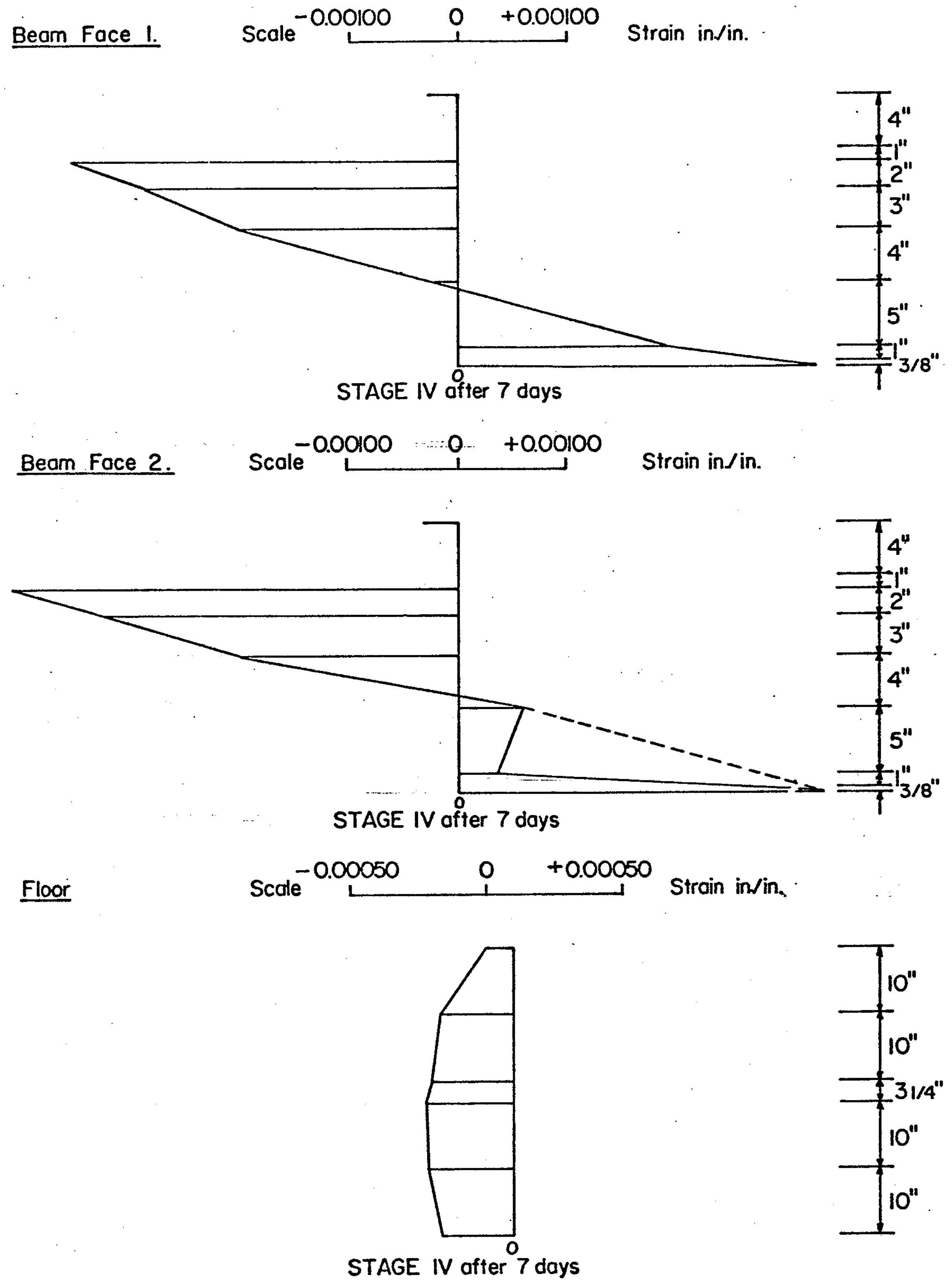
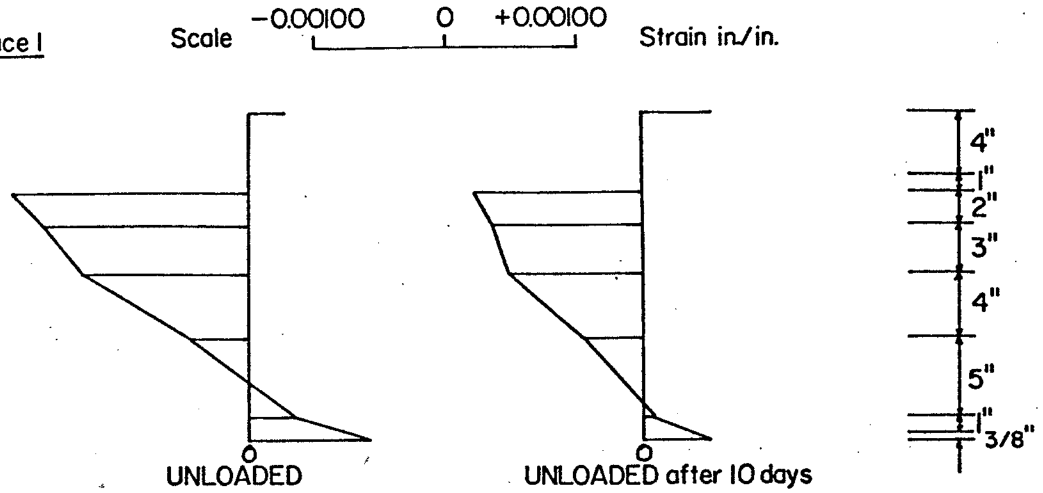
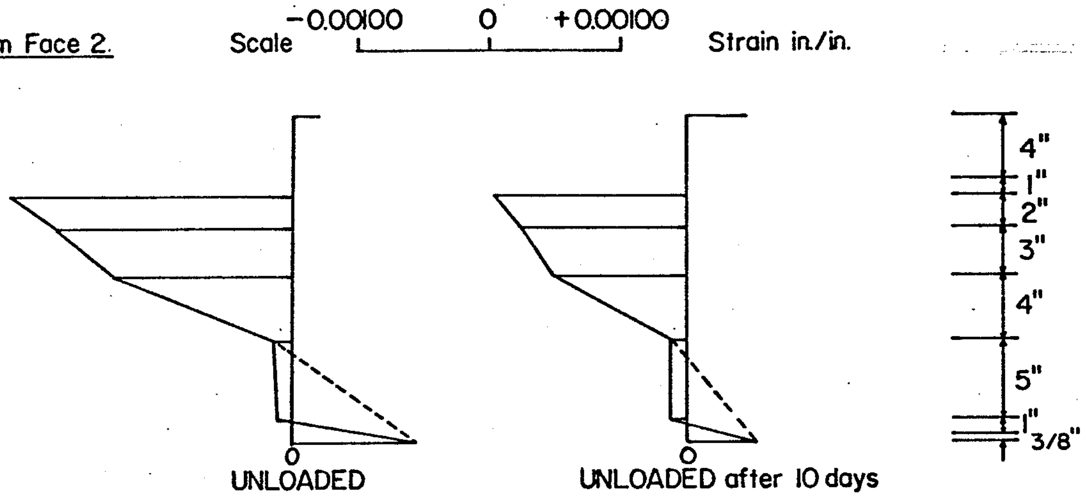


Fig. C−2.5 Strain Variation at Location 5. (continued).

Beam Face I



Beam Face 2.



Floor

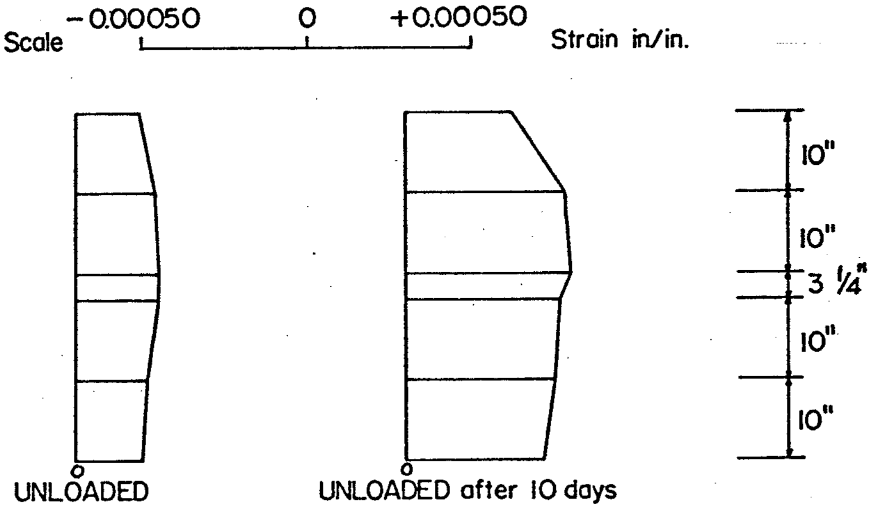


Fig. C-2.5. Strain Variation at Location 5. (continued).

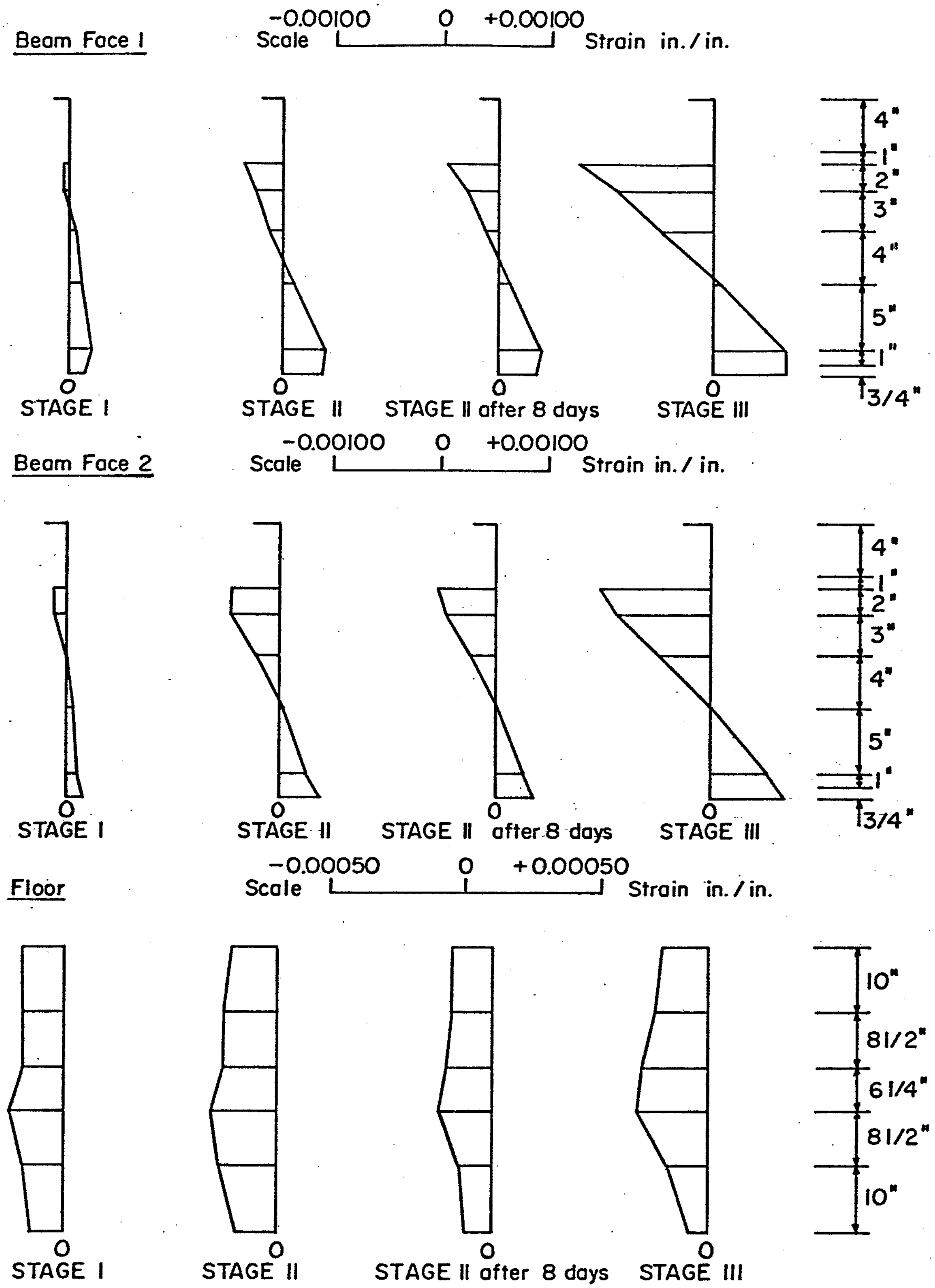


Fig. C-2.6 Strain Variation at Location 6.

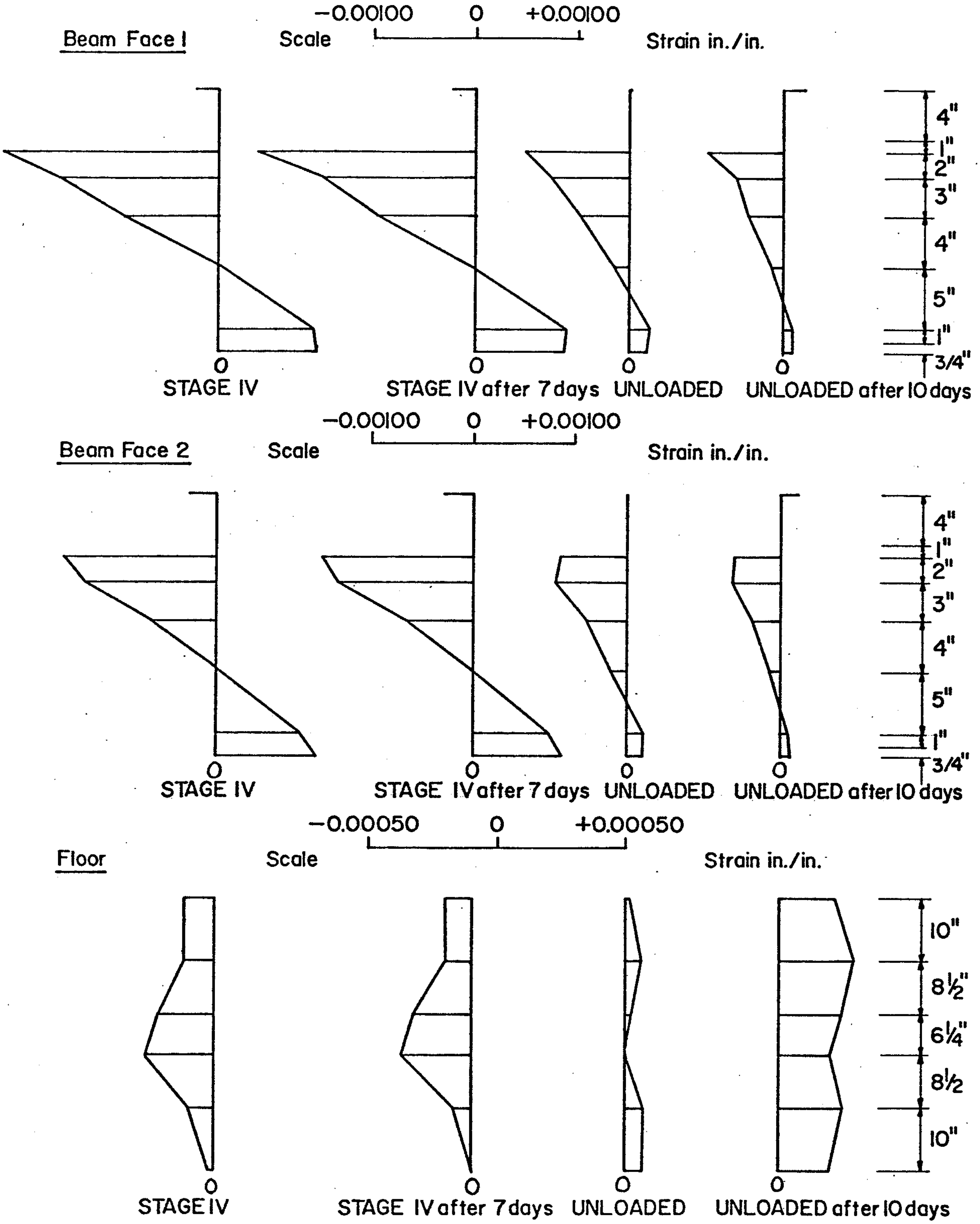


Fig. C−2.6 Strain Variation at Location 6 (Continued).

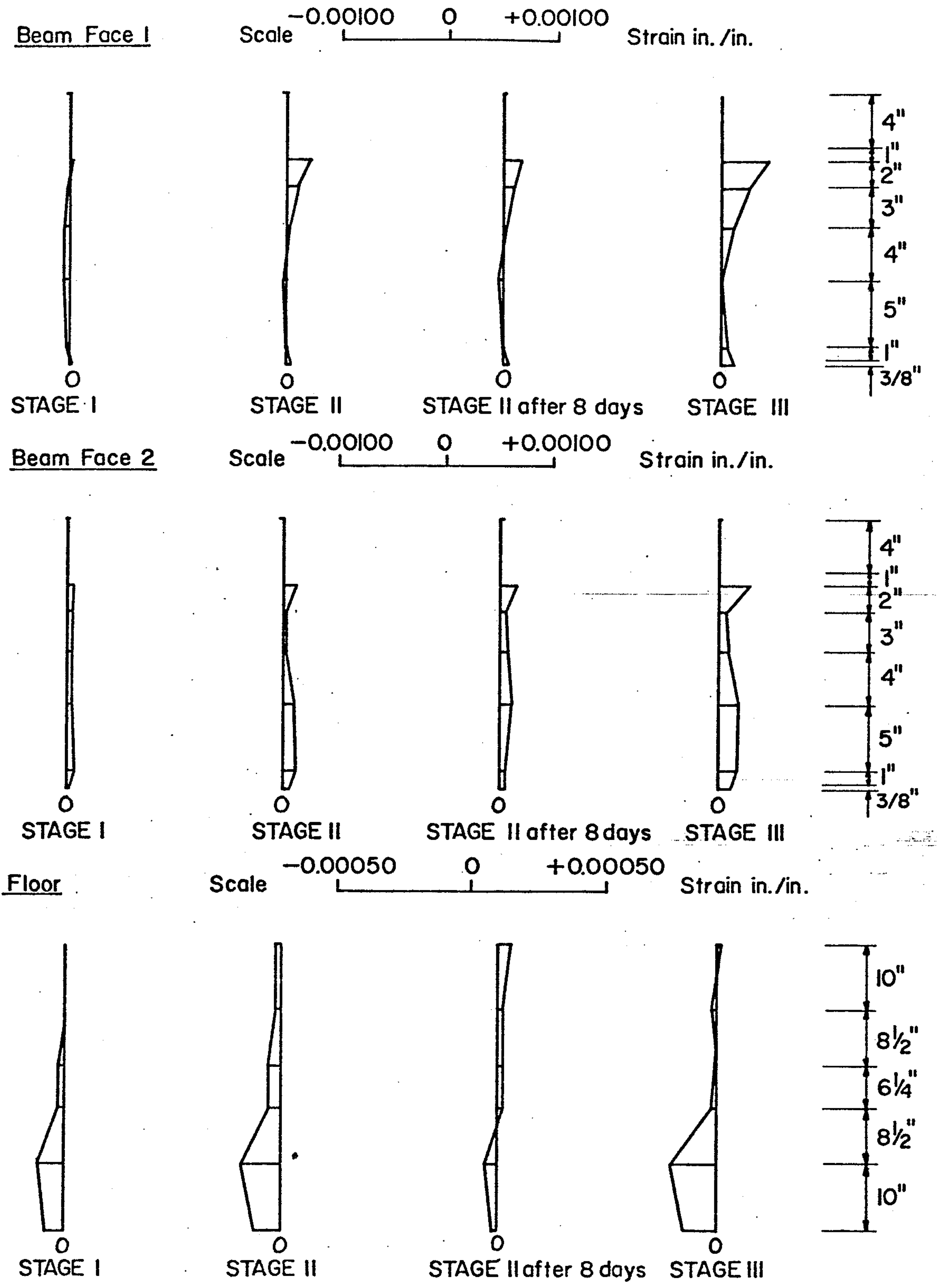


Fig. C-2.7 Strain Variation at Location 7.

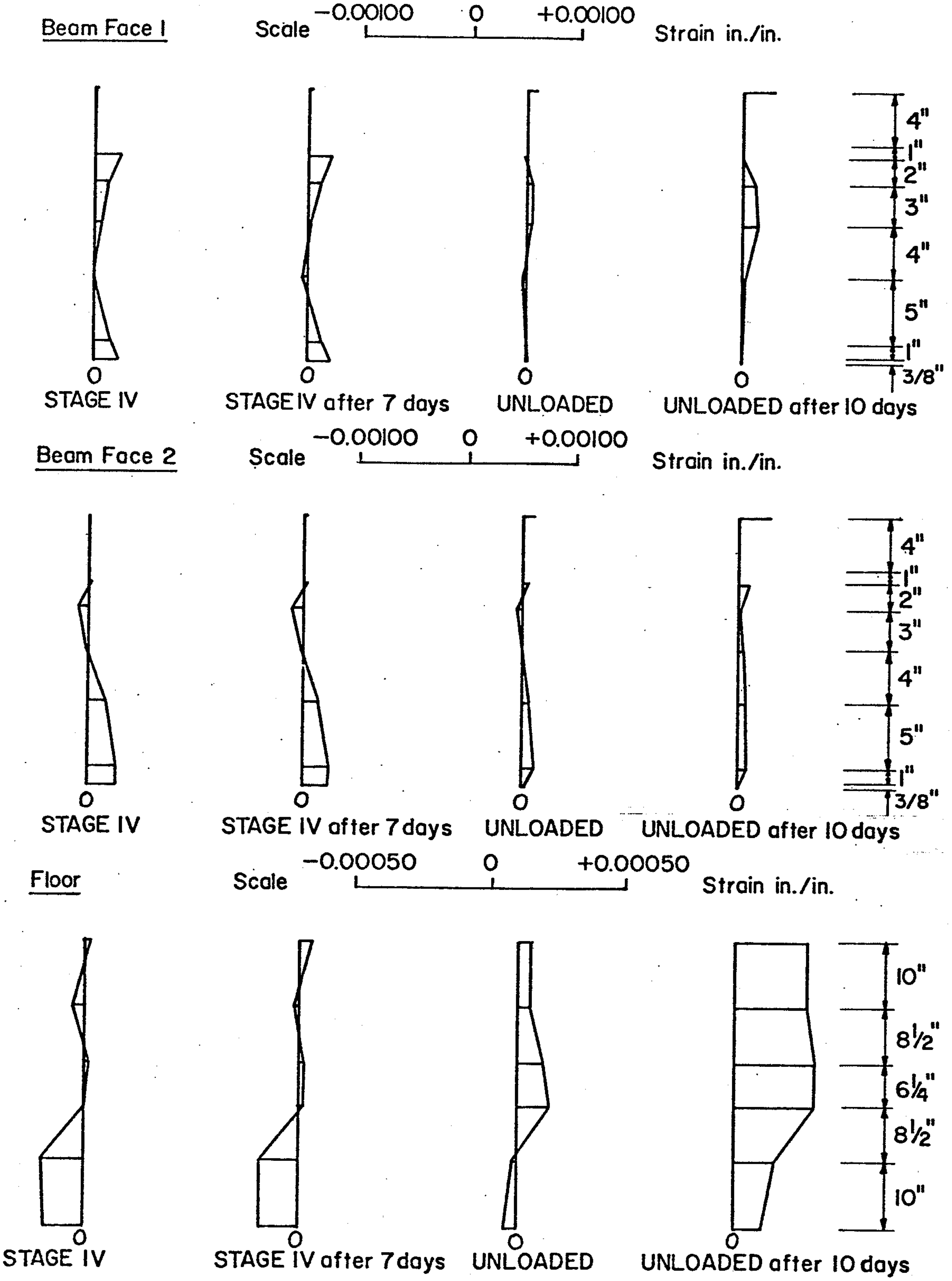


Fig. C-2.7 Strain Variation at Location 7 (Continued).