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Structural Engineering Report 158

THE FLEXURAL CREEP BEHAVIOUR OF OSB STRESSED SKIN PANELS

by
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and
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April 1988

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THE FLEXURAL CREEP BEHAVIOUR OF OSB STRESSED SKIN PANELS

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April, 1988

Abstract

Creep is defined as the time-dependent deformation under sustained mechanical stresses. The linearity of viscoelastic behaviour can be tested by applying Boltzmann's Principle of Superposition. If a material indeed behaves linearly, then correspondence principle (elastic-viscoelastic analogy) may be applied to the time-dependent analysis of a viscoelastic member.

This research work specifically studied the time-dependent behaviour of oriented strandboard (OSB) in bending and its implication in the design of stressed skin panel (SSP) that has OSB as the skin. Four parameters were included in the design of experiments – stress level, humidity, temperature, and grain orientations (parallel and perpendicular).

The OSB and SSP specimens were tested indoor for 90 days under two types of environment – controlled and uncontrolled. Under each type of environment, a portion of the specimens was subjected to sustained-flexural loads applied in three steps; the remaining portion was subdivided into three groups where each group was subjected to a different magnitude of sustained-flexural load. The perpendicular-to-grain OSB specimens were tested only in the uncontrolled environment.

In addition to the Boltzmann's principle of superposition, fractional deflection and isochrone

techniques were applied to determine if OSB and SSP behave in a viscoelastic manner. The time-dependent deflections of the SSP were calculated, by applying the correspondence principle, based on the components' flexural properties.

The linearity tests confirmed that linear viscoelastic theories are applicable to the time-dependent behaviour of OSB in both grain directions under low flexural stress levels and steady-state environment. Time-dependent deflection of the OSB stressed skin panel can be calculated by simply reducing each component's Young's modulus, E, with a time factor that is associated with the creep characteristics of the material.

Acknowledgements

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Nomenclature

e	NATURAL EXPONENT
E	YOUNG'S MODULUS (M.O.E.)
F	VISCOUS CONSTANT
FD(t)	FRACTIONAL DEFLECTION FUNCTION
$G(t-\tau)$	STRESS RELAXATION FUNCTION
I	MOMENT OF INERTIA
$J(t-\tau)$	CREEP COMPLIANCE FUNCTION (IN TERMS OF STRAIN-STRESS)
$J^*(t)$	CREEP COMPLIANCE FUNCTION (IN TERMS OF LOAD-DISPLACMENT)
K	ELASTIC CONSTANT
L	SPAN
M.O.E.	MODULUS OF ELASTICITY (E)
M.O.R.	MODULUS OF RUPTURE
P	FORCE
s	INITIAL TIME OF EXCITATION
S-P-F	SPRUCE-PINE-FIR
t	TIME
$\frac{d}{dt}$	DERIVATIVE WITH RESPECT TO TIME
Δ	DISPLACEMENT
ε	STRAIN
$\varepsilon(t)$	STRAIN HISTORY
η	VISCOSITY CONSTANT
∞	INFINITY
σ	STRESS
$\sigma(t)$	STRESS HISTORY
Θ	TIME AT WHICH THE LOAD IS APPLIED
τ	RETARDATION TIME

//	PARALLEL-TO-GRAIN
$\perp$	PERPENDICULAR-TO-GRAIN

1. INTRODUCTION

1.1 General

When a stress is imposed and maintained on a substance, the deformation of the substance will increase through time. Upon removal of the sustained stress, that substance may not recover to its original undeformed state. The phenomenon just described is called creep (Nielsen 1972).

Creep is the amount of time-dependent deformation that is beyond the instantaneous deformation under sustained loading conditions. It can be separated into primary, secondary, and tertiary stages as shown in Figure 1.1. The primary stage of creep is characterized by the portion of the creep that increases at a decreasing rate. Secondary creep takes place at a more-or-less constant rate. At sufficiently high sustained loading, a tertiary deformation creep phase will take place. The tertiary stage of creep is characterized a rapid increase in deformation rate. This last stage of creep is associated with creep rupture phenonmenon (Sugiyama 1967).

Building materials such as plastic, concrete, and lumber are considered linear viscoelastic when the intensity of the sustained load is low. Creep rupture can occur if there is sufficiently high sustained load present.

1.2 Theories

Viscoelasticity is a branch of rheology which studies the deformation of materials (Reiner 1969). Rheology has its beginning dated back many centuries ago (Blair 1949). The development of polymers in this century has intensified the study of rheological phenomena (Alfrey 1948).

Viscoelasticity applies to the materials which exhibit both elastic and time-dependent behaviour. It can be used to describe and predict the primary and secondary creep. The use of phenomenological models often provides a good comprehension of the viscoelastic behaviour of a substance as will be seen later.

1.2.1 Linear Elastic

A material is classified as elastic when there is no energy dissipated during the loading and unloading processes under isothermal conditions (Christensen 1971). The constitutive relationship for a linear elastic material in the uniaxial case is:

$$\sigma = E \bullet \varepsilon \qquad [1]$$

where E is the Young's modulus of the material. The ratio of strain to stress is called compliance. The behaviour of an ideal linear elastic material can be modeled with a spring that has the following load-displacement relation:

$$P = K \bullet \Delta \qquad [1A]$$

where K is the spring constant.

1.2.2 Linear Viscous

A material is classified as viscous when the stress is proportional to the strain rate and all energy is dissipated during the loading process (Christensen 1971). The constitutive relationship for a linear viscous material in the uniaxial case is:

$$\sigma = \eta \cdot \frac{d\varepsilon}{dt} \qquad [2]$$

where η is the coefficient of viscosity of the material. Eq.2 is analogous to the expression for a material that behaves according to a linear Newtonian fluid whose shear stress is proportional to the shear strain rate. A dashpot can be used to represent the behaviour of an ideal linear viscous material that has the following load-displacement relation:

$$P = F \cdot \frac{d\Delta}{dt} \qquad [2A]$$

where F is the viscous constant of the dashpot.

1.2.3 Linear Viscoelastic

If the deformation history is proportional to the load history, or vice versa, then the material is classified as a linear viscoelastic material. This is analogous to the linear elastic material described above except that time is also a consideration here. The constitutive relationship between stress and strain for a linear viscoelastic material is given below:

$$\sigma(t) = \int_{-\infty}^{t} G(t-s)\,\frac{d\varepsilon(s)}{ds}\,ds \qquad [3]$$

An inverse relationship also exists between strain and stress as shown below:

$$\varepsilon(t) = \int_{-\infty}^{t} J(t-s)\,\frac{d\sigma(s)}{ds}\,ds \qquad [4]$$

where G(t) and J(t) are defined as the stress-relaxation function and creep-compliance function respectively (Gross 1968); s denotes the time at which the excitation is applied. For a linear viscoelastic material, these two functions are independent of the magnitude of the excitations. The excitation can either be stress or strain.

1.2.3.1 Modelling

Linear viscoelastic behaviour of a material is sometimes represented with a phenomenological model. An example of such models is that shown in Figure 1.2. It is called a Maxwell-Voigt model or simply a four-element model. When a spring and a dashpot are placed in series, the arrangement is called a Maxwell body. It is called a Voigt or Kelvin body when the same are placed in parallel.

The four-element model is simple yet it approximates the elastic response and the first two stages of creep. The spring, E_2 represents the instantaneous response of the material. The Kelvin body represents the primary, sometimes called delayed-elastic response, stage of creep. The dashpot, η_2, represents the secondary creep. The model is restricted to uniaxial condition with no inertial effect. The constitutive relationship for the Maxwell-Voigt model can be derived from statics and is given below:

$$\varepsilon(t-t_o) = \sigma\left[\frac{1}{E_2} + \frac{1}{E_1}\left(1 - e^{-\frac{t-t_o}{\tau}}\right) + \frac{t-t_o}{\eta_2}\right] \quad [5]$$

where $\tau = \dfrac{\eta_1}{E_1}$

t_o = time of loading

τ is called the retardation time. It is the time necessary to achieve about 63 percent of the primary creep.

It can be seen from Eq.5 that the material constants are independent of the load intensity. Thus, the creep-compliance function J(t), defined as the ratio of the strain history to the applied stress, is as follows:

$$J(t) = \frac{\varepsilon(t)}{\sigma} \quad [6]$$

The creep compliance may be redefined more specifically in terms of the load-displacement response as follows:

$$J^*(t) = \frac{\Delta(t)}{P} \quad [6A]$$

However, most materials do not follow the behaviour depicted by such simple model. A more realistic phenomenological model is that shown in Figure 1.3. A real material actually has many retardation times which are characterized by the retardation spectrum (Alfrey 1948). Nevertheless, it is not necessary to know the retardation spectrum in order to solve some simple creep problems. Only the creep-compliance function is required because it actually contains the retardation times.

1.2.4 Boltzmann's Principle of Superposition

If a material's behaviour indeed follows that of linear theories, then superposition techniques can be employed to solve a problem by parts. Boltzmann's principle of superposition states that the effects of mechanical history are linearly additive (Nielsen 1962). Equations 3 and 4 are actually the mathematical representations of this principle. This means that the response of a material is the cumulative effect of all previous excitations. The application of this principle is illustrated in Figure 1.4 for the creep problem. Three sustained static loads of different magnitudes are introduced at various times to a system. Both the loads and the time-dependent deformations are simply summed to obtain the total excitation and total response respectively.

1.2.5 Isochrones & Fractional Deflections

The application of Boltzmann's principle of superposition is one way of confirming if a material behaves in a linear viscoelastic manner. Two other methods – isochrone (Ward 1971) and fractional deflection – can also be applied.

If one carries out a number of creep tests under various intensities of stress and plot the data on the orthogonal axes representing the stress, strain, and time, a three-dimensional surface as shown in Figure 1.5 is obtained. If one slices into the space at selected points along the time axis, a set of isochronous stress-strain curves is obtained. If a material is linear viscoelastic, then the isochronous curves should be straight as shown in Figure 1.6; it can be seen that each stress-strain curve is analogous to that found in the standard short-term material testing. The time associated with each curve may be viewed as the amount of time consumed in reaching the designated test load. For a material that has non-linear viscoelastic behaviour, the curvature of each line becomes more pronounced as the elasped time increases.

Fractional deflection technique is another way of identifying linear behaviour. Fractional deflection is defined as the ratio of the total deflection and the instantaneous deflection. The ratio is expressed in Eq.7 below:

$$FD(t) = \frac{\Delta(t)}{\Delta_i} \qquad [7]$$

The relationship between the creep-compliance function $J^*(t)$ and the fractional deflection can be established using Eqs. 1A and 6A as follows:

$$FD(t) = J^*(t) \cdot K_2 \quad \geq 1.0 \qquad [8]$$

It can be seen that, in terms of dimensions, the creep-compliance function J*(t) is the inverse of the spring constant K_2. If a material is linearly viscoelastic, the fractional deflections associated with various load intensities will also be identical.

In many literatures, the term fractional creep or relative creep is often used (Gnanaharan & Haygreen 1979). Relative creep is usually defined as the ratio of creep deformation and the instantaneous deformation. It is obvious that the relationship between the fractional deflection and the relative creep is that their absolute difference is one.

1.3 Oriented Strandboards

A piece of oriented strandboard panel basically consists of layers of nearly oriented wood flakes which are held together with well distributed resin. The flakes can be originated from various species of wood (CAN3-O437.0-M85 1985). Oriented strandboard (OSB) is a reconstituted wood product manufactured in Alberta from Aspen wood. The demands for this wood product have increased substantially since its entrance into the market. Panels are usually available in 1220 mm x 2440 mm with thickness varying between 6.35 to 38.1 mm.

The Alberta-made panels are usually composed of two surface layers and a core layer. The flakes in the surface layers are oriented parallel to the length of the panel. In order to reduce the effect of moisture on the dimensional stability of the panel, the flakes in the core layer are oriented perpendicular to the length of the panel. When the orientation of the flakes on the surface is aligned with the direction of the load, the panel is loaded in the parallel-to-grain direction. The panel is loaded perpendicular-to-grain if the alignments of the load and that of the flakes on the surface are orthogonal to each other.

As for many wood-based products, OSB panel exhibits a significant amount of creep deformation. The following variables, without considering the order of importance, are deemed significant in contributing to the creep of the oriented strandboard:

- time
- stress level
- relative humidity
- temperature
- grain orientation
- shelling ratio
- resin content
- board density

Stress level is defined as the ratio between the actual initial stress and the maximum strength of the material. The ratio between the thickness of the two surface layers and that of the panel is called shelling ratio. By varying the shelling ratio, resin content, and board density, one can alter the stiffness and the strength of the panel.

1.4 Stressed Skin Panels

A stressed skin panel (SSP) is made up of two primary components. These two components are webs and flanges. The flange component is often called a skin because it is usually made out of a thin sheet of material. The skin and the web are bonded together to form a composite unit. The panel is usually used as a flexural member. When loaded in bending, the skin of the panel are more-or-less subjected to axial stresses. The skin becomes the major load-carrying component.

A wooden SSP is generally made out of plywood skin and dimensioned lumber as shown in Figure 1.7. The components are bonded together with resin. Nails are often used to maintain the pressure on the glueline while the glue is cured. When the bottom skin is excluded, the arrangement gives a cross section which resembles a series of tee-beams. The design of wooden SSP has been documented in various publications. An example can be found in "Plywood Construction Manual" published by The Council of Forest Industries of British Columbia (COFI 1976). Data are only available where Douglas fir plywood is used as the skin of the panel.

1.4.1 Deflection Calculations

When one wishes to determine the deflections of a simply-supported beam, methods such as moment-area method can be used. Spring analogy can also be used to determine the deflections. If one uses the type of formulation shown in Eq.1A, the deflection of the beam at a specific location along the beam, can be represented with a translational spring. The spring constant can be determined using methods such as virtual work. It contains information such as the beam stiffness, span length, and loading configuration. For the three-point load shown in Figure 1.8a, the spring constant, K, is given in Eq.9 for the midspan location.

$$K = \frac{48\ E\ I}{L^3} \tag{9}$$

where the product of E and I is called flexural stiffness. Eq.9 is simply a result of manipulation of the standard deflection equation for the three-point loading condition.

In order to calculate the deflection of a simply supported SSP, the composite flexural stiffness of the section must be known because different materials are present. The composite flexural stiffness can be obtained by applying the spring analogy. The cross section basically consists of two components - skin and webs. Each component can be replaced with a translational spring as shown in Figure 1.8c. By enforcing displacement compatibility requirement, the springs are placed in parallel. For each component, the modulus of elasticity needed in Eq.9 is obtained from the bending test; the moment of inertia is calculated based on the geometry of the composite cross section. One has to keep in mind that this set of springs represents a particular location in the span. In applying this idealization, the following assumptions are invoked:

1. components are linear elastic.
2. shear deflection is ignored.
3. plane section remains plane.
4. the tensile behaviour is the same as that in compression.

1.5 Scope and Objectives

There is a need to determine the material properties of OSB panels. Engineering data must be gathered in order to develop proper design criteria. It is important to know if the material will exhibit creep rupture behaviour under sustained service load conditions. Another problem is associated with deflection serviceability; does the material, by itself or as a component of a composite structure, creep excessively during its service life?

The main purpose of this investigation is to determine if linear viscoelastic theory can be applied to OSB in flexure; therefore, the subject of creep rupture is not considered here. Also, bending moments are used as the sustained excitation instead of stress as originally defined for creep.

In order to gain some insight into the design of viscoelastic structures, the research will also study the flexural creep behaviour of a composite panel that is made of two different viscoelastic materials. The panel is similar to the type of wooden SSP introduced earlier. The panel's cross section actually resembles that of a composite box beam. The webs are made of S-P-F lumber and the flanges (skin) are made of OSB. The shear lag phenomenon associated with the box beam will not be considered here. The environmental effects on the flexural creep behaviour of the OSB and SSP will also be observed.

There are four objectives in this investigation:

1. carry out flexural creep tests, in both environmentally controlled and uncontrolled conditions, to observe the time-dependent behaviour of OSB panels, S-P-F lumber, and SSP's.

Based on the test results:

2. to determine the applicability of Boltzmann's principle of superposition for both OSB and SSP.
3. to analyze the creep deflection of SSP based on components' (OSB and lumber) behaviour obtained experimentally; compare the calculated results against that of the test data.
4. to compare the long-term deformation characterisitcs of the creep specimens tested under controlled and uncontrolled environmental conditions.

There are three criteria used in the design of the SSP:

a). The initial centerline deflection of the panel, that will be subjected to multi-step loadings, does not exceed 1/550 of the span length.

b). The superimposed loads should be within the range anticipated in actual service.

c). The S-P-F lumber used in the SSP is assumed to be a linear viscoelastic material within the stress range considered.

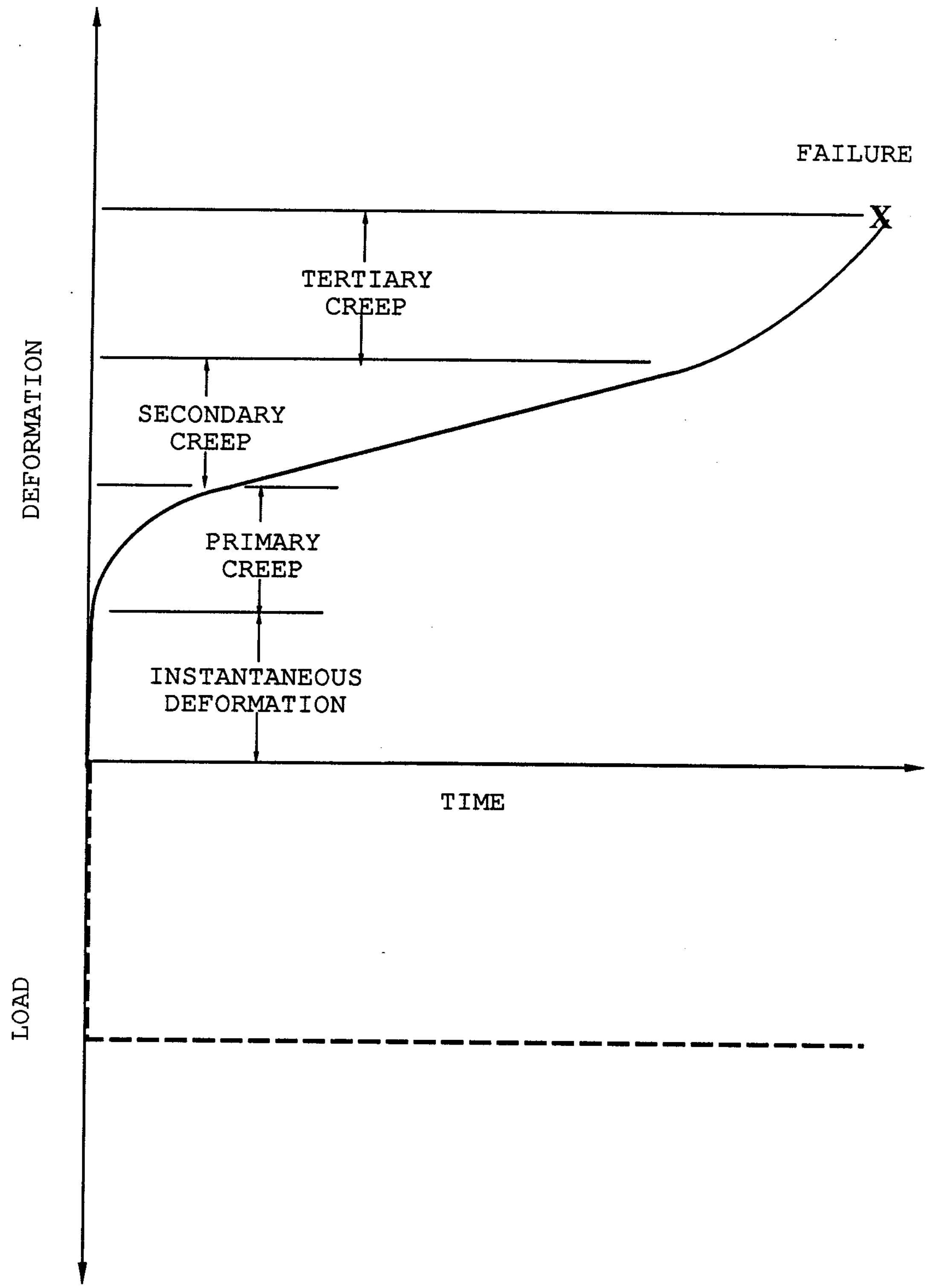


FIGURE 1.1 THREE STAGES OF A CREEP CURVE FOR A VISCOELASTIC MATERIAL UNDER SUSTAINED SUSTAINED LOAD CONDITION

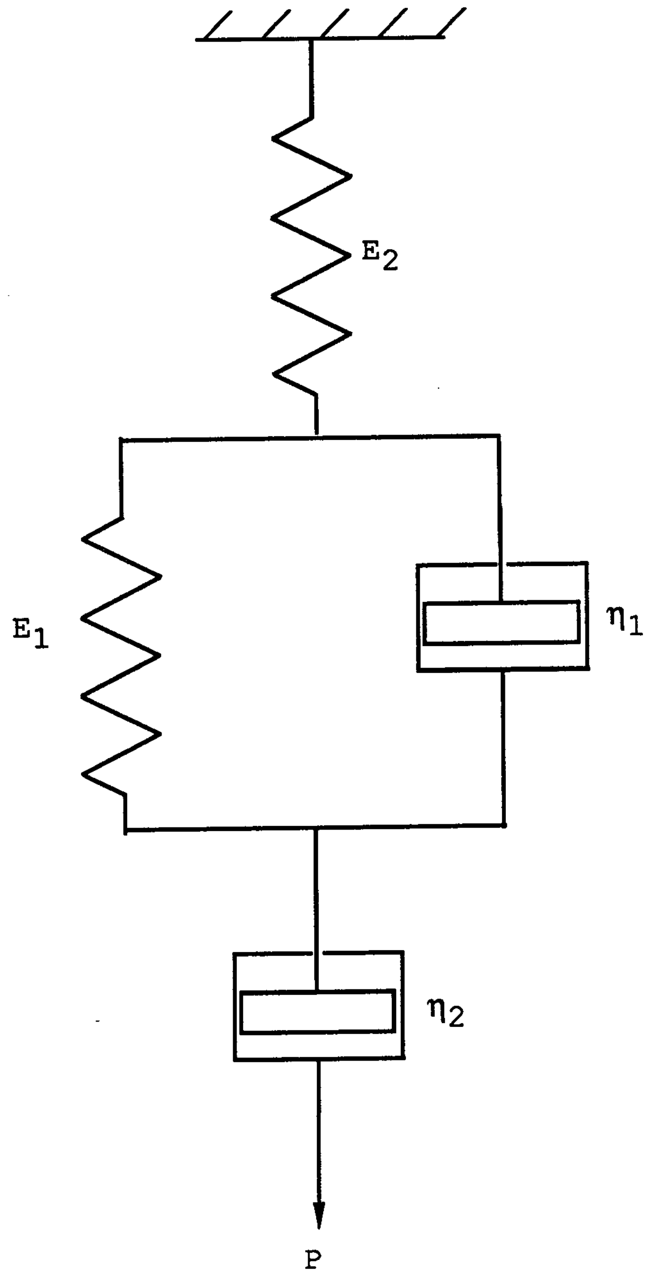


FIGURE 1.2 MAXWELL-VOIGT MODEL

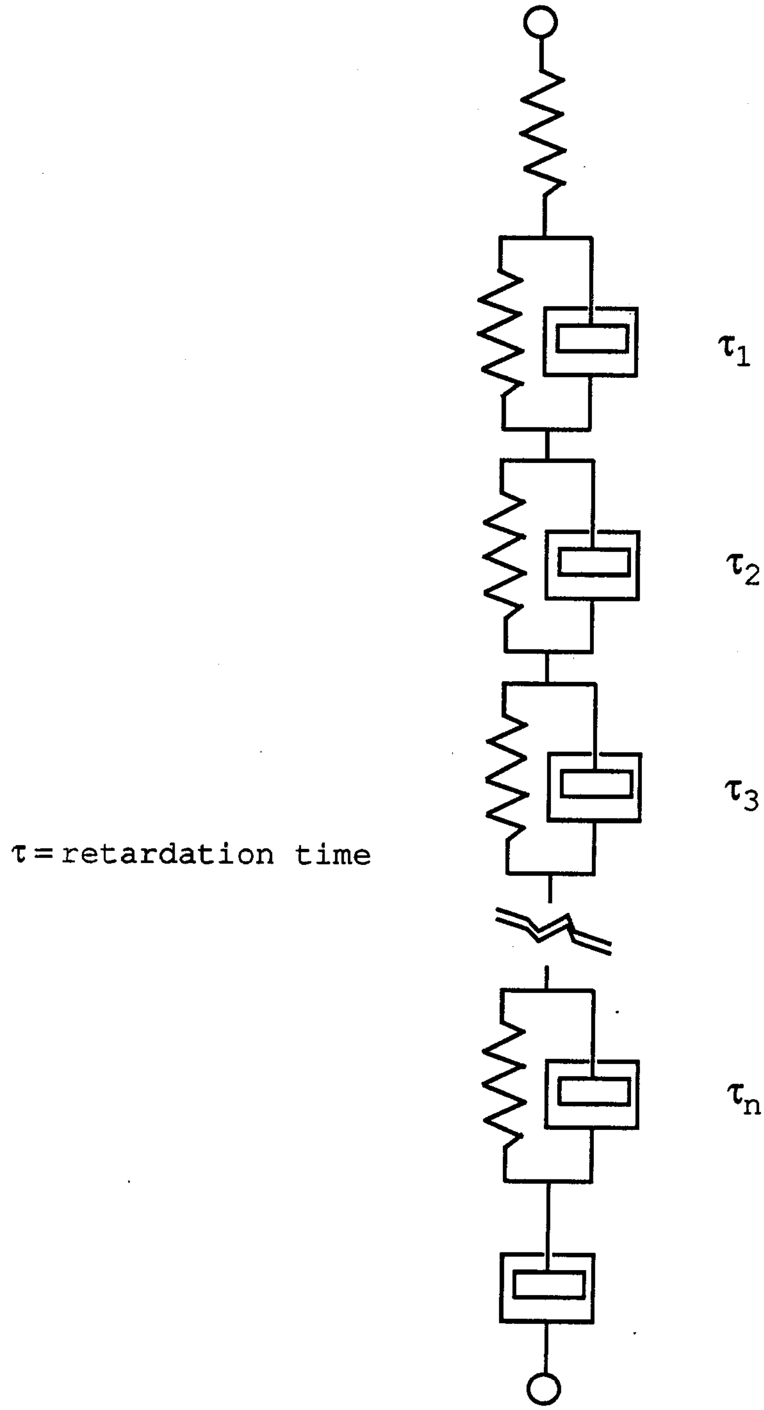


FIGURE 1.3 A MAXWELL ELEMENT IN SERIES WITH MULTPLE NUMBER OF KELVIN ELEMENTS

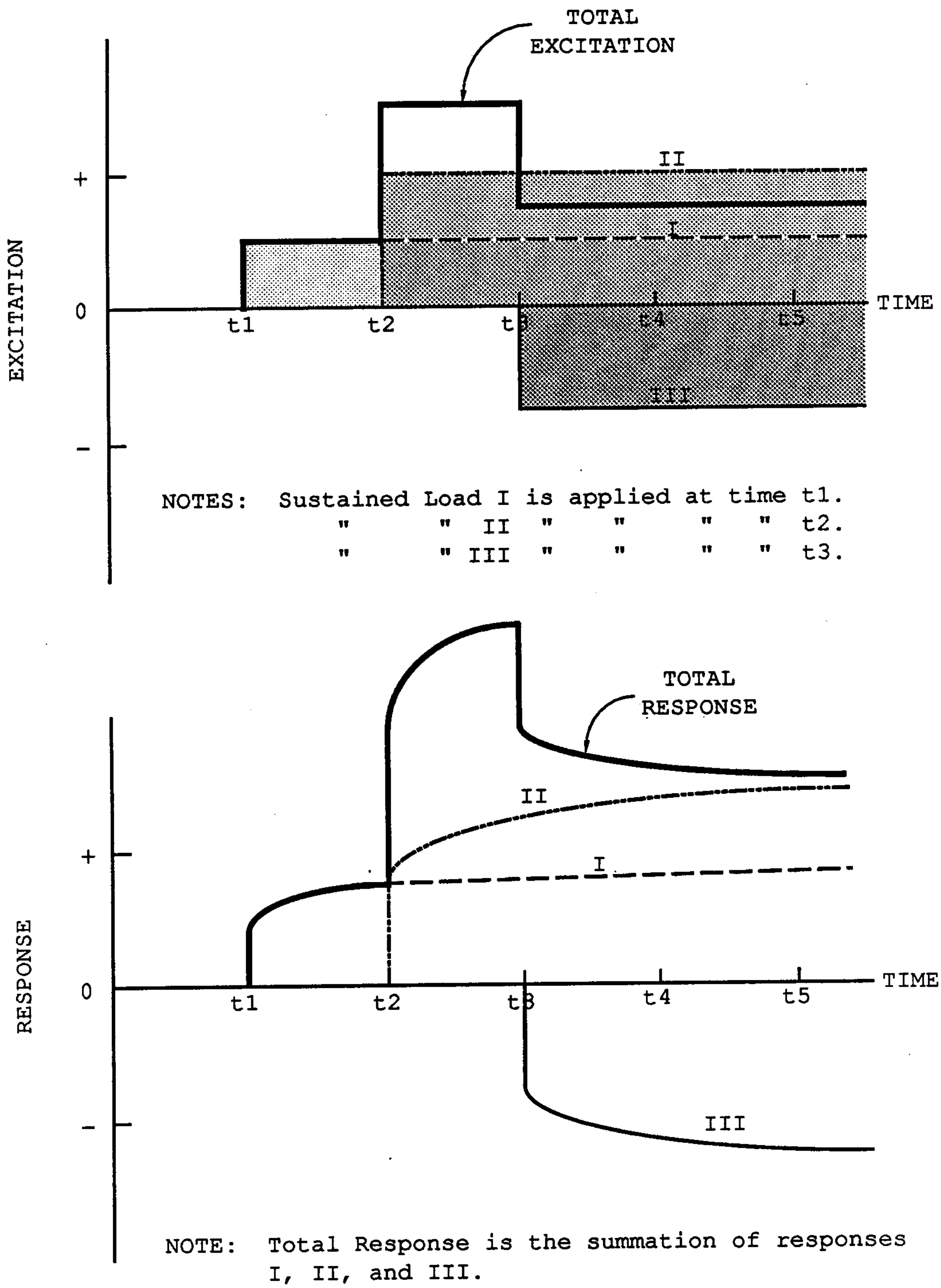


FIGURE 1.4 ILLUSTRATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION

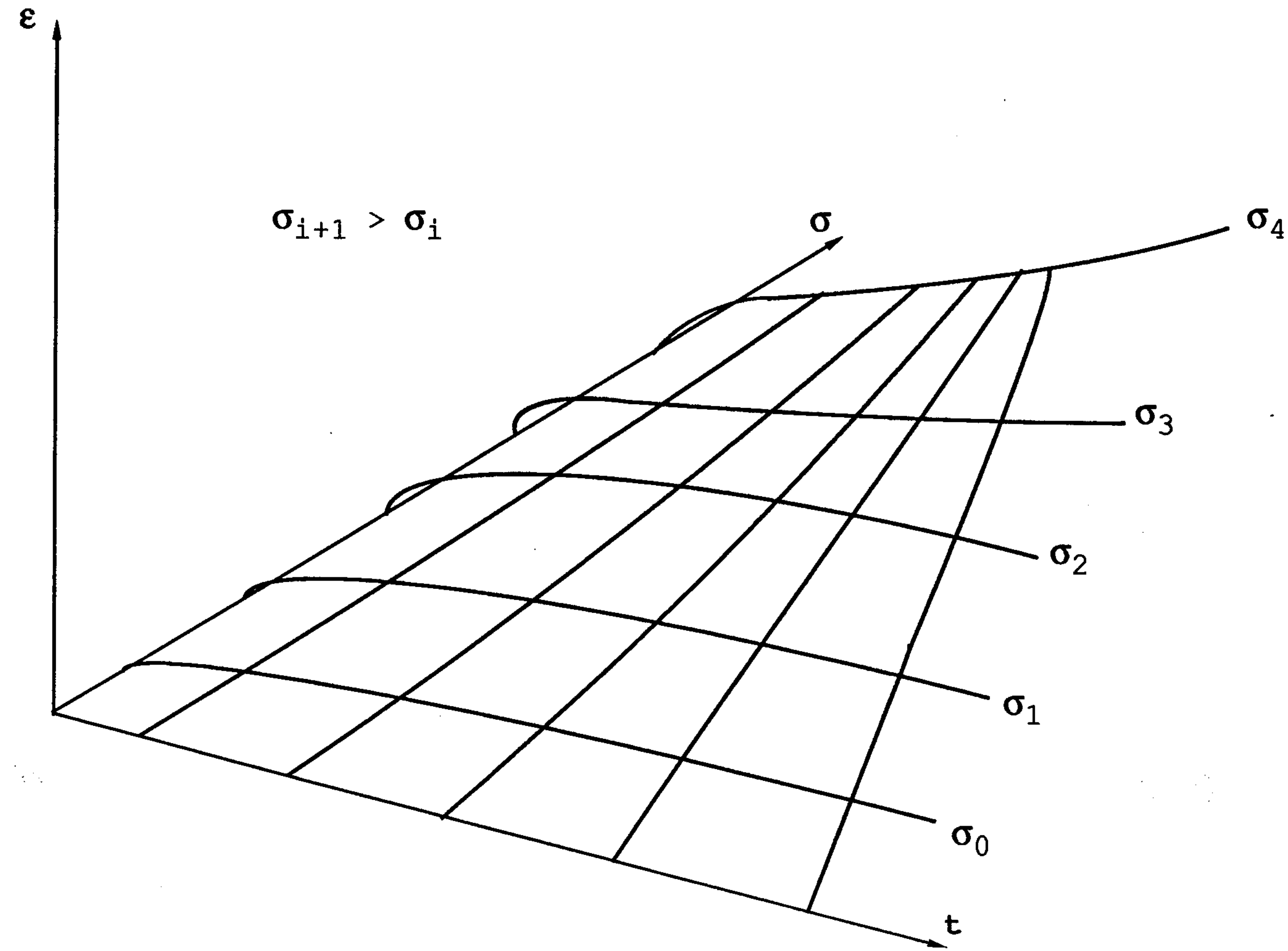


FIGURE 1.5 GENERAL STRESS-STRAIN-TIME SURFACE

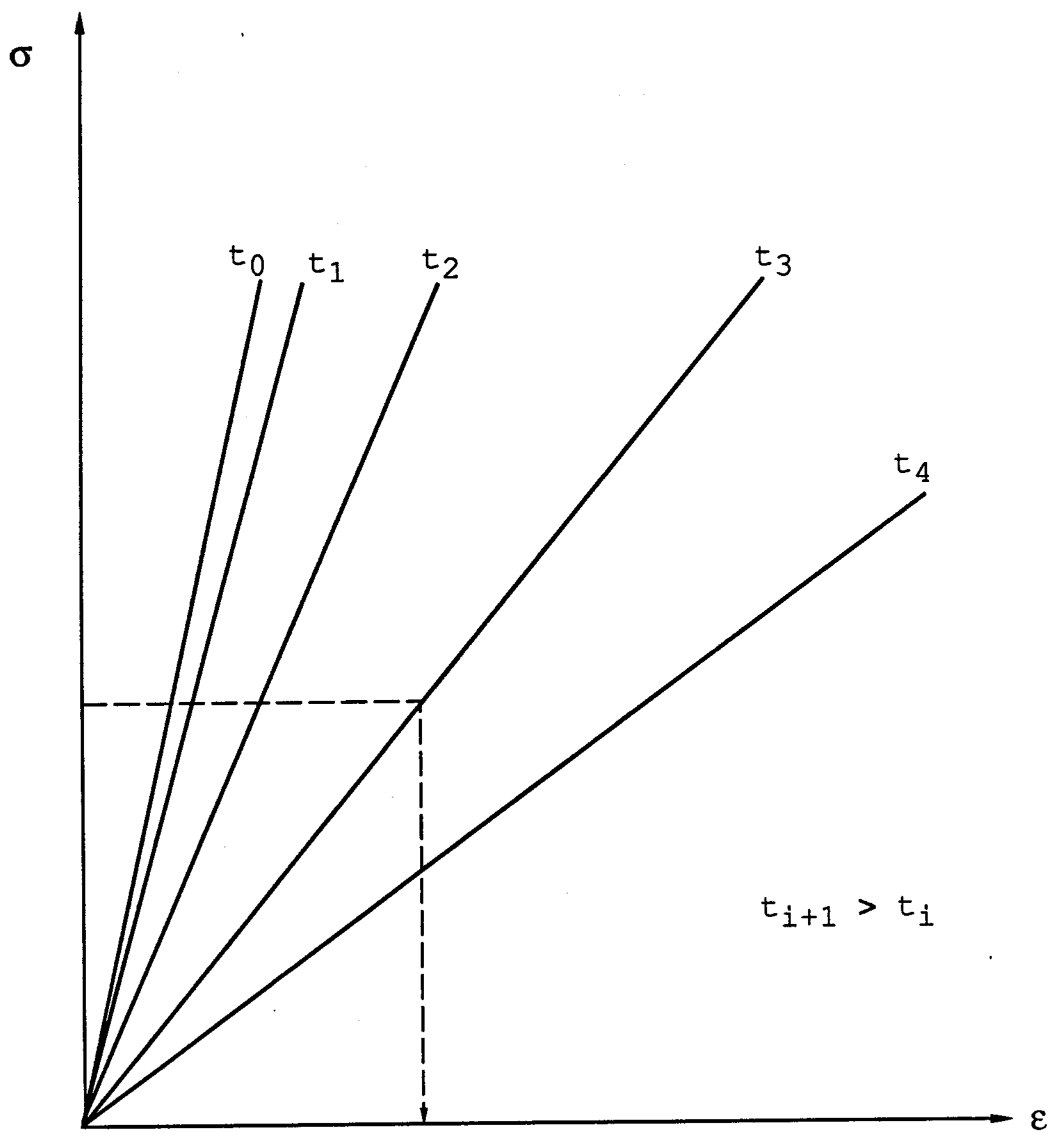


FIGURE 1.6 ISOCHRONOUS STRESS-STRAIN CURVES FOR AN IDEALIZED LINEAR VISCOELASTIC MATERIAL

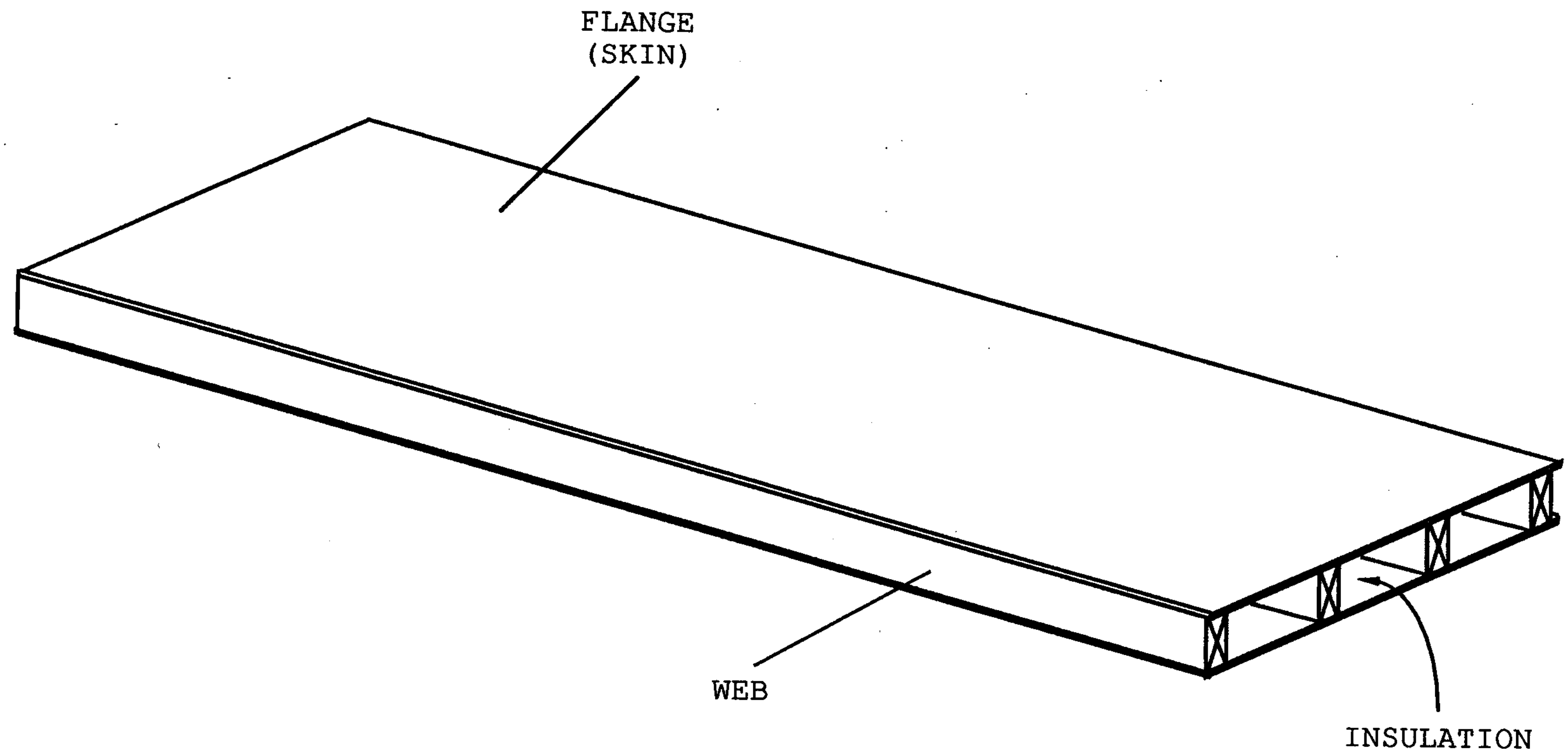
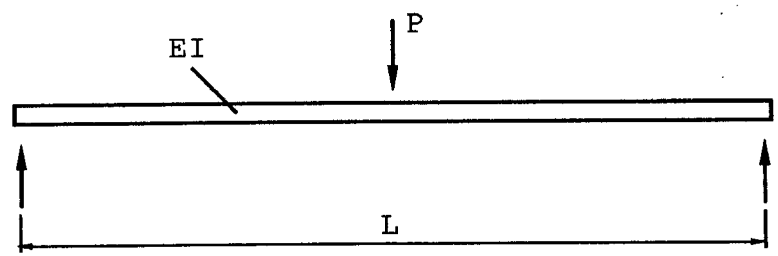
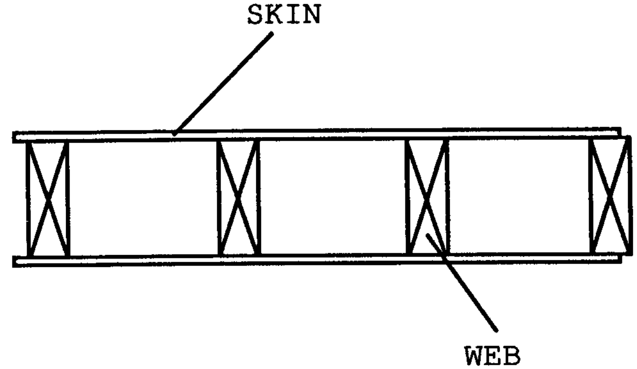


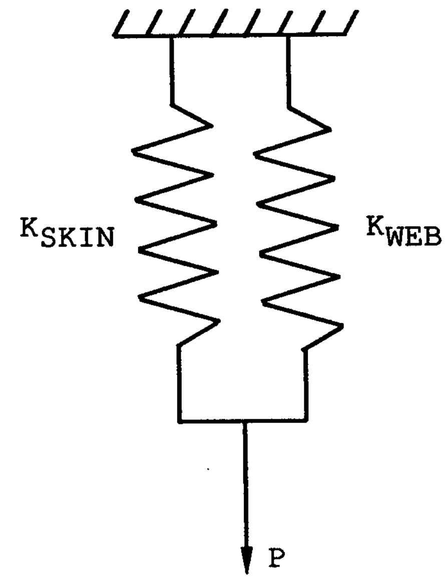
FIGURE 1.7 TYPICAL WOODEN STRESSED SKIN PANEL DETAIL



1.8a THREE-POINT LOADING CONFIGURATION



1.8b CROSS SECTION OF A STRESSED SKIN PANEL



1.8c SPRINGS IN PARALLEL

FIGURE 1.8 DETERMINATION OF FLEXURAL STIFFNESS OF SSP USING SPRING MODEL

2. EXPERIMENTAL PROGRAM

2.1 General

The experiment was divided into two parts. The first part, called short-term testing, was to determine the material properties of the S-P-F lumber and the oriented strandboards (OSB). The second part, called long-term testing, was to determine the time-dependent deflection behaviour of the lumber, OSB panels, and their assembled version — stressed skin panels (SSP).

A portion of the short-term testing was carried out at the I.F.Morrison Structural Laboratory, The University of Alberta. The other portion was carried out at the Forest Products Testing Laboratory, Alberta Research Council.

The majority of the long-term testing was carried out in Building F-34 located in the Edmonton Research Station, The University of Alberta. The materials in this group were subjected to static flexural loads for ninety days. A small portion of the creep testing was done at the I.F. Morrison Structural Laboratory. The specimens in this group were subjected to a constant compressive load for more than 100 minutes. The compressive creep tests were done to check if there is any appreciable difference between the axial and flexural creep behaviour in the OSB.

The four parameters chosen in the flexural creep experiment were:

- stress level

- relative humidity
- temperature
- grain orientation.

A total of forty flexural specimens were creep tested. Table 2.1 identifies the types and the distribution of specimens used in the flexural creep tests. Parallel-to-grain means that the directions of the forces resulting from bending are parallel to that of the flakes on the surface of the OSB panel. There were two types of sustained loading schemes used — step and constant. Loading scheme A (step-sustained loads) is illustrated in Figure 2.1a. All steps had the same magnitude and duration of load. Loading schemes B, C, and D (constant-sustained loads) are illustrated in Figure 2.1b. The durations of these loadings were the same. Scheme D had a load which was triple that of B and only 1.5 times that of C. The magnitude of each step-sustained load found in Scheme A was 1/3 of that found in Scheme D.

2.2 Test Materials and Sample Preparations

The amount of wood products used for the entire experiment is listed below:

Material	Quantity	Dimensions[1] (mm)
Oriented Strandboards	15	1220 X 2440 X 6.35 thick
S-P-F Lumber	15	38 X 140 X 3660 long

[1]Dimensions specified hereon are approximate values only.

These materials were produced in Alberta. The OSB panels were purchased directly from the mill. The lumber was purchased from a local lumber dealer. The grade of the lumber was No.2 or better. The adhesive used for all fabrication was resorcinal resin. It was provided by Western Archrib Ltd. in Edmonton. The assembly of the SSP's and OSB compression specimens was done in the vacant building.

2.2.1 S-P-F Lumber

The cross-sectional dimensions of each lumber specimen was set at 38 X 64 mm for this experiment. Therefore, each piece of the original lumber was sawn in half at the lumber yard. The lumber was air-dried to an average moisture content of 16% prior to sawing. A total of thirty 38 X 64 X 3660 mm long lumber was actually received. Average moisture content of the specimens was obtained using representative samples that were cut from the same batch. The average mass density of the lumber was determined after the shipment arrived.

The specific cutting patterns are summarized in Appendix A. Eight pieces of 64 X 38 X 2440 mm lumber were subjected to long-term bending tests. The same number of specimens was used in the short-term testing. The dimensions of these specimens were 38 X 64 X 1220 mm.

2.2.2 Oriented Strandboard Panels

Fifteen pieces of OSB panels were cut into various sizes according to the cutting patterns shown in Appendix A. Each specimen was coded so that the origin of the specimen and the type of test that it would be subjected to could be readily identified. The selection of panels was made randomly.

Alpha-numeric format was used in the coding. An example of the code would be 10FC15B. Table 2.2 gives a summary of the allocation of OSB flexural creep specimens which have been coded. The first entry , a number, represented which full-size panel (1220 X 2440 mm) that the specimen was cut from. The second entry, two letters, denoted the type of test that the specimen would be subjected to. The first letter corresponded to the test – flexural (F) or compression (C). The second letter identifed the duration of the test – short-term strength (S) or creep (C). The third entry in the specimen's code was a number which was assigned to that particular specimen. The last entry, a letter, indicated whether the specimen was loaded parallel-to-grain (A) or perpendicular-to-grain (B). The third and fourth entries were given only if there was duplicate samples cut from the same full-size panel (No.12 to 15). The dimensions and quantities of OSB specimens used in all the tests are summarized in Table 2.3.

There was a total of twelve compression specimens prepared as listed in Table 2.3. A typical OSB compression specimen is shown in Figure 2.2. The sandwiched structure was held together by resorcinal resin. The fabrication details are shown in Appendix A. The waxy surface of each piece of OSB panel was sanded down before the application of glue. Two C-clamps were used to maintain the pressure on the glue during curing process. The specimens were cured under ambient conditions for at least 48 hours before the clamping pressure was released. Prior to the tests, each specimen was trimmed to rid the excess glue that was squeezed out during clamping. The squareness of the specimen was also corrected at this time.

2.2.3 Stressed Skin Panels

The details of the SSP is illustrated in Figure 2.3. After the skeleton or the webs were nailed together, resorcinal resin was applied to one side. A piece of OSB panel was then nailed onto the glued surface. Due to the difficulty of obtaining the desired size of common nails, 32 mm long underlay ring nails were used to maintain the pressure on the glue lines. The same procedure was then repeated for the other side. In selecting the top and bottom skin, their flexural elastic moduli were matched as close as possible. The same selection criterion was used for the lumber webs. The SSP's were cured under the same conditions as that for the compression specimens. The distribution of the SSP's, randomly numbered 1 to 11, is shown in Table 2.4. The letter suffix denotes the type of loading scheme.

2.3 Mechanical Test Equipment and Procedures

With the exception of the SSP's, flexural specimens were machine stiffness rated to determine their stiffnesses in bending non-destructively. The test set-up is illustrated in Figure 2.4. The apparent modulus of elasticity was determined using a three-point loading system. The machine stiffness rating device was programmed to measure the total intensity of the line load exerted on a specimen with a preset deflection. The load was recorded when stress-relaxation was sensed.

2.3.1 Short-term Tests

2.3.1.1 Bending

Each specimen was tested to failure under a three-point loading configuration. The centerline deflection of each specimen was measured with a linear variable differential transformer (LVDT). The load-deformation relation was tracked with an X-Y recorder. The maximum load and time to failure were recorded. Moisture contents were determined after the completion of the destructive tests.

The lumber specimens were tested using an universal testing machine with 1000 kN capacity. The procedures used were similar to that outlined in the ASTM standard D198-84

(1985). Each specimen was tested with the 64 mm side being the vertical face. The test set-up is shown in Figure 2.5.

The OSB specimens were tested using an Instron Universal Testing Machine with a capacity of 5 kN. The test set-up is illustrated in Figure 2.6. Procedures found in the CAN3-O437.1-M85 (1985) were followed for this particular test segment.

2.3.1.2 Compression

The procedures outlined in the ASTM D3501-76 (1985) were followed closely in determining the compression properties of OSB panels. The test set-up is illustrated in Figure 2.7. The axial deformation was measured with a LVDT attached to a circular aluminum frame. The frame was clamped onto the rectangular specimen at the top and bottom with two and four screws respectively. The circular frame was originally used for testing concrete cylinders. The load-deformation relation was also tracked with an X-Y plotter. The maximum load and time to failure were recorded.

2.3.2 Long-term Tests

2.3.2.1 Environmental Controls

The flexural creep tests were carried out in both controlled and uncontrolled environments. The controlled environment was maintained at about 70 % relative humidity (R.H.) with a temperature range of 18 to 23 °C. The uncontrolled environment was similar to that found in a warehouse equipped with a natural-gas furnace. The lower temperature limit was kept at 18 °C inside and outside the chamber with this furnace.

One half of the vacant building was set aside for the environmentally uncontrolled creep experiment. The other half was to house the environmental chamber so that identical creep tests could be done inside this chamber. The uninsulated chamber was built specifically for the experiment. It was equipped with a humidifier and a dehumdifier. These two units were activated by an electronic controller through a sensing unit with an accuracy of ± 2 % R.H. Although the chamber was not insulated, the upper temperature limit of 23 °C was kept with the aid of an air conditioner. The cooling unit was activated by an in-line thermostat. The air was recirculated continuously with two fans.

In the environmentally uncontrolled area, the air circulation was also maintained with two fans. The temperature and relative humidity were monitored with a sensor. The sensor has an accuracy of ± 2 % R.H. and ± 1 °C. The signals from this sensor were recorded on an X-T plotter.

The two sensors, mounted inside and outside the chamber, were also backed up by assorted types of hygrometers in the event of an electrical failure or equipment malfunction.

2.3.2.2 Bending

For the specimens that would be subjected to constant environment during the creep period, they were preconditioned in that same environment for thirty days. These specimens were machined stress rated again prior to the creep tests.

The experimental set-up for the flexural creep tests is shown in Figure 2.8 schematically. The types of loads, load distribution systems, and methods of measurement are summarized in the table located above the figure. The centerline deflections were measured for both the SSP and OSB specimens. Deflection in the pure moment region was measured for the lumber as shown in Figure 2.9.

There were two types of supports used for the SSP as illustrated in Figure 2.10. The specimen that is closer to the bottom of the figure had a roller/roller support. The other was supported on a roller/knife-edge system. The reason for using different supports was to determine if there was any appreciable difference in deflections under the same prescribed loads. Since there was a pair of SSP specimens assigned to load scheme A under each type of environment (total=4), each specimen in the pair was assigned a different support system. As a result, each environment would have a pair of SSP specimens with different supports. In addition, the two specimens (2A and 10A) supported on roller/knife-edge were also attached with demec points at midspan so that local longitudinal strains could be measured periodically during the tests. Figure 2.11 shows the locations of these demec points relative to the cross section of the panel. The gauge length for the demec points was 200 mm.

The deflection of a specimen would normally be determined from a datum. However, the effect of local crushing, at load points, on the deflections of these wood-based specimens was unknown. Dial gauges were instead attached to an aluminum frame as shown in Figure 2.12. The frame was designed to 'float' with the test specimen and to have a span that was identical to the specimen's test span. It was able to clear any obstacles so that it could be moved from one specimen to another. The midspan deflection of a SSP specimen was measured with two dial gauges mounted on each side of the aluminum frame.

Due to limited availability of test space, the lumber and the majority of the OSB (parallel-to-grain) specimens were supported by a steel frame as shown in Figure 2.13. Each environment had an identical arrangement. The mid-span deflection of an OSB specimen was measured with the same technique as that for the SSP. The aluminum frame for the OSB specimens is shown in Figure 2.14.

The deflections of the lumber specimens were measured with only one dial gauge as illustrated earlier in Figure 2.9. The lumber specimens were tested with the 38mm side being the vertical face.

There were three OSB specimens tested in the perpendicular-to-grain direction. The test set-up for these specimens is illustrated in Figure 2.15. The vertical position of the dial gauge was made adjustable because large deflection was anticipated. Effect of local crushing was ignored here.

2.3.2.3 Compression

The test set-up for these tests was identical to that for the destructive tests in compression. The load was maintained for a minimum of 100 minutes. During such time, the deformation was continuously tracked on an X-T recorder.

TABLE 2.1 SUMMARY OF QUANTITIES OF SPECIMENS USED IN THE FLEXURAL CREEP EXPERIMENT

LOADING SCHEME	TYPE OF SUSTAINED LOAD	TYPE OF SPECIMENS							
		SSP		OSB PARALLEL-TO-GRAIN		OSB PERPENDICULAR-TO-GRAIN		SOLID LUMBER	
		CO	UC	CO	UC	CO	UC	CO	UC
A	STEP (3)	2	2	3	3	0	0	0	0
B	CONSTANT	0	2	2	2	0	1	0	0
C	CONSTANT	1	2	2	2	0	1	0	0
D	CONSTANT	0	2	2	2	0	1	4	4
TOTAL QUANTITIES		3	8	9	9	0	3	4	4

NOTES: CO = CONTROLLED ENVIRONMENT
UC = UNCONTROLLED ENVIRONMENT

TABLE 2.2 IDENTIFICATION OF OSB SPECIMENS USED IN THE FLEXURAL CREEP EXPERIMENT

TEST ENVIRONMENT		CONTROLLED		UNCONTROLLED
GRAIN ORIENTATION		PARALLEL	PERPENDICULAR	PARALLEL
LOADING SCHEME	B	12FC4A, 13FC1A	13FC1B	6FC, 11FC
	C	12FC2A, 14FC1A	14FC1B	2FC, 10FC
	D	1FC, 15FC1A	15FC1B	7FC, 9FC
	A	4FC	---	3FC
		5FC	---	8FC
		12FC3A	---	12FC1A

TABLE 2.3 LIST OF OSB PANELS USED IN THE EXPERIMENTS

TYPE OF TEST	SURFACE GRAIN ORIENTATION	QUANTITY	DIMENSIONS (mm)
SHORT-TERM FLEXURAL	PARALLEL	18	75 X 210 X 6.35
SHORT-TERM FLEXURAL	PERPENDICULAR	9	75 X 210 X 6.35
LONG-TERM FLEXURAL	PARALLEL	18	300 X 1220 X 6.35
LONG-TERM FLEXURAL	PERPENDICULAR	3	300 X 1220 X 6.35
SHORT-TERM COMPRESSION	PARALLEL	3	100 X 350 X 55
SHORT-TERM COMPRESSION	PERPENDICULAR	3	100 X 350 X 55
LONG-TERM COMPRESSION	PARALLEL	3	100 X 350 X 55
LONG-TERM COMPRESSION	PERPENDICULAR	3	100 X 350 X 55
LONG-TERM FLEXURAL (SSP)	PARALLEL	22	445 X 2440 X 6.35

TABLE 2.4 IDENTIFICATION OF SSP SPECIMENS USED IN THE FLEXURAL CREEP EXPERIMENT

TEST ENVIRONMENT		CONTROLLED	UNCONTROLLED
LOADING SCHEME	B	---	9B, 11B
	C	1C	4C, 5C
	D	---	7D, 8D
	A	2A, 3A	6A, 10A

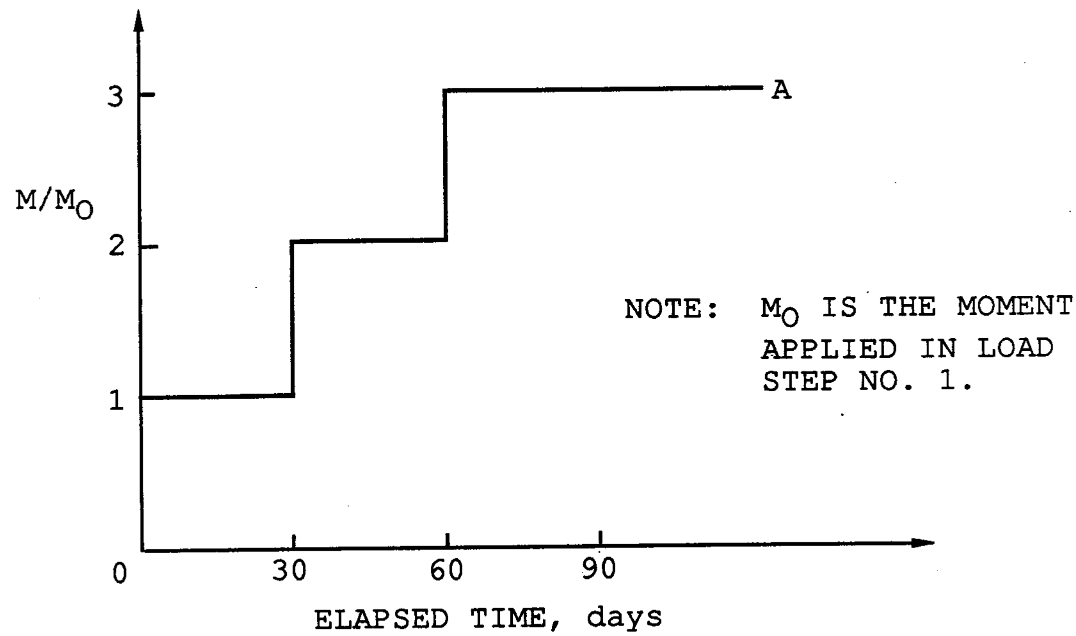


FIGURE 2.1a FLEXURAL LOAD HISTORY UNDER LOADING SCHEME A

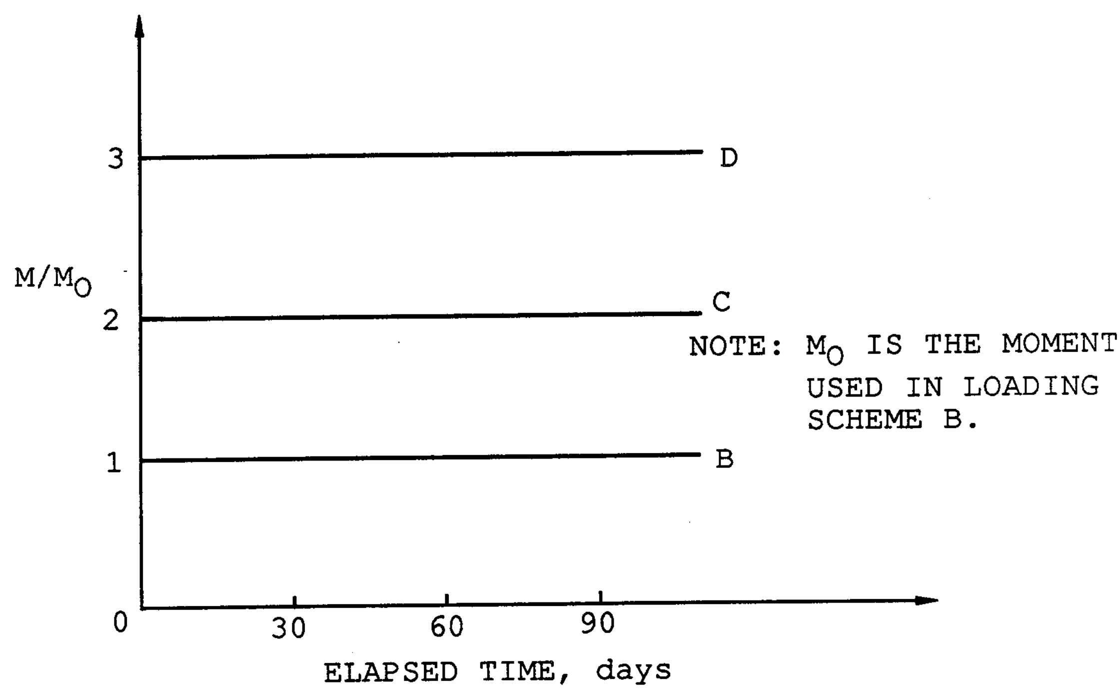
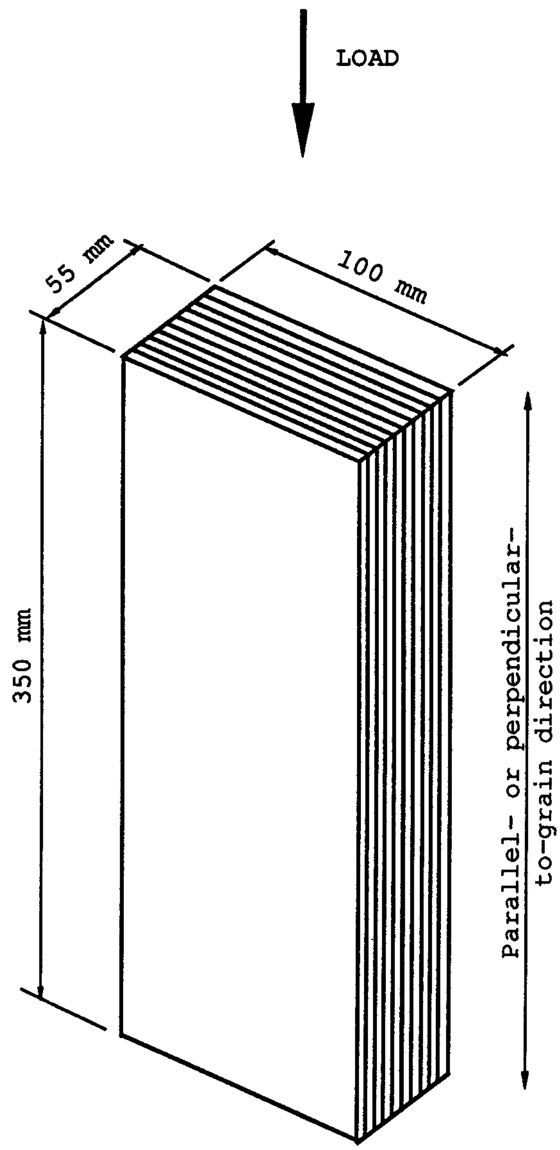
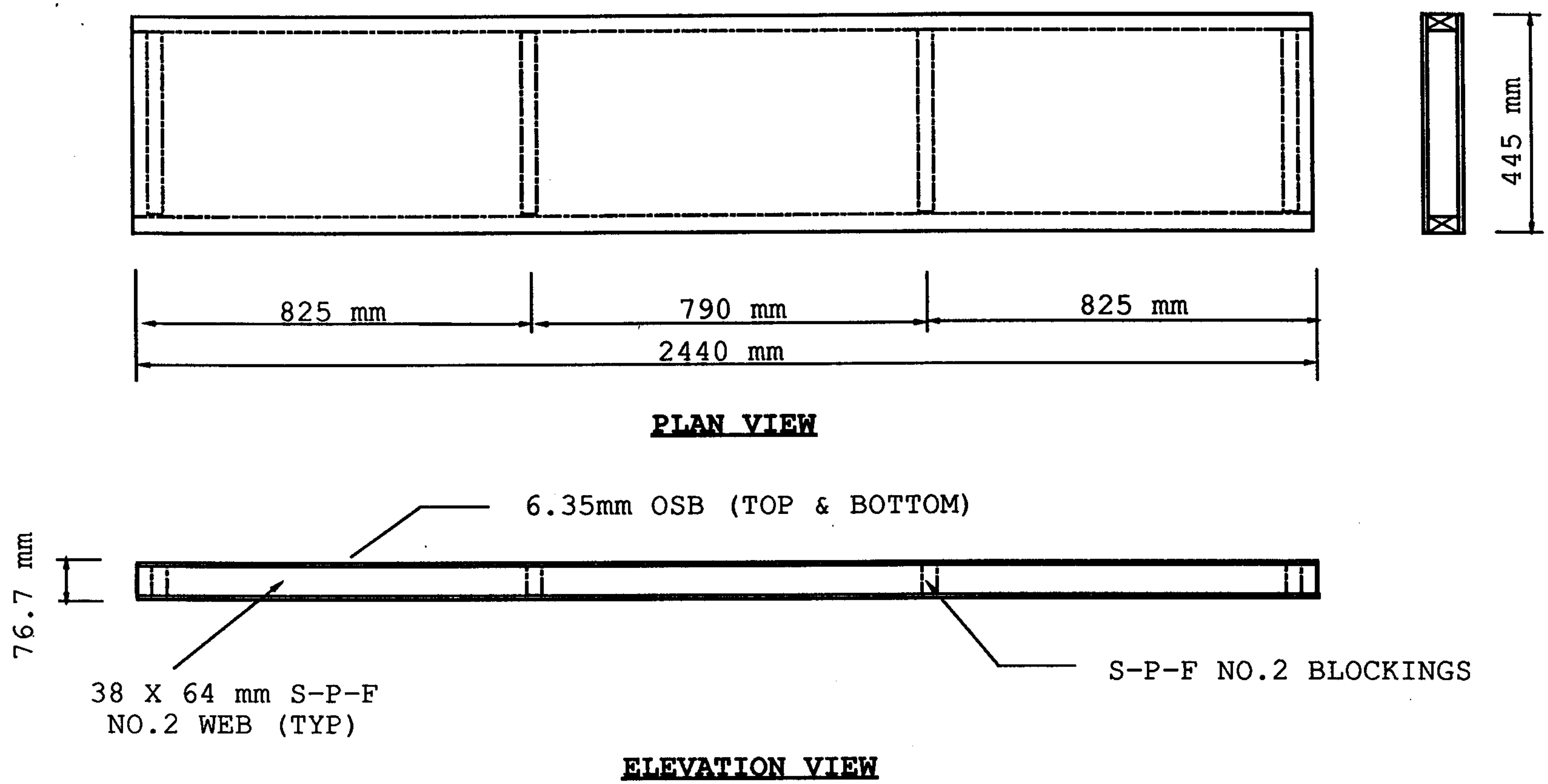


FIGURE 2.1b FLEXURAL LOAD HISTORY UNDER LOADING SCHEMES B, C, AND D



Note: Diagram is not drawn to scale.

FIGURE 2.2 OSB COMPRESSION SPECIMEN



Note: Diagram is not drawn to scale.

FIGURE 2.3 DETAILS OF OSB STRESSED SKIN PANEL

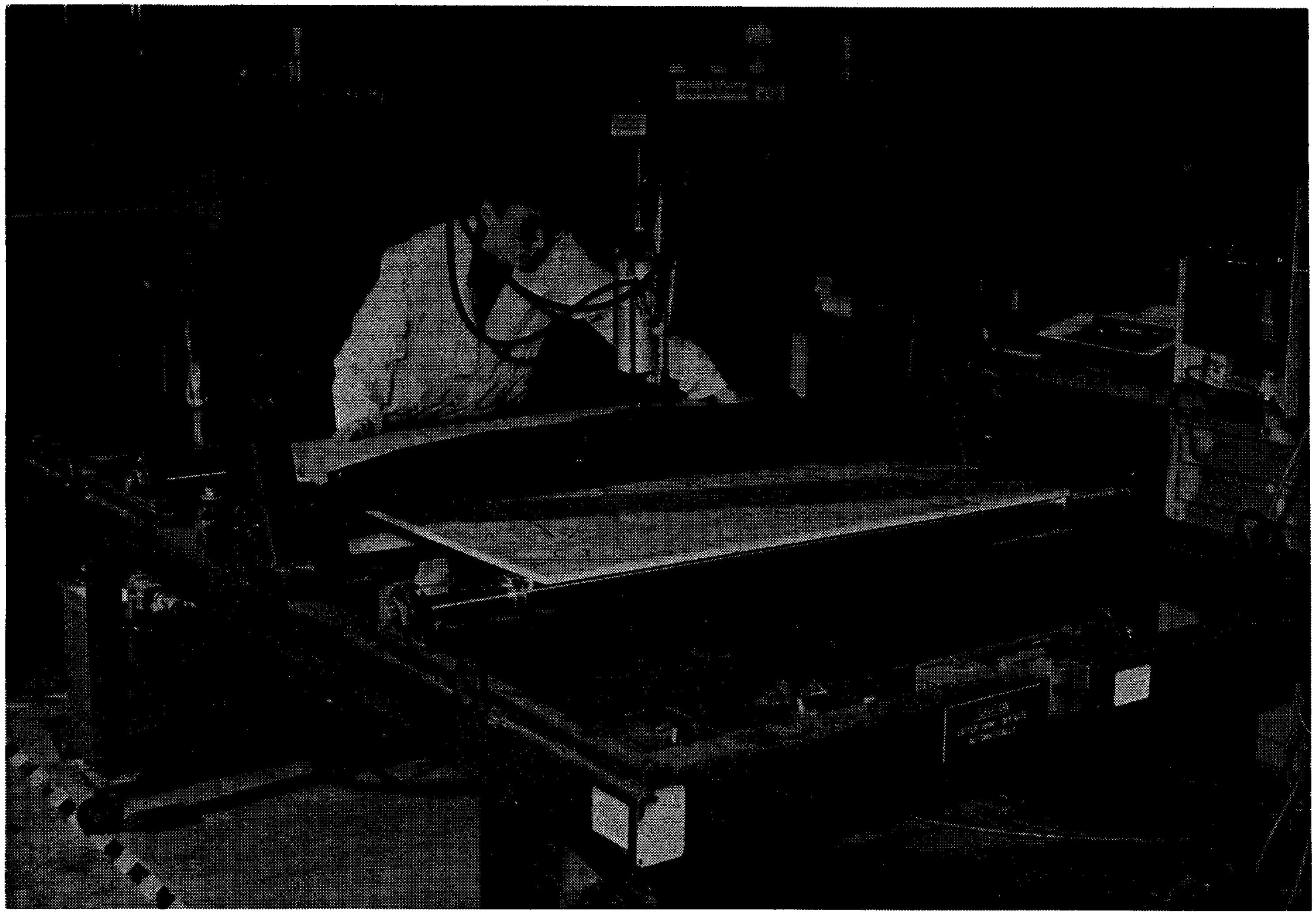


FIGURE 2.4 MACHINE STIFFNESS RATING DEVICE

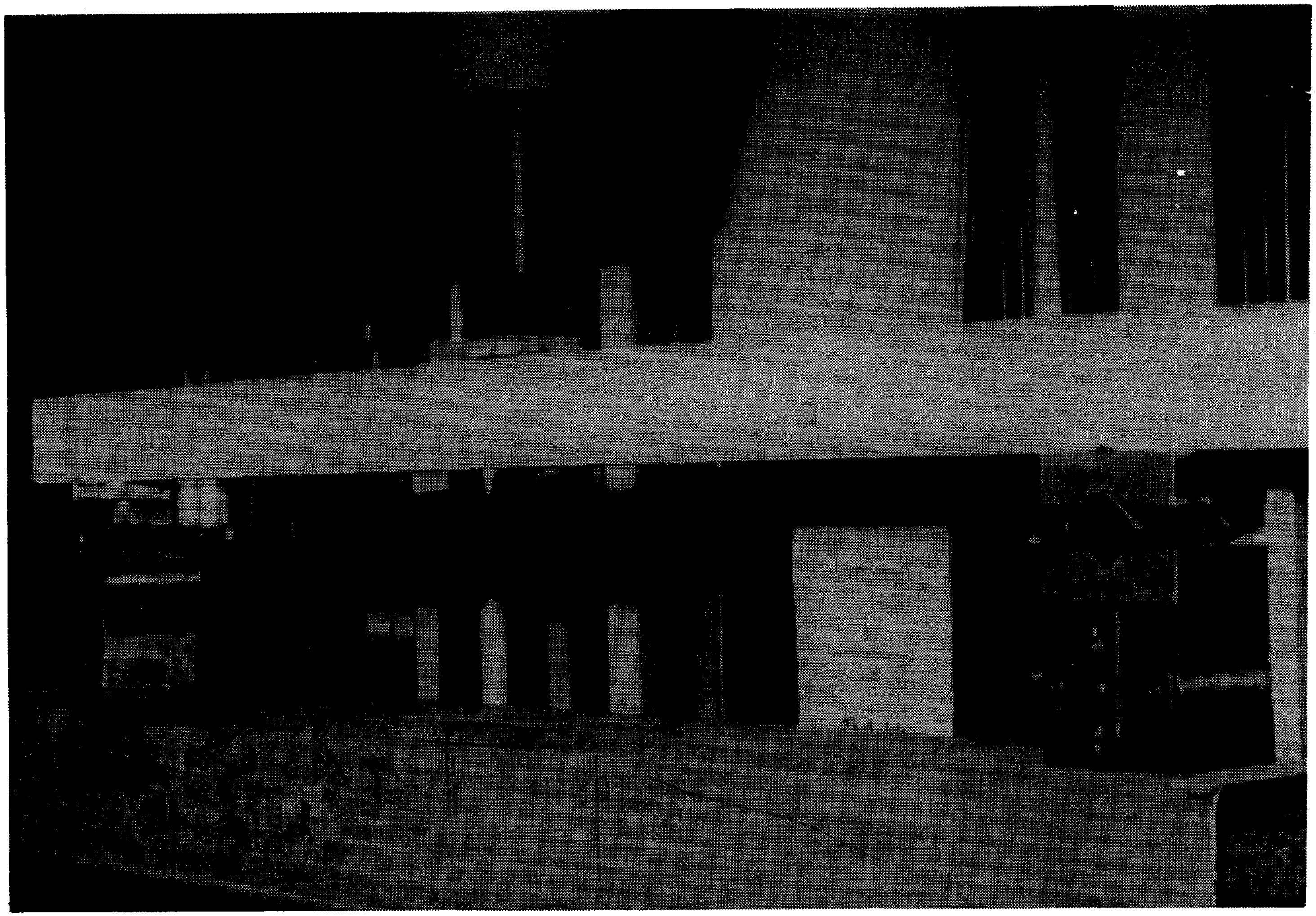


FIGURE 2.5 SHORT-TERM FLEXURAL TEST SET-UP FOR LUMBER SPECIMENS

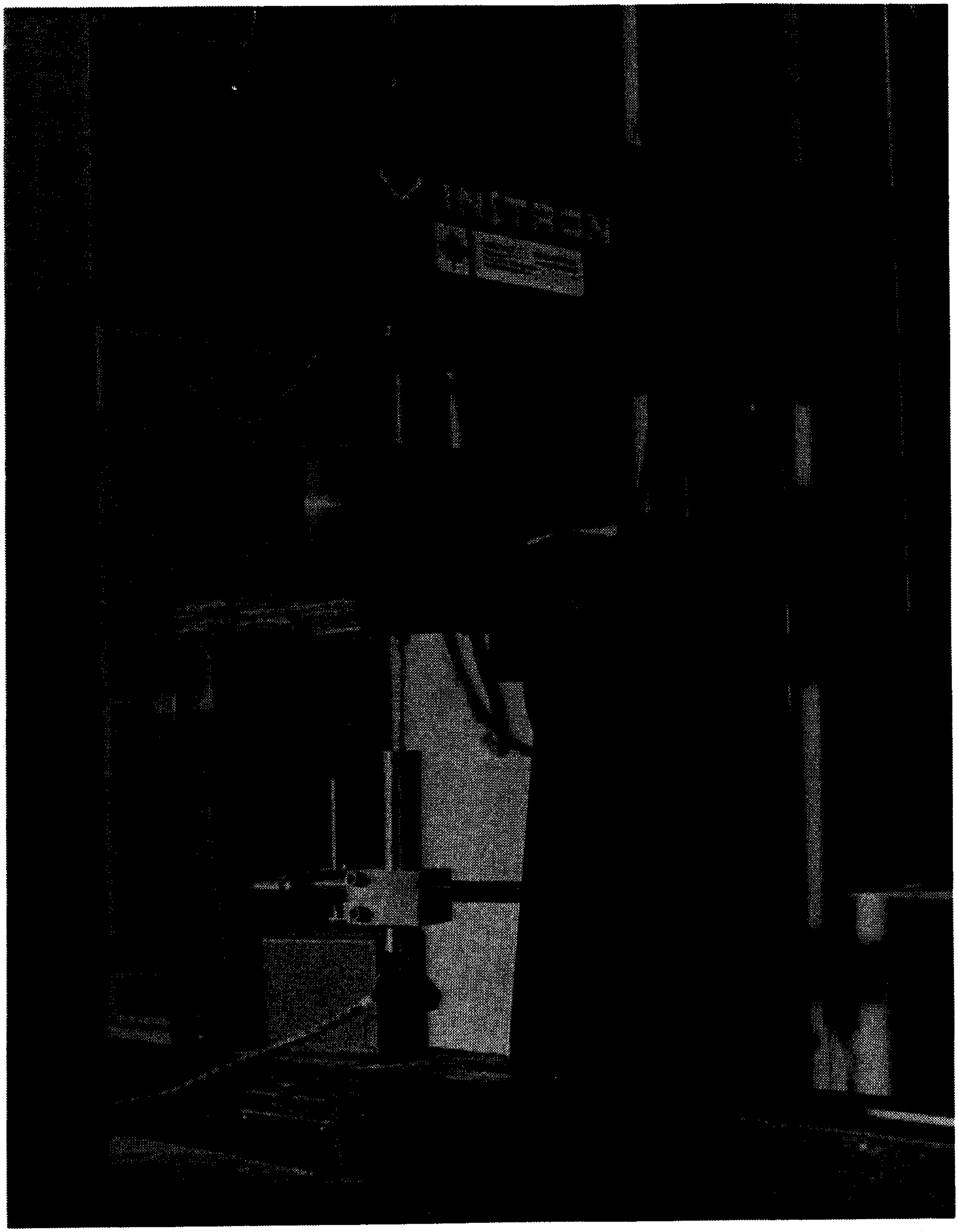


FIGURE 2.6 SHORT-TERM FLEXURAL TEST SET-UP FOR OSB SPECIMENS

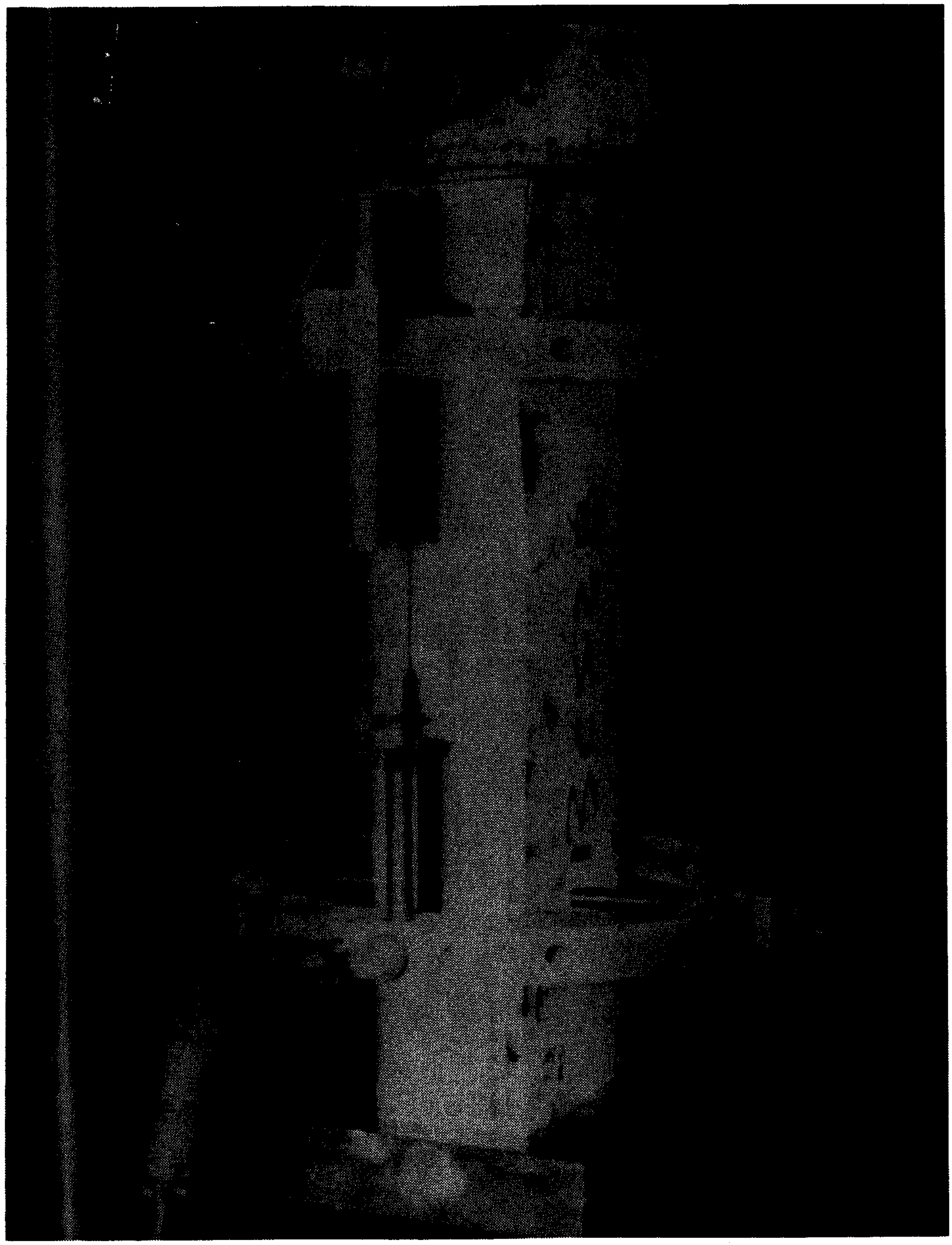


FIGURE 2.7 COMPRESSION TEST SET-UP FOR OSB SPECIMENS

	TYPE OF SPECIMENS			
	SSP	SSP	OSB	LUMBER
QUANTITY	2	9	21	8
L, mm	2360	2360	1067	2230
A, mm	785	785	255	740
TYPES OF SUPPORTS	ROLLERS / KNIFE EDGES	89mm Ø STEEL PIPE	25 mm Ø ROD	25 mm Ø ROD
LOAD SPREADERS	89mm Ø STEEL PIPE	89 X 89 LUMBER	25 mm Ø ROD	25 mm Ø ROD
SOURCE OF LOADS	CONCRETE BEAMS	CONCRETE BLOCKS	LEAD BRICKS	LEAD BRICKS
DEFLECTION MEASUREMENT	0.001 " DIAL GAUGE	0.001 " DIAL GAUGE	0.001 " DIAL GAUGE	0.0001" DIAL GAUGE
DEMEC GAUGE	YES	NO	NO	NO

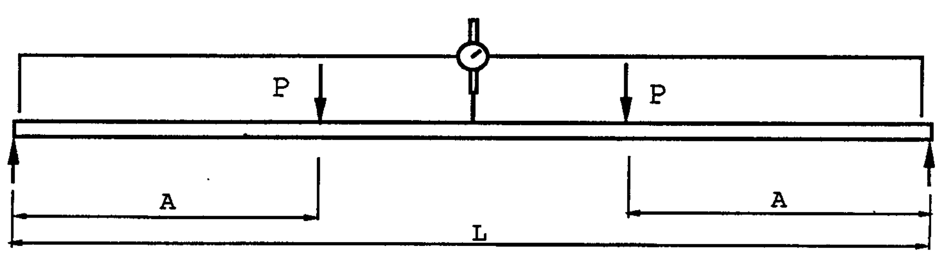


FIGURE 2.8 TYPICAL FLEXURAL CREEP EXPERIMENTAL SET-UP

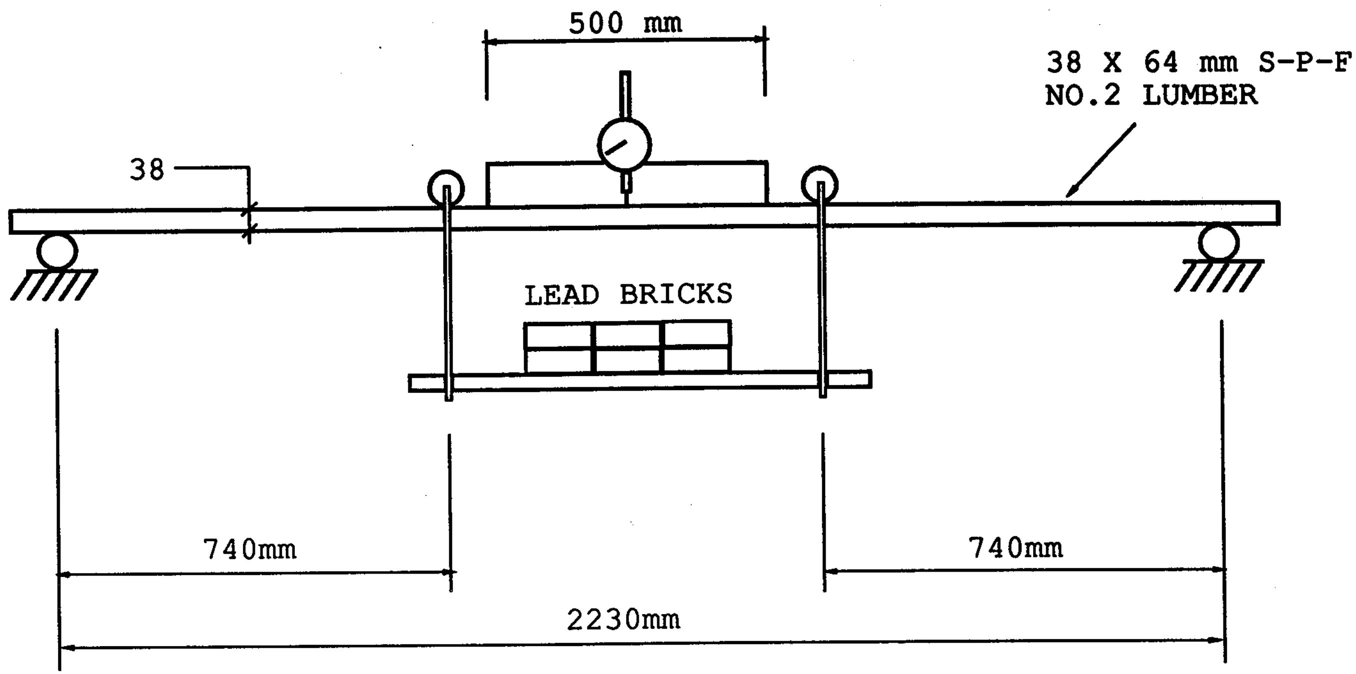


FIGURE 2.9 FLEXURAL CREEP EXPERIMENTAL SET-UP FOR S-P-F LUMBER

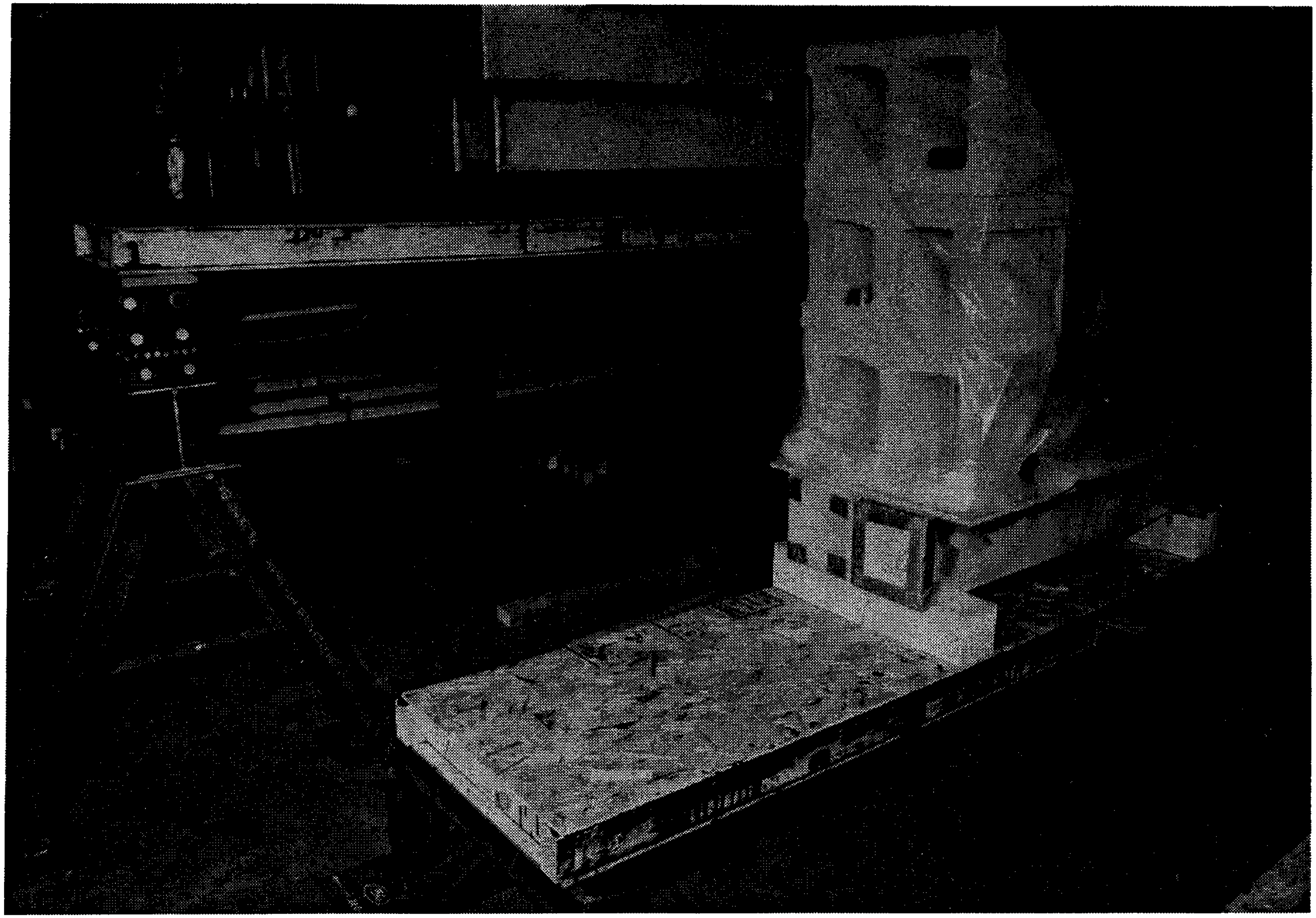
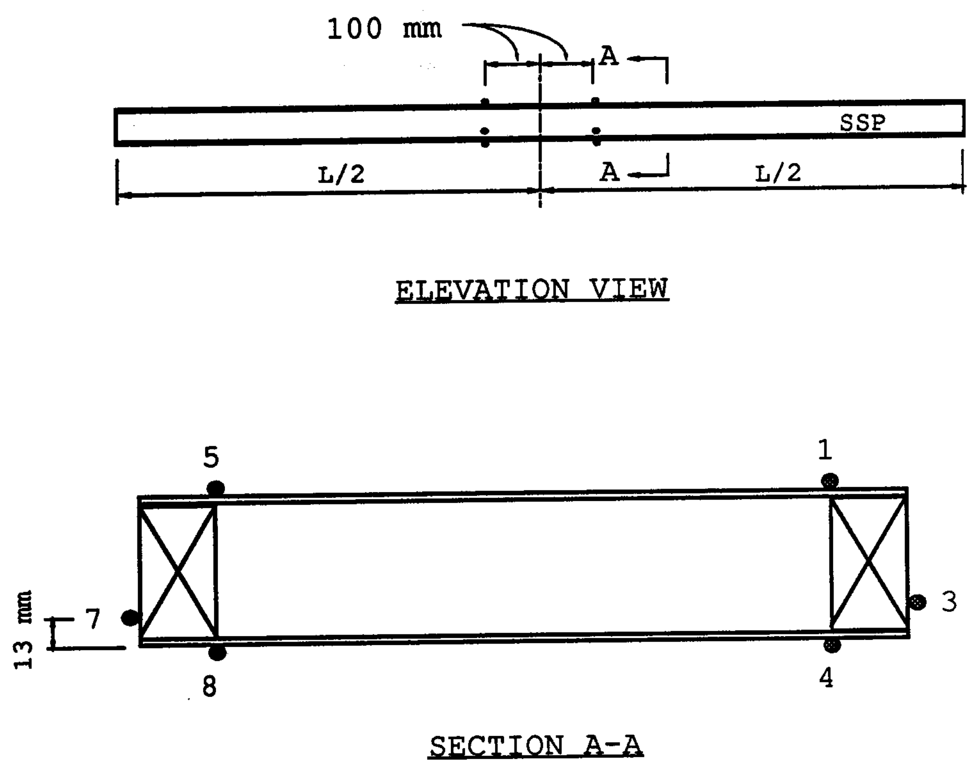


FIGURE 2.10 FLEXURAL CREEP EXPERIMENTAL SET-UPS FOR SSP SPECIMENS



NOTE: Diagram is not drawn to scale.

FIGURE 2.11 LOCATIONS OF DEMEC POINTS ON THE SSP

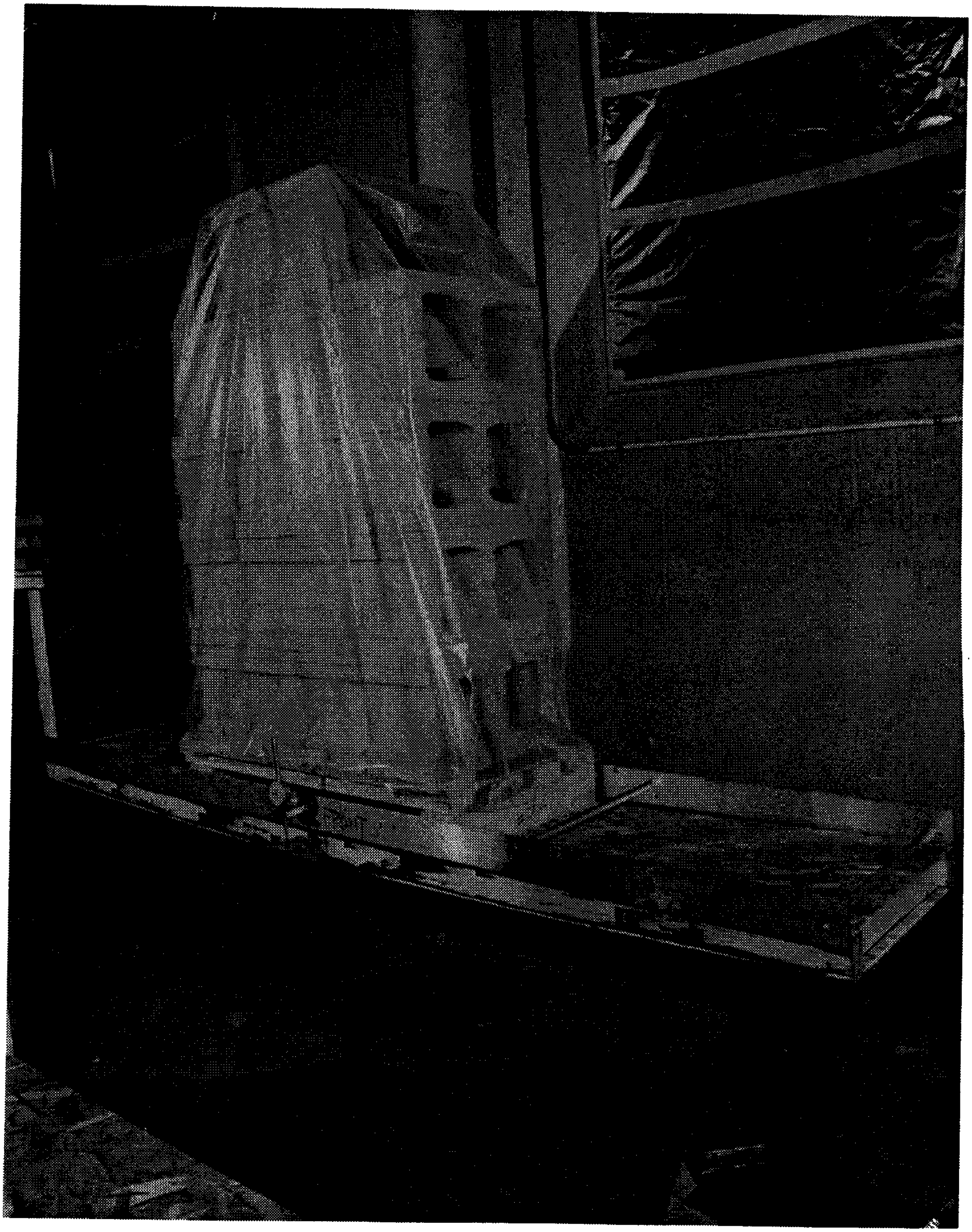


FIGURE 2.12 ALUMINUM DEFLECTION-MEASURING FRAME FOR SSP CREEP SPECIMENS

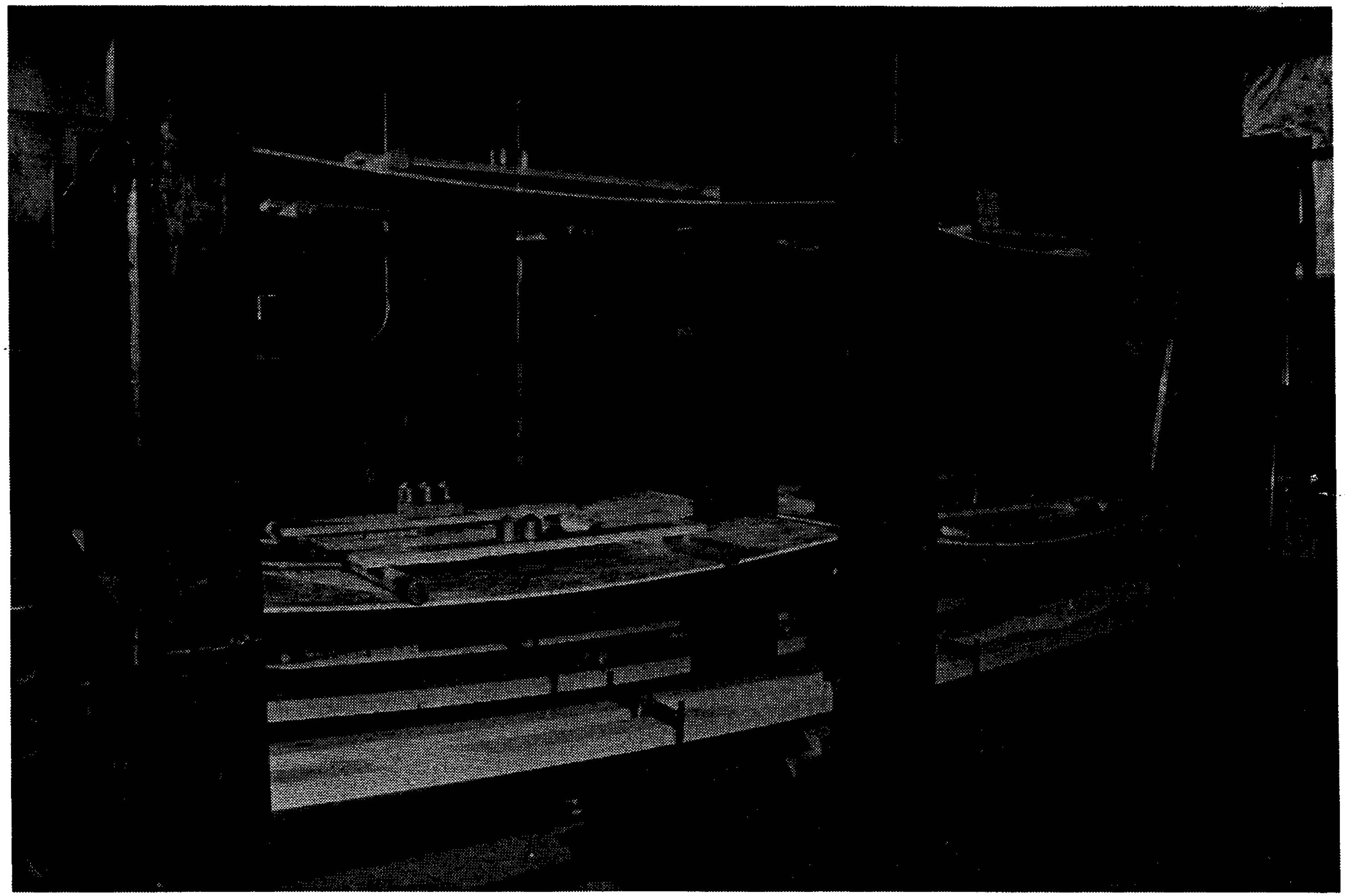


FIGURE 2.13 STEEL SUPPORT FRAME FOR OSB (parallel-to-grain) AND S-P-F CREEP SPECIMENS

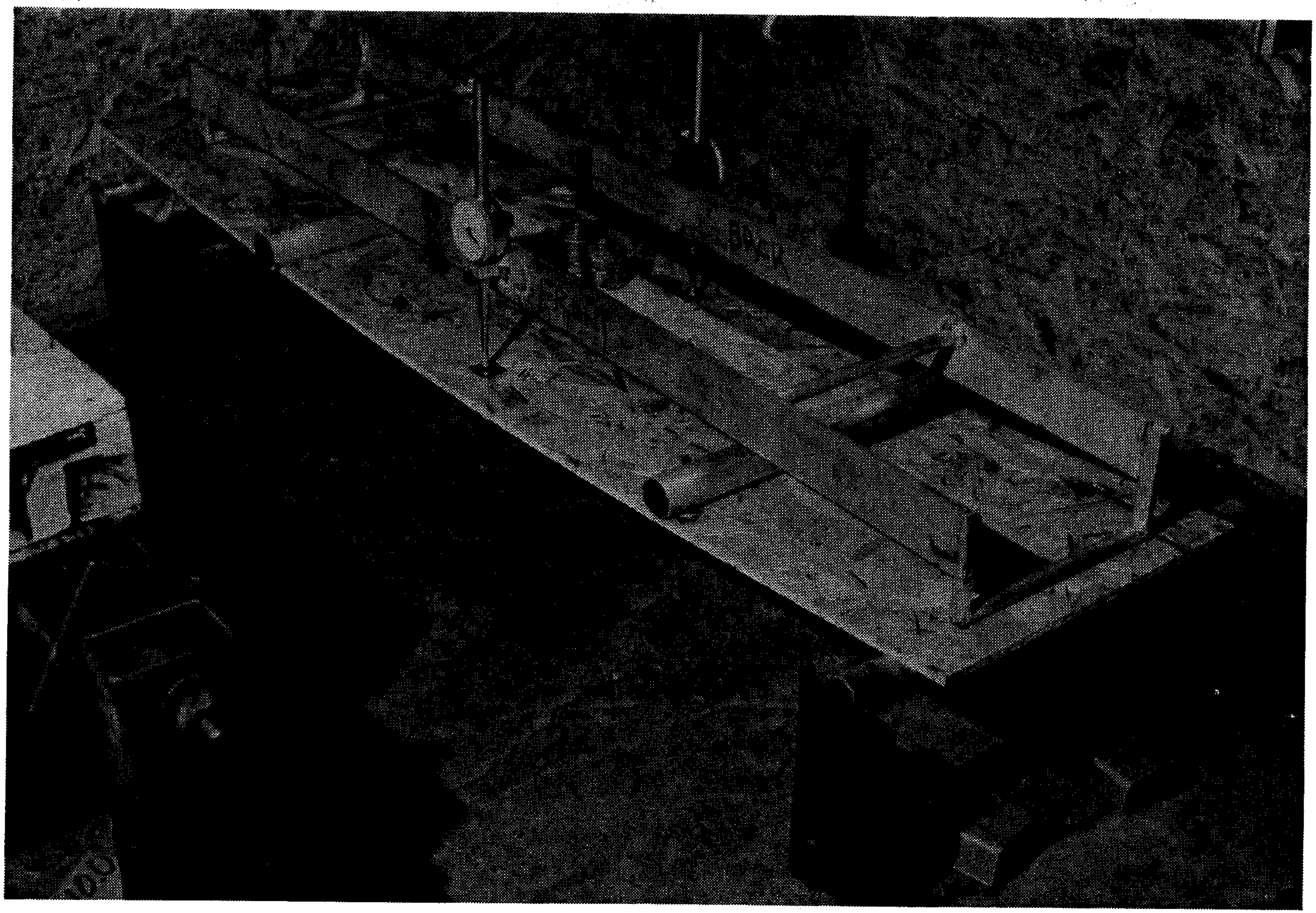


FIGURE 2.14 ALUMINUM DEFLECTION-MEASURING FRAME FOR OSB (parallel-to-grain) CREEP SPECIMENS

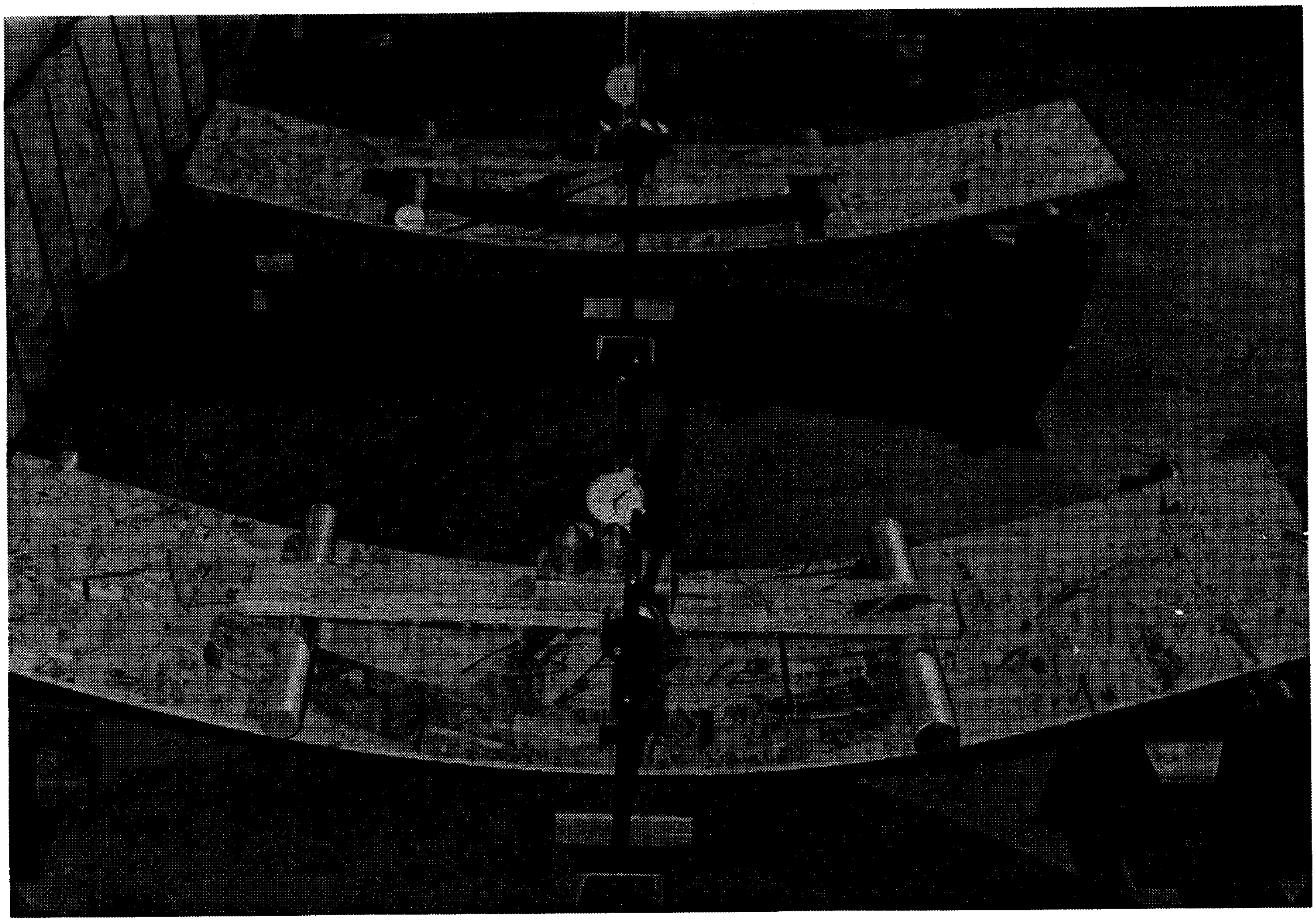


FIGURE 2.15 FLEXURAL CREEP EXPERIMENTAL SET-UP FOR OSB (perpendicular-to-grain) SPECIMENS

3. TEST RESULTS

3.1 Short-term Material Properties

The machine stiffness rating (MSR) results for the OSB and lumber specimens are tabulated in Table 3.1 and are summarized below:

	OSB (//)	OSB (⊥)	Lumber
Quantity	47	6	30
Ave. E.(MPa)	7460	3155	10010
Coeff.of Var.(%)	7.13	6.64	11.9

Eight pieces of 38 X 64 lumber were tested destructively. The results are tabulated in Table 3.2 and are summarized below:

	M.O.R.	M.O.E.	M.O.E[2]
Average (MPa)	65	9400	10310
Coeff.of Var.(%)	19.1	30.2	16.5

For OSB specimens that were subjected to flexural and compressive tests, the results are tabulated in Tables 3.3 and 3.4 respectively. Both sets of results are then summarized, together with the MSR results, in Table 3.5.

[2] Machine Stiffness Rating (non-destructive) Results.

3.2 Environmental Records

3.2.1 Uncontrolled Environment

The interior temperature and relative humidity were recorded for the duration of the flexural creep tests. Figure 3.1 shows the fluctuation of the two environmental variables for the uncontrolled experiment. The room temperature was more-or-less constant after the first 20 000 minutes. In the initial 20 000 minutes, the interior environment was drastically affected by the weather. The interior temperature ranged between 18 to 28 °C. The weather was characterizied by high humidity and high temperature which eventually led to the formation of a tornado in the region. The interior relative humidity varied between 40 to 70 % for the first 100 000 minutes. It dropped to an average of 25 % for the last 30 000 minutes. Unfortunately, a continuous tracking of the humidity was made impossible due to mechanical failures. Attempt was then made to at least record the humidity once a day. The time of the recording was selected at random.

3.2.2 Controlled Environment

The controlled chamber's temperature and humidity are shown in Figure 3.2. The humidity readings were taken almost daily. The chamber's temperatures were taken to be the same as that outside the chamber. However, the upper limit was maintained at about 23 °C. The relative humidity fluctuated between 68 and 72 % with an average of 70 %. The drop in the humidity at about 10 000 minutes was caused by the depletion of the water reservoirs inside the humidifier. The loss of humidity was discovered within 24 hours. The rapid loss of water supply was caused by a chain of events. As described earlier, the interior temperature was much higher than the 23°C limit set for the chamber. Since the chamber was not insulated, it was directly affected by the building's internal temperature. The cooling process required dehumidifcation of the air. Therefore, whenever the air conditioning unit was activated, the humidifier was also activated. In order to compensate for the rapid loss of moisture, the reservoirs were emptied much sooner than expected.

There were other appreciable drops in the relative humidity in the first 10 000 minutes. These losses were only temporary because they were caused by the momentarily activation of the air conditioner.

3.3 Long-term Deflection Data

The deflection histories of all specimens were monitored closely in the first day of the creep experiment. The intervals were set at approximately 1/3 of a full normal log cycle using minutes as the time scale. Readings were then taken on a daily basis until secondary creep stage was fully established. The readings were taken at two or three day intervals thereafter unless the creep rate changed substantially.

The deflection of a SSP or OSB specimen was measured from two sides (front and back) of the specimen using dial gauges. There were discrepancies between the front and the back deflections. However, these discrepancies differed from one specimen to another; the discrepancies even fluctuated throughout the history of the data collection for a single specimen. The midspan deflection was then taken as the average of these two deflections under such circumstances.

The creep data obtained from both environmental conditions have been consolidated in both tabulated and graphical formats. Raw data were used for plotting the creep curves. The deflection data in the tables were obtained using cubic-spline interpolation technique with the requirement that the original data would not be altered. For specimens tested under environmentally controlled conditions, they may be referred to as controlled specimens. An uncontrolled specimen is the one that situates outside the chamber.

The elapsed time for deflection data collection was based on the instance that the load was introduced to the system. It would include the time required to achieve the full creep load. For the SSP specimens, the loading time varied between 20 to 90 seconds depending on the amount of concrete blocks used. The first reading was made at either the one or two minute elapsed time. For the OSB and lumber specimens, the first reading was taken at 15 seconds elapsed time. The loading time varied between 3 to 6 seconds. The start of the perpendicular-to-grain flexural creep test was delayed by about 8 days due to inadequate planning.

3.3.1 Stressed Skin Panels

The results for all SSP specimens have been tabulated in Tables 3.6 and 3.7. Table 3.6 is for the specimens tested according to loading schemes B, C, and D. Loading scheme B had a flexural moment of 388 N-m. Table 3.7 is for specimens tested according to loading scheme A. The table is divided into three sections. Each section contains the data for an individual loading step. Each loading step had a flexural loading of 388 N-m.

The creep results are graphically illustrated in Figure 3.3 for the three SSP specimens tested inside the chamber. For the specimens tested outside the chamber, two were subjected to step-sustained loadings. Their results are shown in Figure 3.4. The other six SSP specimens were subjected to constant-sustained load schemes B, C , and D. Their results are shown in Figure 3.5.

The strain measurements for specimens 2 and 10 are shown in Figures 3.6 and 3.7 respectively. Demec point no.7 had fallen off specimen 10 in the early stage of the experiment.

3.3.2 Oriented Strandboards

The creep data have been tabulated in Tables 3.8, 3.9, and 3.10. The results for specimen tested under loading schemes B, C, and D are contained in Tables 3.8 and 3.9. Loading scheme B had a flexural moment of 3.55 N-m for the parallel-to-grain specimens and 2.14 N-m for the perpendicular-to-grain specimens. Table 3.10 contains the data for loading scheme A. The results associated with both types of environment are separated under two headings as shown. Each loading step had a flexural load of 3.55 N-m.

There were nine parallel-to-grain specimens tested inside in the chamber. The results for these nine specimens are shown in Figures 3.8 and 3.9. Figures 3.10 and 3.11 illustrate the results for the other nine parallel-to-grain specimens tested outside the chamber.

There were three specimens used for the perpendicular-to-grain flexural creep tests. A single specimen was assigned to each constant-sustained loading scheme as outlined in Table 2.2. Their results are plotted in Figure 3.12.

Compression creep test results for the five OSB specimens are illustrated in 3.13. The data for specimen 13CC1B were lost due to equipment problem.

3.3.3 S-P-F Lumber

Four lumber specimens were tested under each type of environment. The results are summarized in Table 3.11. The data are grouped according to the environmental conditions. The total load used for an uncontrolled specimen was, an error made during loading, 16.5 % higher than that predetermined for a controlled specimen. As a result, the flexural load for an uncontrolled specimen was 114 N-m and 98 N-m for a controlled specimen. The creep data are plotted in Figures 3.14 and 3.15 for the controlled and uncontrolled specimens respectively.

TABLE 3.1 MACHINE STIFFNESS RATING RESULTS FOR OSB AND S-P-F LUMBER SPECIMENS

MATERIAL	SURFACE GRAIN ORIENTATION	SOURCE * OF SPECIMENS	NOMINAL WIDTH (mm)	NUMBER OF SPECIMENS	AVERAGE M.O.E. (MPa)	COEFFICIENT OF VARIATION	MOISTURE CONTENT (%)	TYPE OF USAGE
OSB	PARALLEL	1 TO 11	445	11	7264	5.4%	4.2	FLEXURAL STRENGTH AND CREEP
OSB	PARALLEL	1 TO 11	300	22	7672	7.8%	4.2	SSP SKINS
OSB	PARALLEL	12	300	8	7145	4.2%	4.2	FLEXURAL STRENGTH AND CREEP
OSB	PARALLEL	13 TO 15	300	6	7482	6.3%	4.2	FLEXURAL STRENGTH AND CREEP
OSB	PERPENDICULAR	13 TO 15	300	6	3155	6.6%	4.2	FLEXURAL STRENGTH AND CREEP
LUMBER	PARALLEL	1 TO 30	64	30	10010	12.9%	13.9	SSP WEBS & FLEXURAL STRENGTH
OSB	PARALLEL	N/A	300	9	7850	4.4%	UNKNOWN	CONDITIONED @ 70% R.H.
LUMBER	PARALLEL	N/A	64	4	10775	22.6%	UNKNOWN	CONDITIONED @ 70% R.H.

* THIS COLUMN IDENTIFIES THE SOURCE OF THE SPECIMENS. i.e. A SHEET (1220mm X 2440mm) OF OSB PANEL OR A PIECE OF 3660mm LONG S-P-F LUMBER

Notes: The modulus of elasticity calculated for an OSB panel was based on a homogeneous cross section.
The densities of the materials are 716 and 435 kg/m3 for the OSB and lumber respectively.

TABLE 3.2 SHORT-TERM BENDING TEST RESULTS FOR 38 X 64 S-P-F LUMBER

SPECIMEN I.D.	MOMENT OF INERTIA(mm4)	TIME TO FAILURE(min)	MAXIMUM LOAD (N)	M.O.E. (MPa)	M.O.R. (MPa)	M.O.E. (MPa)*	MOISTURE CONTENT(%)
23	728800	10	7800	13850	75	12510	11.6
24	744500	20	6340	7640	60	10050	12.5
25	745900	16	7140	10375	68	10470	12.5
26	736100	14	5610	6820	54	9060	12.8
27	741800	7	8390	12860	80	11710	13
28	738300	15	5220	6230	50	7560	11.9
29	708700	13	8085	9920	80	11980	11.6
30	830000	20	5980	7510	53	9140	11.4

* These were machine stiffness rating results.

Note: The average moisture content of the eight specimens was 12.2% at time of destructive tests.

TABLE 3.3 SHORT-TERM BENDING TEST RESULTS FOR OSB SPECIMENS

SURFACE GRAIN ORIENTATION	SOURCE * OF SPECIMENS	NUMBER OF SPECIMENS	MODULUS OF ELASTICITY (MPa)	COEFFICIENT OF VARIATION (%)	MODULUS OF RUPTURE (MPa)	COEFFICIENT OF VARIATION (%)
PARALLEL	12	12	6985	13.9	44.8	16.7
PARALLEL	13	3	7825	9.9	42.3	18.1
PARALLEL	15	3	6475	23.7	35.3	27.5
PERPENDICULAR	13	3	2955	7.5	24.7	15.4
PERPENDICULAR	14	3	3325	8.5	28.7	17.5
PERPENDICULAR	15	3	3270	10.9	29	13.8

* THIS COLUMN IDENTIFIES THE SOURCE OF THE SPECIMENS FROM A PARTICULAR SHEET (1220mm X 2440mm) OF OSB PANELS.

NOTES: THE AVERAGE MOISTURE CONTENT OF ALL SPECIMENS TESTED WAS 3.7% WITH A COEFFICIENT OF VARIATION OF 15%.
MODULUS OF RUPTURE WAS CALCULATED BASED ON A HOMOGENEOUS CROSS SECTION.

TABLE 3.4 SHORT-TERM COMPRESSION TEST RESULTS FOR OSB SPECIMENS

SURFACE GRAIN ORIENTATION	SPECIMEN I.D.	CROSS-SECTIONAL AREA (mm)	MAXIMUM LOAD (kN)	MODULUS OF ELASTICITY (MPa)	MAXIMUM STRESS (MPa)
PARALLEL	13CS2A	5715	104.1	2090	18.2
	14CS2A	5505	103.7	2245	18.8
	15CS2A	5620	108.3	1900	19.3
PERPENDICULAR	13CS2B	5690	99.2	2090	17.4
	14CS2B	5700	100.5	2020	17.6
	15CS2B	5450	104.4	2315	19.2

NOTES: AVERAGE FAILURE TIME WAS 4.5 MINUTES.
MOISTURE CONTENT WAS NOT MEASURED AFTER THE TESTS.

TABLE 3.5 SUMMARY OF SHORT-TERM TEST RESULTS FOR OSB SPECIMENS

GRAIN ORIENTATION	TYPE OF TEST	MODULUS OF ELASTICITY			MAXIMUM STRESS		
		QTY.	AVE. (MPa)	C.V. (%)	QTY.	AVE. (MPa)	C.V. (%)
PARALLEL	MSR	47	7460	7.1	--	----	---
	FS	18	7135	14	18	43.8	17
	CS	3	2080	8.3	3	18.8	2.9
PERPENDICULAR	MSR	6	3155	6.6	--	----	---
	FS	9	3160	16	9	27.4	9
	CS	3	2140	7.3	3	18.1	5.5

NOTES: MSR = MACHINE STIFFNESS RATING
FS = FLEXURAL STRENGTH
CS = COMPRESSIVE STRENGTH
THE STRESSES WERE CALCULATED BASED ON A HOMOGENEOUS CROSS SECTION.

TABLE 3.6 CENTERLINE DEFLECTION DATA FOR SSP SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS

MOMENT	388 N-m		776 N-m			1164 N-m	
SPECIMEN	9B	11B	1C *	4C	5C	7D	8D
ELAPSED TIME	CENTERLINE DEFLECTION (mm)						
1 minute	4.08	4.08	----	----	8.55	-----	-----
2	4.11	4.13	9.30	9.23	8.65	14.19	11.77
5	4.17	4.18	9.46	9.39	8.76	14.43	11.97
10	4.20	4.22	9.56	9.50	8.86	14.62	12.10
20	4.24	4.25	9.66	9.61	8.94	14.78	12.23
50	4.29	4.36	9.88	9.92	9.13	15.11	12.49
100	4.37	4.42	10.06	10.02	9.30	15.38	12.69
200	4.50	4.53	10.18	10.25	9.50	15.71	12.99
500	4.75	4.77	10.35	10.48	9.95	16.47	13.59
1000	4.87	4.89	10.78	10.98	10.21	16.93	13.93
2000	5.24	5.26	11.34	11.61	10.94	18.06	14.79
5000	5.67	5.72	12.39	12.67	11.97	19.67	16.07
10000	6.47	6.53	13.67	14.17	13.38	22.00	18.09
20000	6.77	6.78	14.46	14.90	14.25	23.37	19.27
50000	7.00	6.90	15.66	15.57	14.95	24.37	20.00
100000	7.03	6.87	16.57	16.18	15.48	25.30	20.45
130000	7.09	6.69	16.93	16.82	16.13	26.29	20.62

* THIS SPECIMEN WAS TESTED UNDER ENVIRONMENTALLY CONTROLLED CONDITIONS

TABLE 3.7 CENTERLINE DEFLECTION DATA FOR SSP SPECIMENS SUBJECTED TO STEP-SUSTAINED MOMENTS

STEP	1				2				3			
SPECIMEN	2A *	3A *	6A	10A	2A*	3A *	6A	10A	2A *	3A *	6A	10A
TIME **	CENTERLINE DEFLECTION (mm)											
1	4.41	4.67	4.55	4.59	4.47	4.56	4.23	4.64	4.66	4.65	4.41	4.75
2	4.42	4.72	4.60	4.63	4.51	4.60	4.27	4.69	4.72	4.70	4.43	4.79
5	4.47	4.79	4.65	4.70	4.57	4.65	4.32	4.73	4.79	4.74	4.50	4.85
10	4.52	4.84	4.67	4.76	4.60	4.70	4.36	4.76	4.84	4.80	4.53	4.89
20	4.60	4.89	4.74	4.81	4.65	4.75	4.39	4.82	4.86	4.89	4.59	4.97
50	4.66	4.95	4.81	4.90	4.75	4.84	4.46	4.88	4.95	4.95	4.66	5.00
100	4.75	4.99	4.91	4.99	4.79	4.90	4.52	4.97	5.00	5.03	4.72	5.07
200	4.85	5.10	5.05	5.14	4.88	4.99	4.56	5.03	5.09	5.12	4.82	5.16
500	4.93	5.34	5.34	5.30	5.04	5.16	4.71	5.16	5.20	5.25	4.96	5.30
1000	5.07	5.52	5.48	5.47	5.12	5.25	4.81	5.23	5.30	5.34	5.09	5.40
2000	5.43	5.73	5.88	5.96	5.23	5.36	4.89	5.32	5.46	5.52	5.27	5.55
5000	5.93	6.28	6.55	6.56	5.54	5.67	5.14	5.54	5.80	5.87	5.55	5.85
10000	6.62	6.94	7.50	7.65	5.80	5.96	5.27	5.70	6.08	6.22	5.77	6.05
20000	6.95	7.17	7.89	8.11	6.28	6.51	5.82	6.19	6.58	6.70	6.20	6.52
40000	7.34	7.58	8.09	8.36	6.80	7.09	6.01	6.41	7.23	7.43	7.46	7.92

* THESE SPECIMENS WERE TESTED UNDER ENVIRONMENTALLY CONTROLLED CONDITIONS.

** TIME = ELAPSED TIME IN MINUTES

TABLE 3.8 CENTERLINE DEFLECTION DATA FOR OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER ENVIRONMENTALLY CONTROLLED CONDITIONS

MOMENT	3.55 N-m		7.09 N-m		10.6 N-m	
SPECIMEN	13FC1A	12FC4A	12FC2A	14FC1A	1FC	15FC1A
ELAPSED TIME	CENTERLINE DEFLECTION (mm)					
1 minute	6.49	8.85	16.01	14.68	27.41	26.52
2	6.54	8.90	16.12	14.81	27.63	26.59
5	6.64	9.04	16.27	14.95	28.65	26.71
10	6.83	9.33	16.70	15.30	29.36	27.15
20	6.99	9.57	17.04	15.61	30.02	27.58
50	7.10	9.64	17.20	15.92	30.84	28.05
100	7.21	9.79	17.45	16.21	31.43	28.42
200	7.34	10.05	17.76	16.54	32.03	28.87
500	7.45	10.20	18.11	16.96	32.59	29.54
1000	7.65	10.50	18.58	17.37	33.53	30.36
2000	8.16	11.20	19.45	18.00	35.21	31.72
5000	8.92	12.11	21.11	19.58	37.81	33.96
10000	10.75	14.97	25.28	23.13	45.19	40.27
20000	12.18	16.26	27.19	24.66	48.35	43.11
50000	13.33	17.49	29.75	26.68	52.31	46.39
100000	14.09	18.27	31.27	28.09	55.53	48.42
130000	14.41	18.55	31.96	28.73	55.67	49.21

NOTE: ALL SPECIMENS WERE TESTED IN THE PARALLEL-TO-GRAIN DIRECTION.

TABLE 3.9 CENTERLINE DEFLECTION DATA FOR OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER ENVIRONMENTALLY UNCONTROLLED CONDITIONS

MOMENT	3.55 N-m		2.14 N-m	7.09 N-m		4.28 N-m	10.6 N-m		6.41 N-m
SPECIMEN	6FC	11FC	13FC1B*	2FC	10FC	14FC1B*	7FC	9FC	15FC1B*
TIME **	CENTERLINE DEFLECTION (mm)								
1 minute	8.38	7.96	9.79	15.54	16.27	18.82	21.69	22.21	31.38
2	8.48	8.04	9.92	15.71	16.68	18.91	21.90	22.66	31.62
5	8.69	8.69	10.07	16.19	17.15	19.02	22.15	23.76	32.36
10	8.98	8.84	10.17	17.16	17.20	19.19	22.44	23.84	32.56
20	9.06	9.07	10.36	17.60	18.59	19.42	23.53	24.66	32.75
50	10.30	9.36	10.60	18.37	19.76	19.81	24.43	25.91	33.32
100	10.27	9.76	10.84	19.06	20.14	20.63	25.51	26.62	35.00
200	10.86	10.22	11.20	20.26	21.53	21.07	26.75	27.94	35.56
500	12.33	11.41	11.69	21.86	23.45	21.39	28.48	30.18	37.91
1000	13.45	12.10	12.80	23.11	24.71	22.43	29.50	31.70	38.96
2000	14.50	13.02	13.99	24.98	26.57	24.03	31.49	34.07	40.25
5000	16.32	15.01	14.91	27.78	29.49	25.93	34.48	37.54	43.99
10000	20.11	18.93	17.97	33.90	36.08	29.83	41.44	45.51	48.97
20000	21.57	20.37	18.48	35.36	38.25	31.29	44.05	48.39	52.85
50000	22.05	20.48	21.29	36.52	39.36	33.42	45.16	50.26	58.48
100000	22.37	20.40	21.85	36.99	40.56	38.39	46.28	52.25	64.41
130000	22.62	19.73	23.51	37.64	41.78	41.99	47.35	54.44	68.30

* THESE SPECIMENS WERE TESTED IN THE PERPENDICULAR-TO-GRAIN DIRECTION.

** TIME = ELAPSED TIME

TABLE 3.10 CENTERLINE DEFLECTION DATA FOR OSB SPECIMENS SUBJECTED TO STEP-SUSTAINED MOMENTS UNDER ENVIRONMENTALLY CONTROLLED & UNCONTROLLED CONDITIONS

ENVIRONMENT		CONTROLLED			UNCONTROLLED		
SPECIMEN		4FC	5FC	12FC3A	3FC	8FC	12FC1A
STEP	TIME *	CENTERLINE DEFLECTION (mm)					
1	1	7.44	8.33	7.47	8.80	9.07	8.64
	2	7.48	8.40	7.54	8.85	9.18	8.69
	5	7.56	8.48	7.72	9.16	9.37	8.79
	10	7.82	9.11	7.93	9.22	9.68	9.21
	20	8.07	9.49	8.13	9.68	10.04	9.42
	50	8.22	9.46	8.24	10.12	10.38	9.84
	100	8.33	9.49	8.34	10.60	10.78	10.04
	200	8.48	9.78	8.53	10.98	11.54	10.73
	500	8.63	10.07	8.70	12.57	12.56	11.70
	1000	8.84	10.29	8.87	13.67	13.15	12.26
	2000	9.34	10.70	9.34	14.71	14.14	13.22
	5000	10.06	11.83	10.16	16.54	16.12	14.90
	10000	12.73	14.47	12.66	20.66	19.34	18.84
	20000	13.60	15.74	13.68	22.25	20.31	20.64
	40000	14.69	16.84	14.60	22.97	20.56	21.29
2	1	6.36	7.24	6.45	6.86	6.52	7.05
	2	6.38	7.26	6.48	6.87	6.53	7.05
	5	6.41	7.28	6.55	6.88	6.58	7.06
	10	6.48	7.30	6.60	6.91	6.64	7.94
	20	6.49	7.33	6.83	8.62	6.68	7.95
	50	7.78	8.34	7.58	8.60	6.72	8.08
	100	8.02	8.51	7.73	8.76	7.91	8.33
	200	8.07	8.65	7.90	8.84	8.13	8.44
	500	8.10	9.03	8.10	9.09	8.29	8.53
	1000	8.32	9.02	8.17	9.47	8.39	8.67
	2000	8.52	9.18	8.34	9.67	8.46	8.93
	5000	9.05	9.76	8.82	9.98	8.89	9.36
	10000	9.53	10.16	9.28	10.54	8.98	9.64
	20000	10.32	11.35	9.94	11.21	10.45	10.78
	40000	11.46	12.32	10.91	12.71	10.44	11.82
3	1	8.17	8.78	7.72	7.87	8.71	7.67
	2	8.18	8.83	7.78	7.89	8.74	7.67
	5	8.18	8.88	7.93	7.90	8.74	7.70
	10	9.39	10.25	7.94	7.90	8.76	7.70
	20	9.42	10.47	9.07	7.91	8.79	7.70
	50	9.47	10.72	9.35	10.92	8.81	9.70
	100	9.49	10.85	9.46	10.94	10.15	9.77
	200	9.66	10.96	9.52	10.96	10.25	9.80
	500	10.05	11.15	9.67	11.06	10.42	10.78
	1000	10.47	11.32	9.82	11.23	11.10	10.97
	2000	10.63	11.72	10.07	11.32	11.51	11.09
	5000	11.09	12.32	10.69	11.37	11.83	11.33
	10000	11.67	13.00	11.32	12.20	12.30	11.91
	20000	12.69	13.99	12.09	13.99	13.16	12.61
	40000	13.32	15.46	13.18	17.58	16.51	17.12

* TIME = ELAPSED TIME IN MINUTES

NOTE: ALL SPECIMENS WERE TESTED IN THE PARALLEL-TO-GRAIN DIRECTION.

TABLE 3.11 LOCAL DEFLECTION DATA FOR S-P-F LUMBER SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER ENVIRONMENTALLY CONTROLLED AND UNCONTROLLED CONDITIONS

ENVIRONMENT	CONTROLLED				UNCONTROLLED			
SPECIMEN	1	7	18	21	15	19	23	28
ELAPSED TIME	LOCAL DEFLECTION (mm)							
1 minute	0.765	0.770	0.752	1.349	0.963	1.262	0.940	1.575
2	0.767	0.772	0.754	1.351	0.965	1.267	0.942	1.585
5	0.772	0.775	0.759	1.354	0.973	1.275	0.947	1.598
10	0.775	0.782	0.765	1.351	0.978	1.280	0.958	1.608
20	0.787	0.785	0.772	1.356	0.986	1.305	0.963	1.618
50	0.787	0.798	0.767	1.384	0.986	1.318	0.965	1.647
100	0.792	0.798	0.787	1.397	0.995	1.308	0.973	1.702
200	0.785	0.808	0.792	1.412	1.011	1.348	0.996	1.737
500	0.832	0.815	0.807	1.414	1.047	1.422	1.034	1.806
1000	0.820	0.809	0.821	1.424	1.095	1.452	1.052	1.815
2000	0.810	0.823	0.843	1.450	1.127	1.494	1.075	1.859
5000	0.838	0.859	0.895	1.530	1.155	1.525	1.097	1.954
10000	0.882	0.924	1.030	1.746	1.256	1.656	1.144	2.141
20000	0.881	0.917	1.057	1.711	1.267	1.718	1.177	2.155
50000	0.882	0.939	1.078	1.726	1.292	1.729	1.272	2.252
100000	0.910	0.959	1.114	1.766	1.347	1.844	1.432	2.443
130000	0.906	0.979	1.128	1.781	1.589	2.033	1.650	2.850

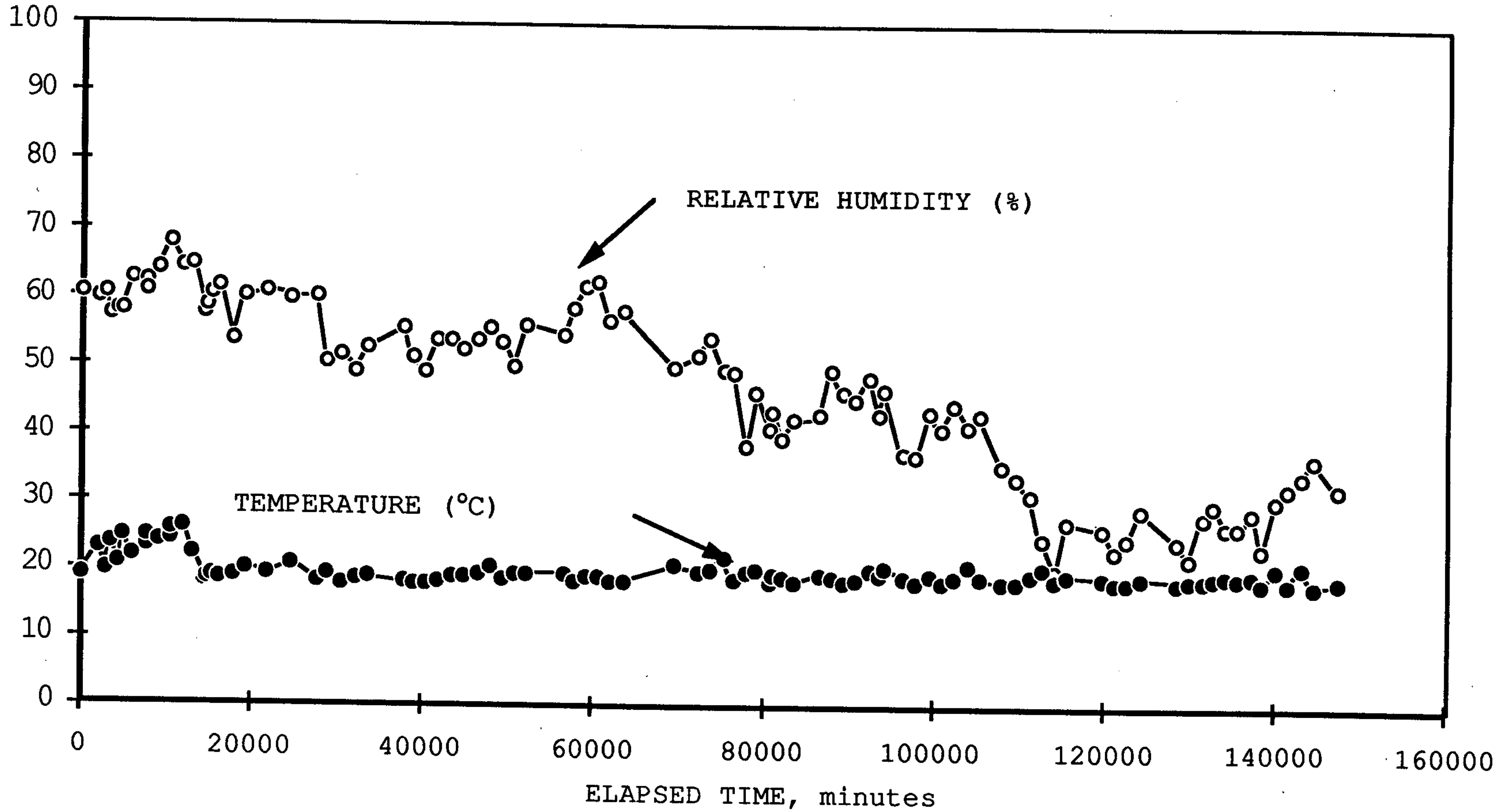


FIGURE 3.1 ENVIRONMENTAL RECORDS FOR THE UNCONTROLLED EXPERIMENT

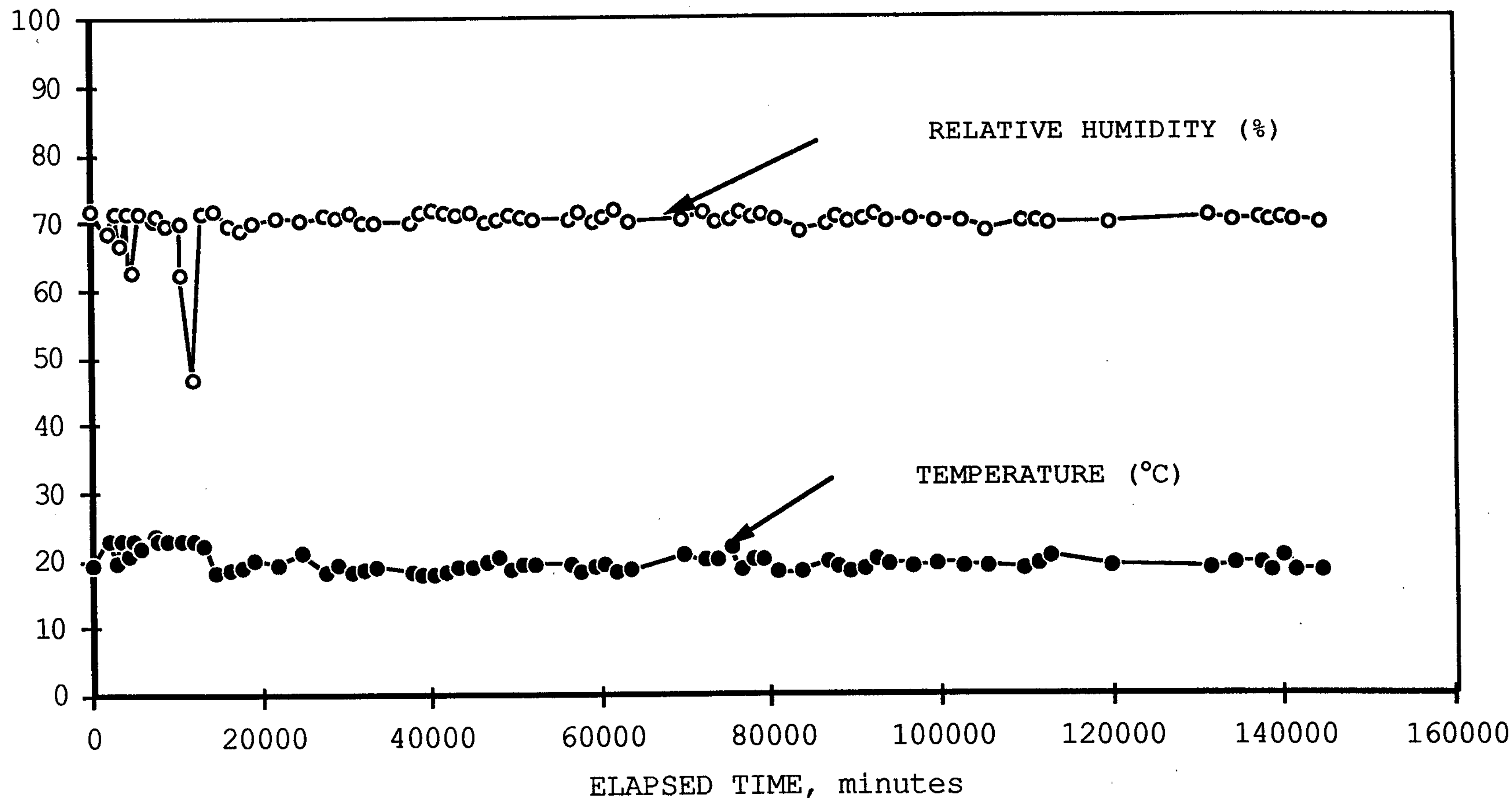


FIGURE 3.2 ENVIRONMENTAL RECORDS FOR THE CHAMBER

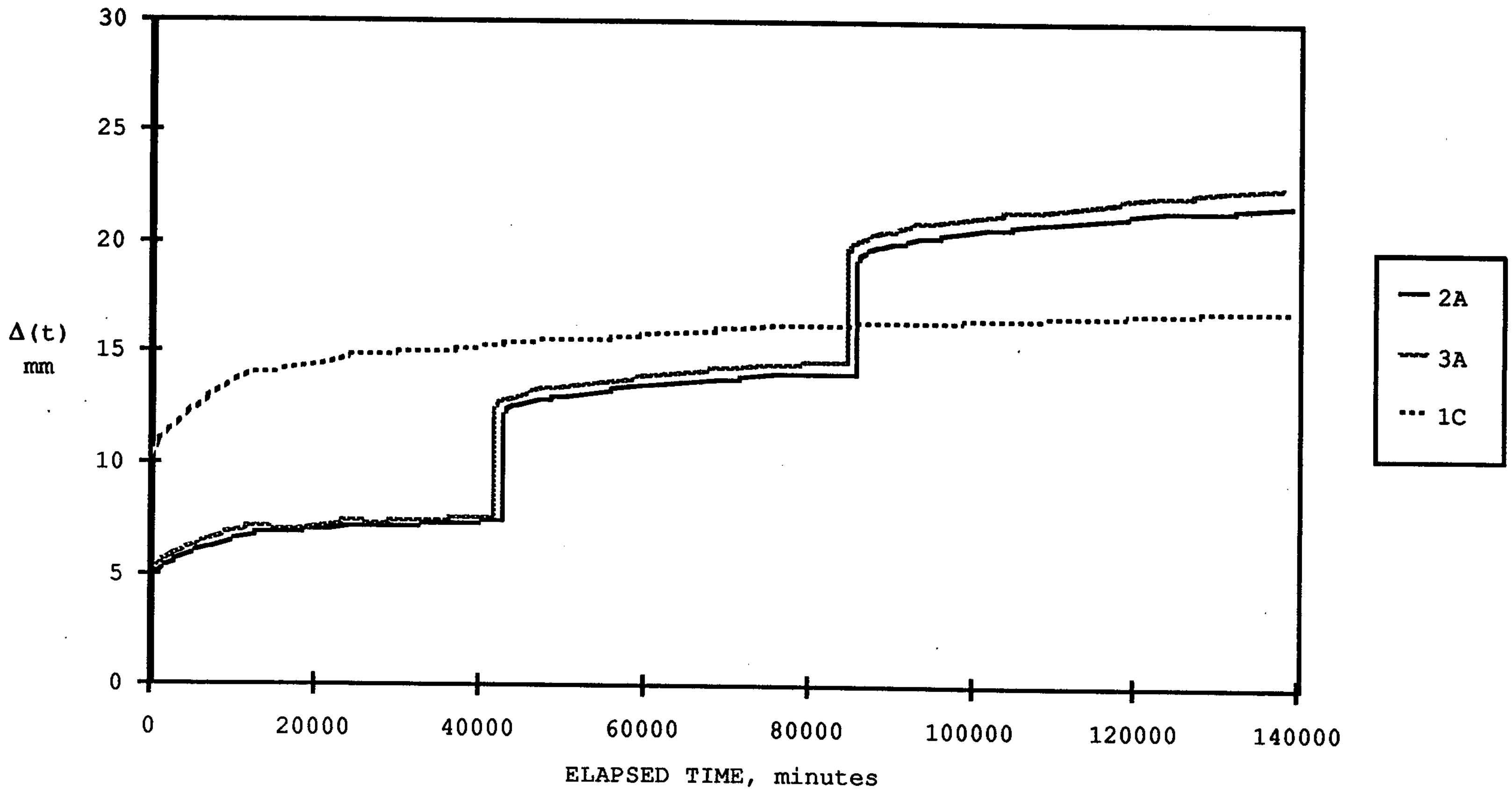


FIGURE 3.3 CENTERLINE DEFLECTION (RESPONSE) HISTORIES OF SSP SPECIMENS TESTED IN CONTROLLED ENVIRONMENT

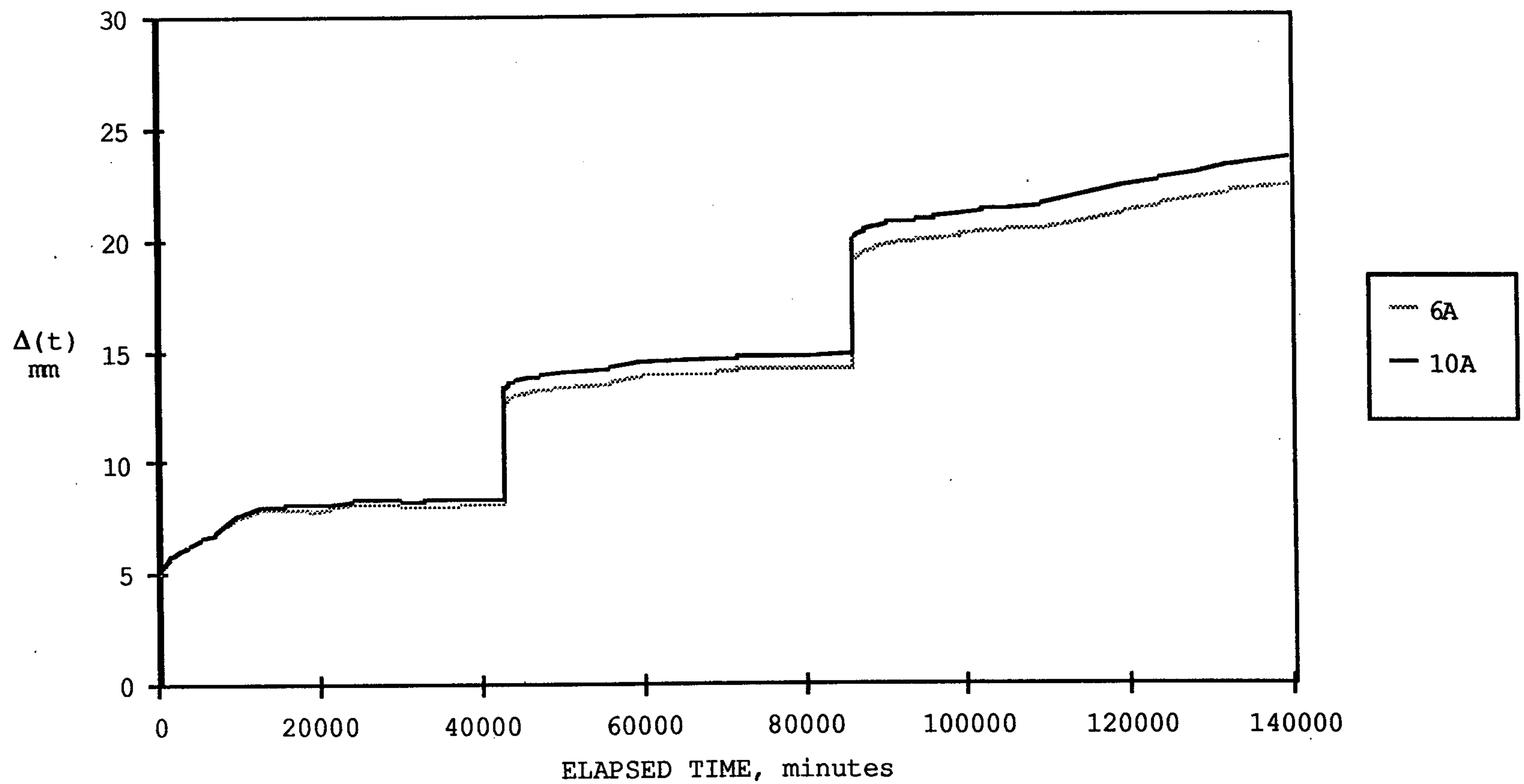


FIGURE 3.4 CENTERLINE DEFLECTION HISTORIES OF SSP SPECIMENS SUBJECTED TO STEP-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

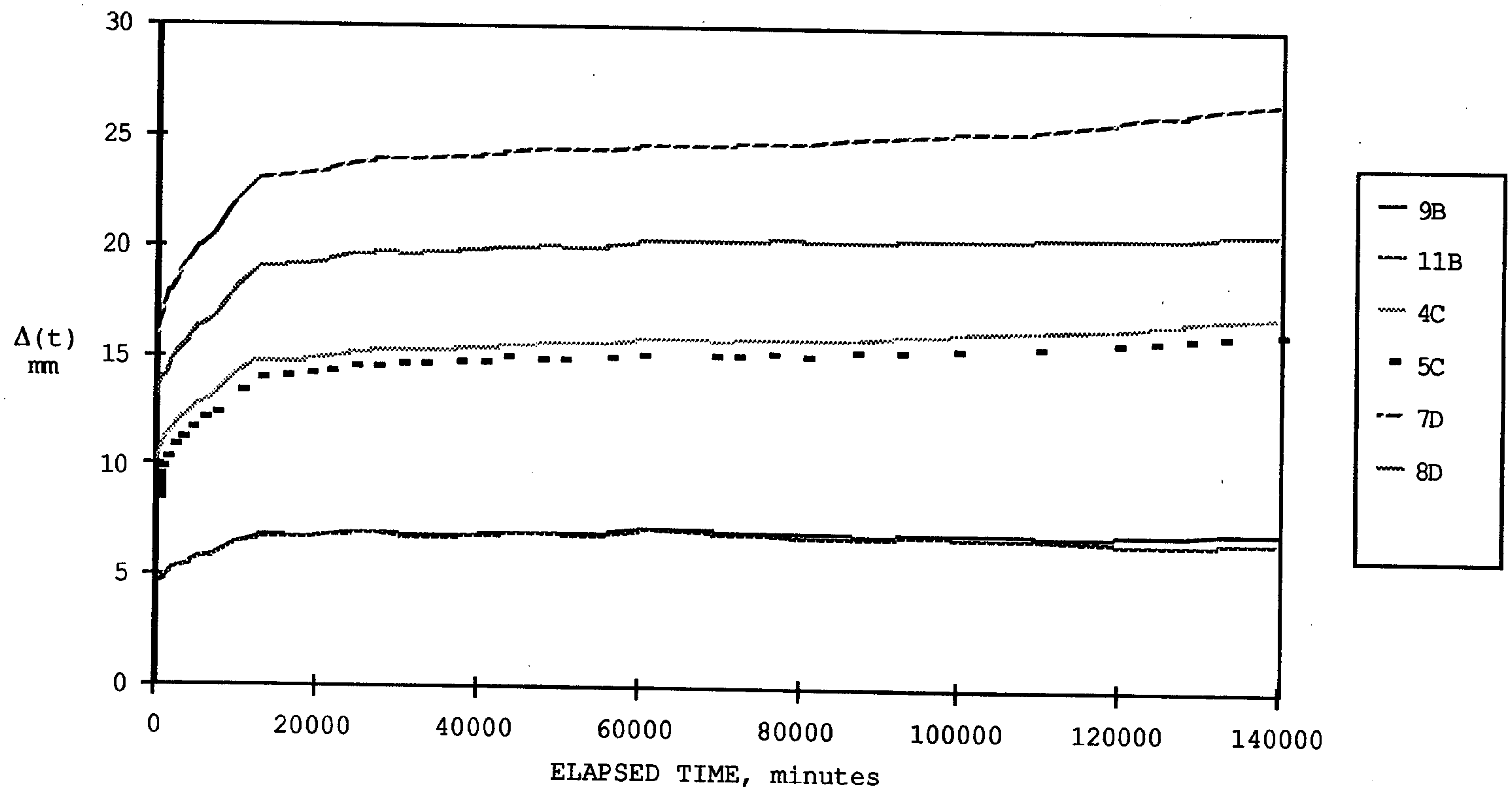


FIGURE 3.5 CENTERLINE DEFLECTION HISTORIES OF SSP SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

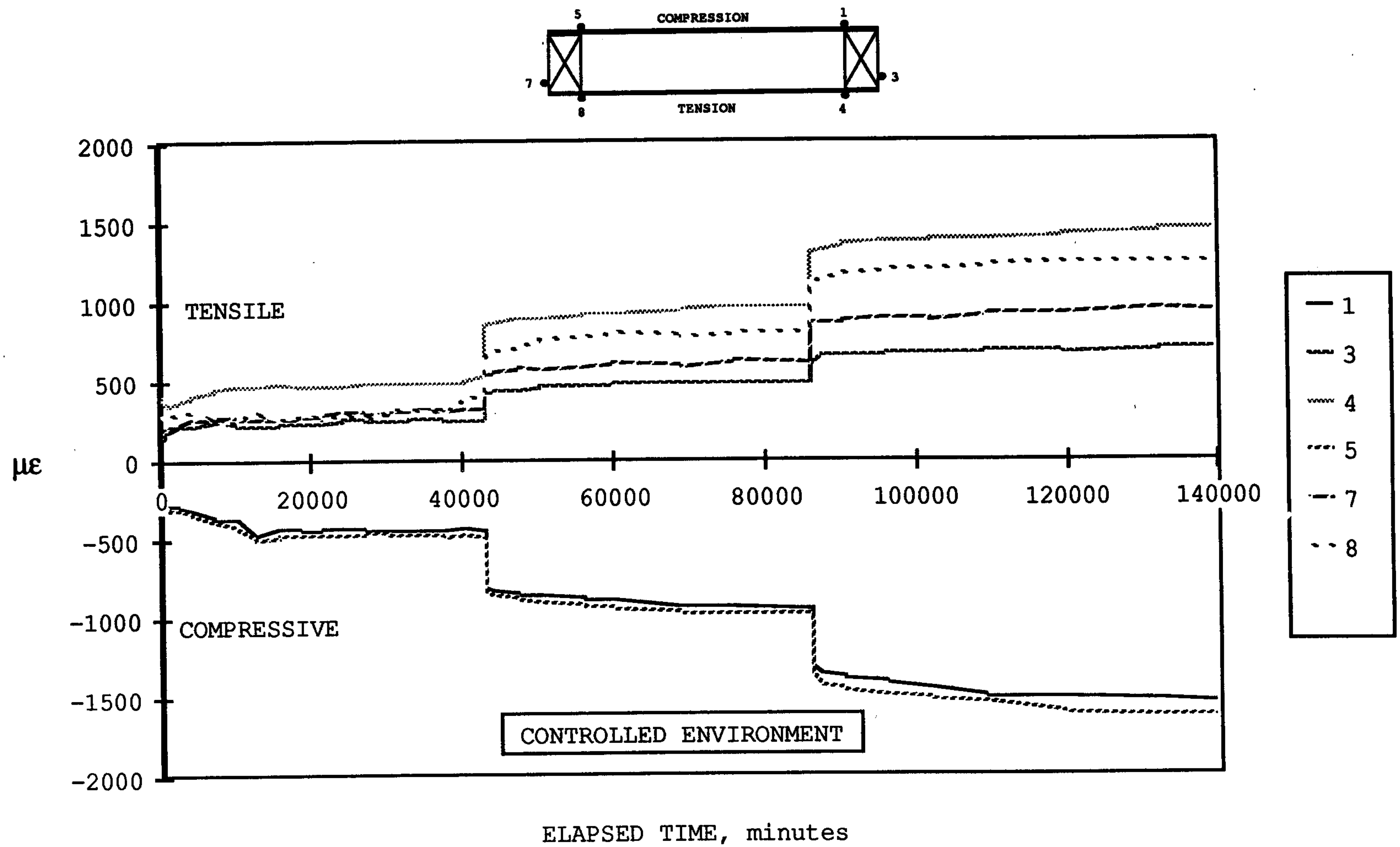


FIGURE 3.6 LONGITUDINAL STRAIN HISTORY AT MIDSPAN OF SSP SPECIMEN 2A SUBJECTED TO STEP-SUSTAINED MOMENTS

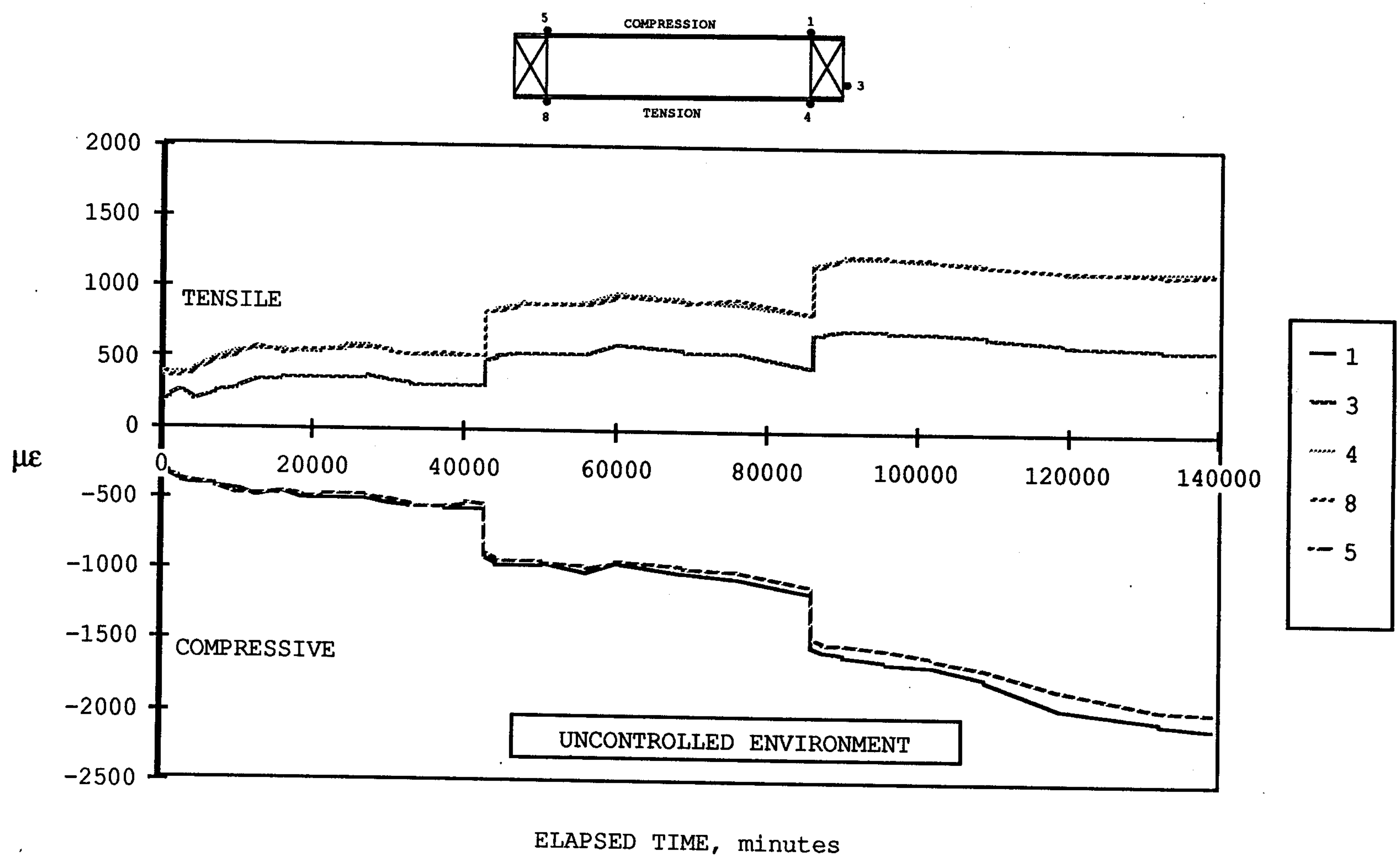


FIGURE 3.7 LONGITUDINAL STRAIN HISTORY AT MIDSPAN OF SSP SPECIMEN 10A SUBJECTED TO STEP-SUSTAINED MOMENTS

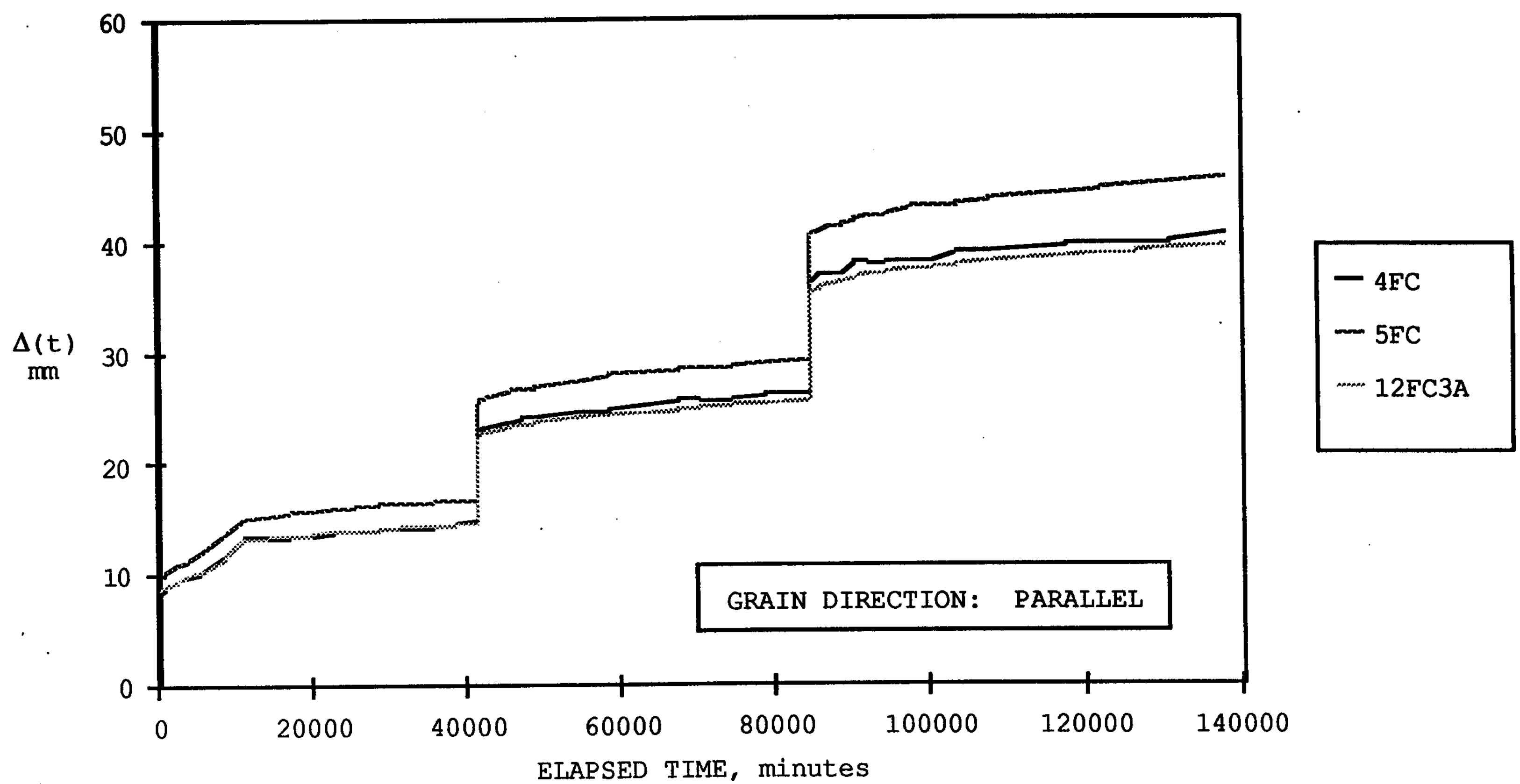


FIGURE 3.8 CENTERLINE DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO STEP-SUSTAINED MOMENTS UNDER CONTROLLED ENVIRONMENT

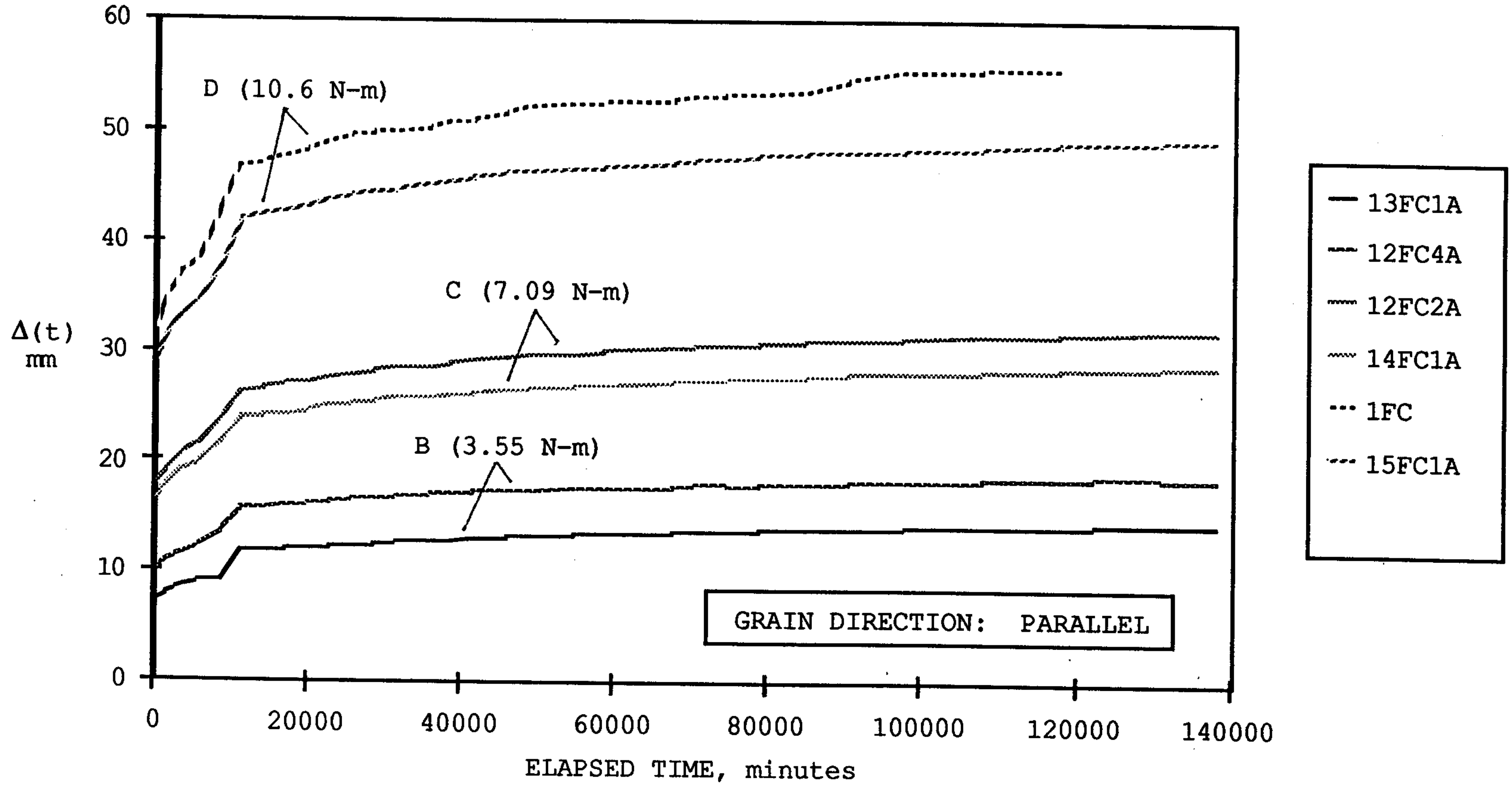


FIGURE 3.9 CENTERLINE DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER CONTROLLED ENVIRONMENT

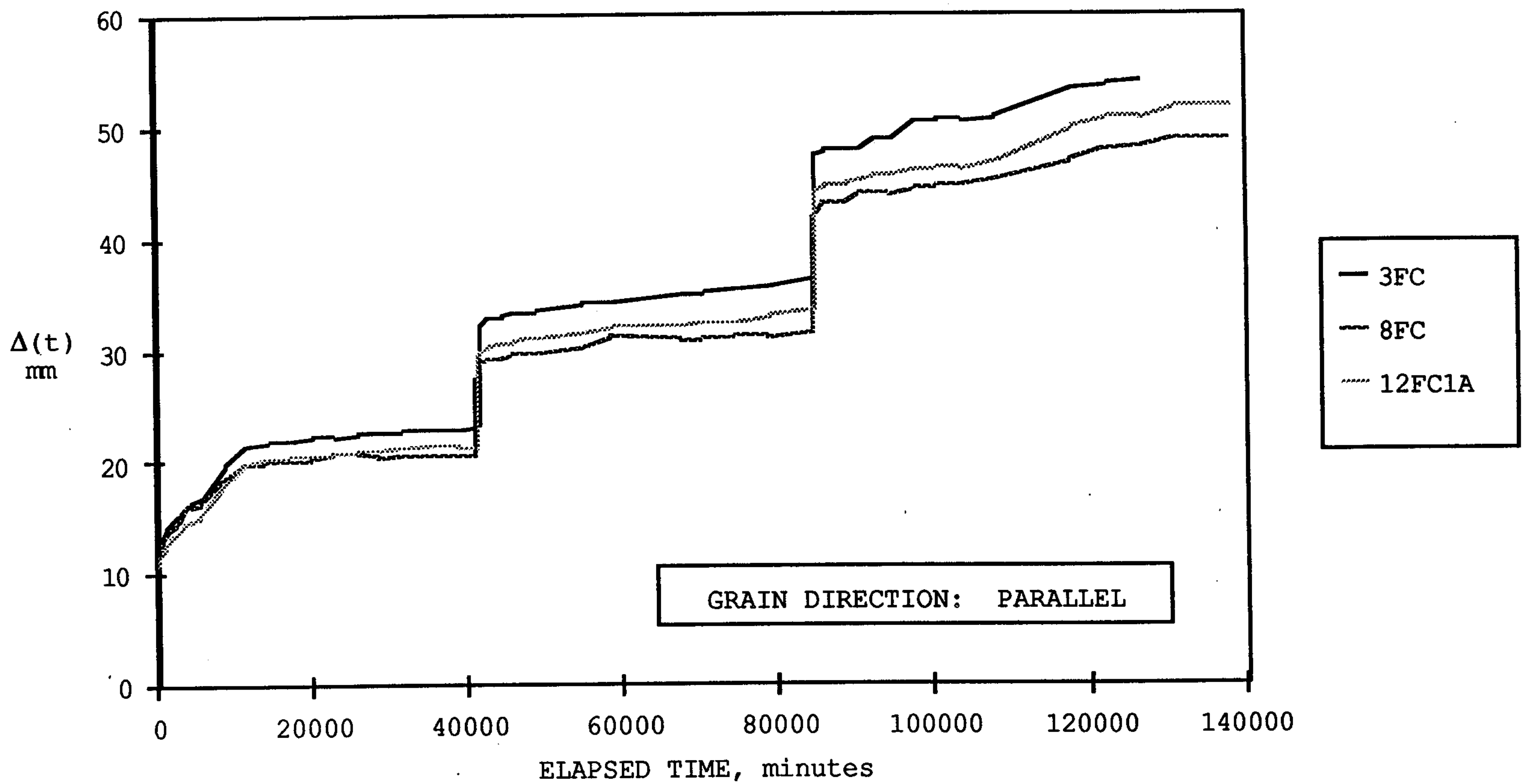


FIGURE 3.10 CENTERLINE DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO STEP-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

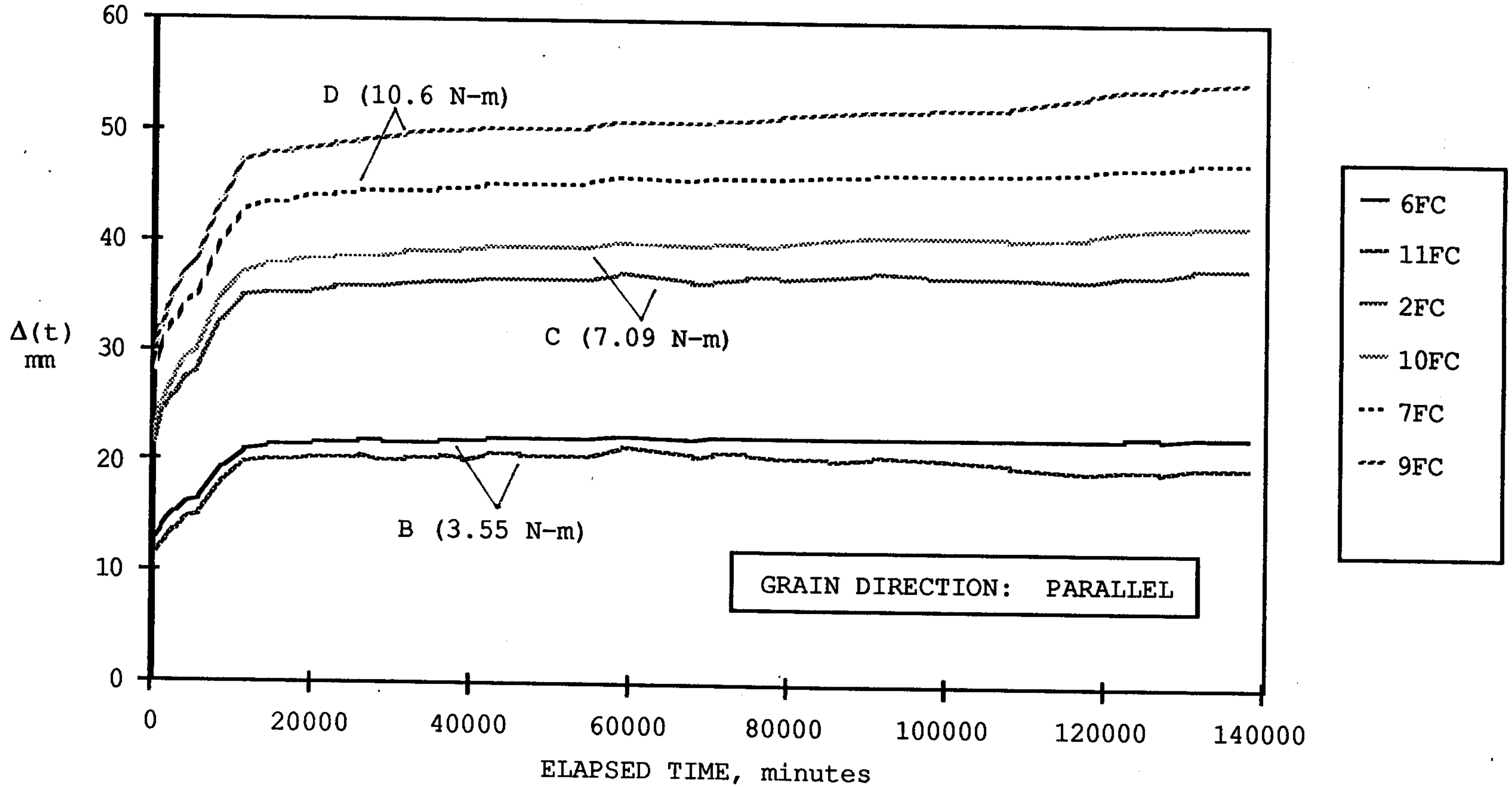


FIGURE 3.11 CENTERLINE DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

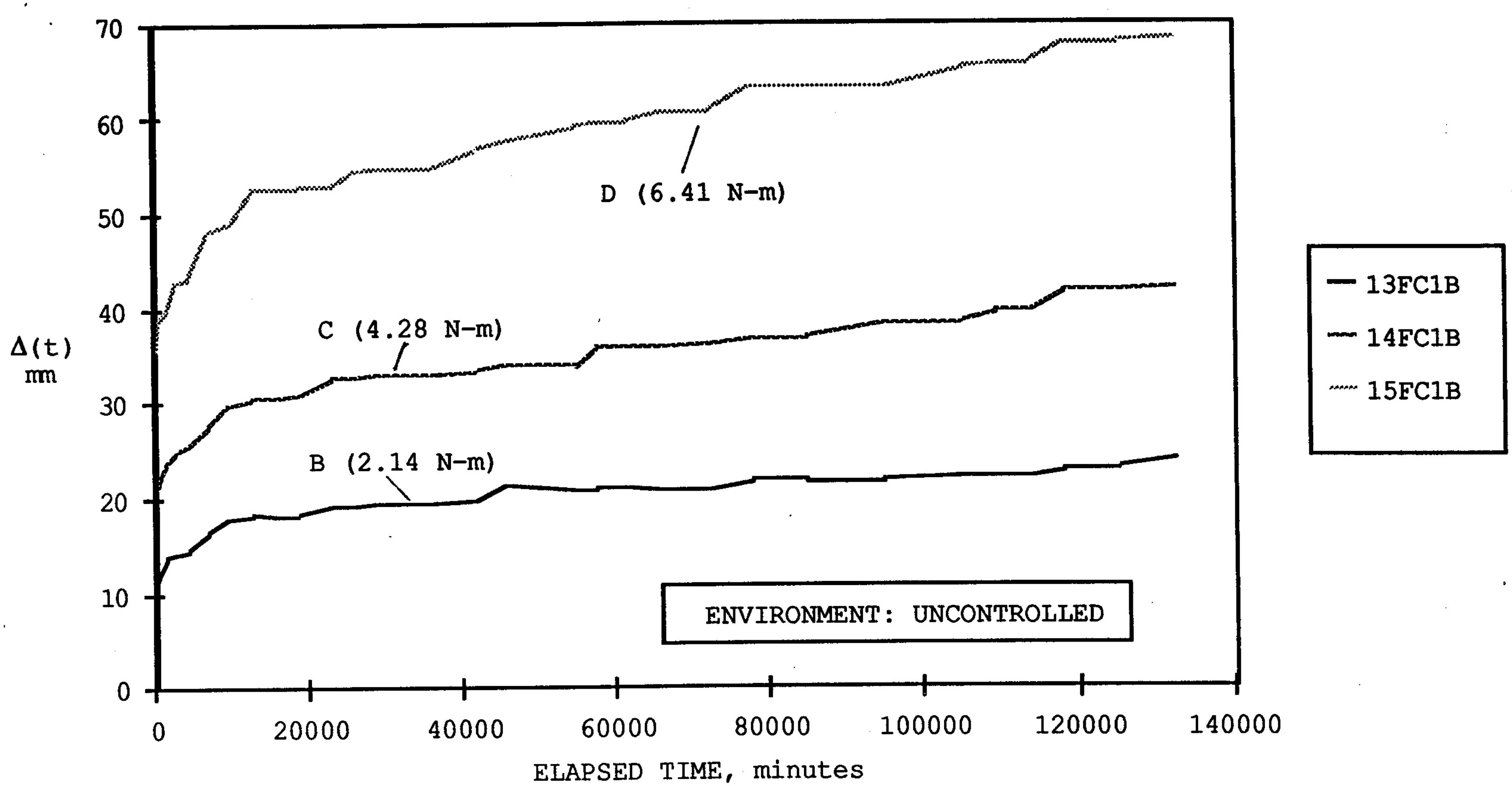


FIGURE 3.12 CENTERLINE DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS IN THE PERPENDICULAR-TO-GRAIN DIRECTION

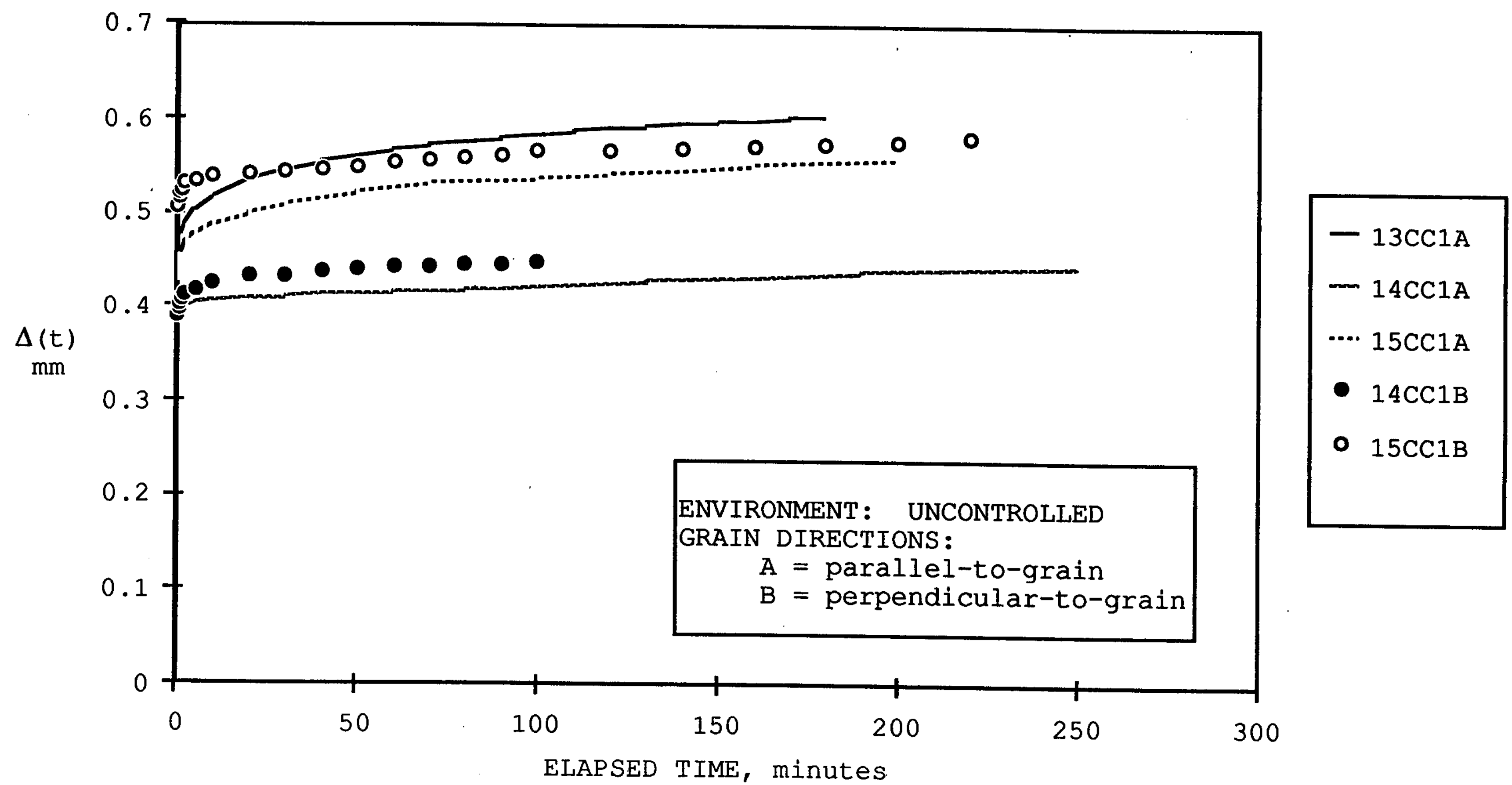


FIGURE 3.13 DEFLECTION HISTORIES OF OSB SPECIMENS TESTED UNDER SUSTAINED COMPRESSION

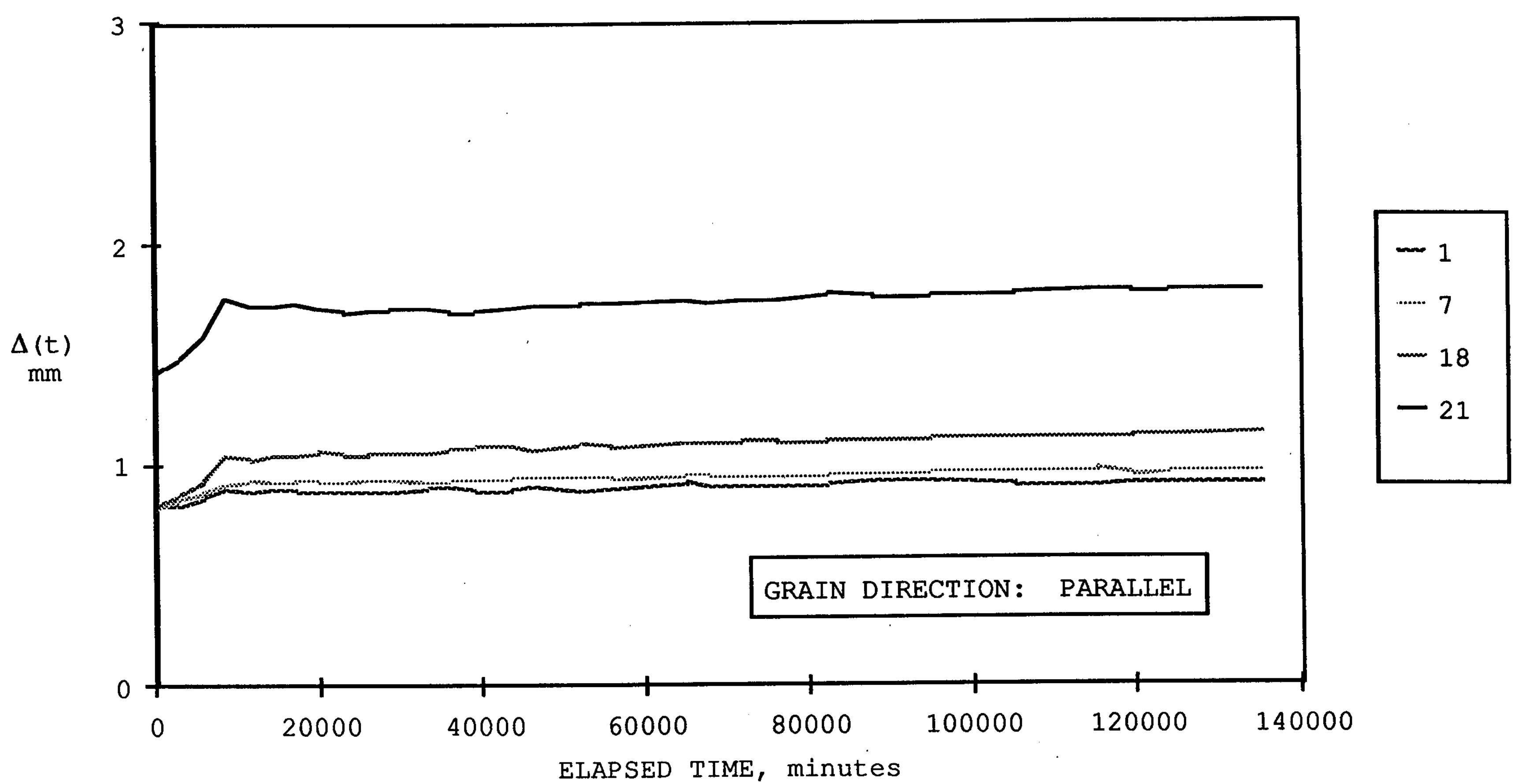


FIGURE 3.14 LOCAL DEFLECTION HISTORIES OF S-P-F LUMBER SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER CONTROLLED ENVIRONMENT

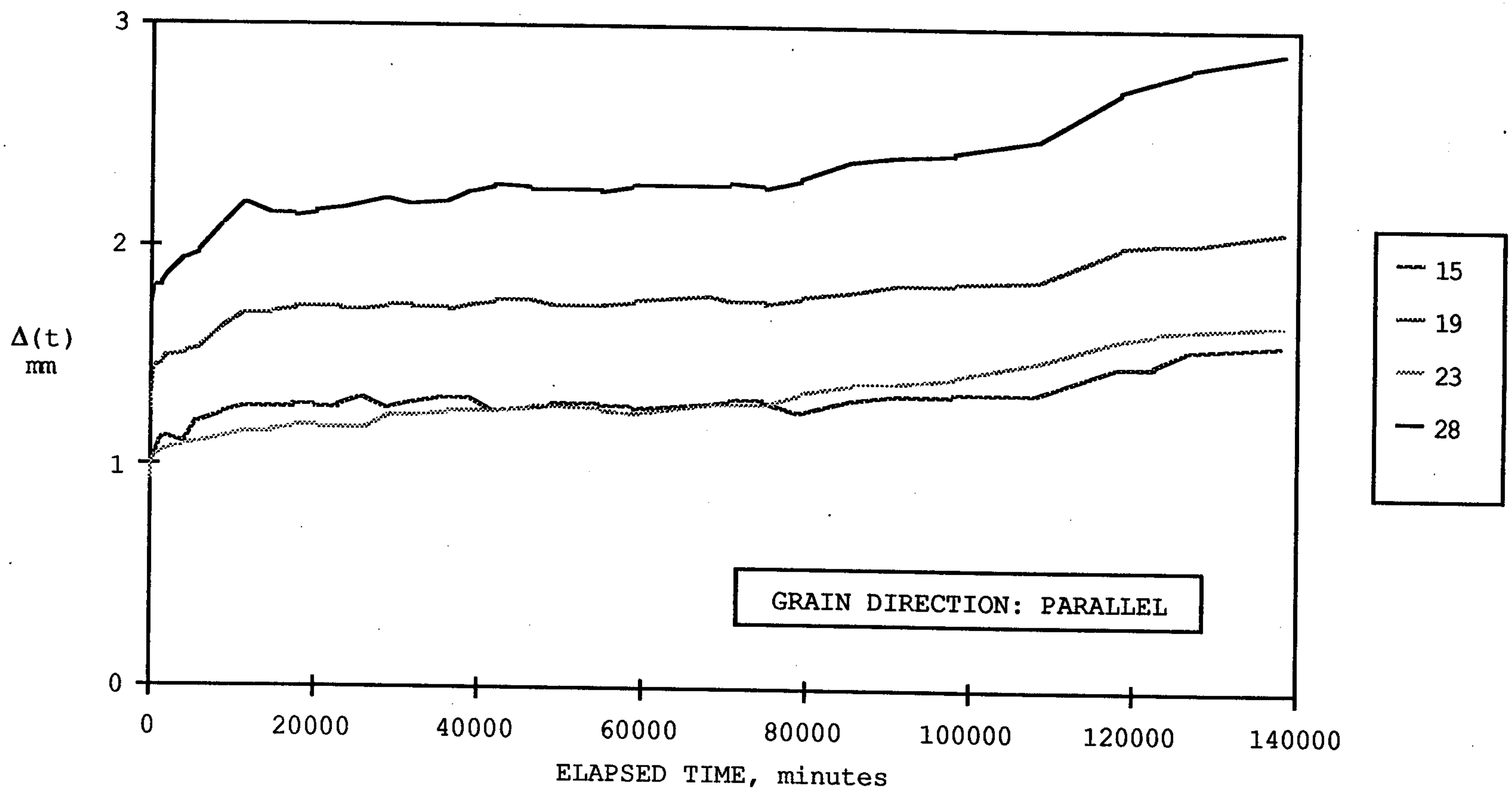


FIGURE 3.15 LOCAL DEFLECTION HISTORIES OF S-P-F LUMBER SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

4. ANALYSIS AND DISCUSSION OF TEST RESULTS

4.1 Viscoelastic Behaviour Analyses

One of the requirements for obtaining viscoelastic behaviour is that the applied load does not induce any yielding or fracture. If the applied load is low enough, the viscoelastic behaviour may be characterized by linear theories.

For the majority of the long-term tests, the excitation took the form of bending moments. These sustained flexural loads were either applied in three steps or maintained constant during the experiment. Stress levels are used to denote the intensities of the applied loads and are given below:

Material	Surface Grain Orientation	Highest Stress Level (%)
OSB	parallel	12.0
OSB	perpendicular	11.6
OSB	compression	30.0
Lumber	parallel	11.4
OSB (SSP)	parallel	14.5

Highest stress level was the ratio of the load used in loading scheme D and the short-term strength of the material. For the OSB specimens tested in compression, it was felt that such high stress level (30 %)

was necessary to gain some meaningful data in such short time. The stresses in the skin (OSB) of the SSP were approximated by assuming that the lumber webs do not exist. Incidentally, the bending moment corresponding to the stress level shown is about double that results from a gravity load of 1.9 kPa.

The creep data are analyzed below to determine whether linear viscoelasticity is applicable to the time-dependent behaviour of the OSB and SSP.

4.1.1 Fractional Deflection Method

Fractional deflection is the ratio of total deflection to the instantaneous deflection. The one-minute deflection is selected as the instantaneous deflection here. For some SSP specimens, two-minute reading is used when the one-minute reading is not available. According to the definition of elapsed time, and from experimental observations, this adjustment does not appear critical.

Figure 4.1 illustrates the fractional results for the uncontrolled SSP specimens. The variations of results become more pronounced as time approaches the end of the test duration. These variations may be attributed to the specimens' different response rates due to climatic changes.

Figures 4.2 to 4.4 are fractional deflection curves for the OSB specimens tested in bending. The results indicate that the material's creep behaviour, for both grain orientations, is not dependent on the magnitude of the loads used in the tests. The discrepancies are random and are attributed to basic variations in the material behaviour.

4.1.2 Application of Boltzmann's Principle of Superposition

For the discrete load cases with finite time, Eq.4 is modified as follows (Bach 1966):

$$\Delta(t) = \sum_{\Theta_i=0}^{\Theta_i=t} J^*(t-\Theta_i) \bullet P_i \qquad [9]$$

Eq.9 is modified by substituting the expression for J*(t) given in Eq.8 as follows:

$$\Delta(t) = \sum_{\Theta_i=0}^{\Theta_i=t} \frac{FD(t-\Theta_i)}{K_2} \bullet P_i \qquad [9A]$$

Eq.9A is used to reconstruct the deflection history of a specimen subjected to step-sustained loads. FD(t) is the average fractional deflections from all the specimens subjected to constant-sustained loads. The ratio between P and K_2 is the instantaneous (1 minute) deflection which is specific to the specimen being analyzed. The comparisons between the calculated and the test results are shown in Figures 4.5 to 4.14 for the SSP and OSB specimens.

The superposition principle applies very well in the controlled-environment case. However, the same cannot be said about the uncontrolled case. The obvious reason is that the effects of climatic fluctuation. However, there is another reason which is common to both cases. That is, the failure of the principle is attributed to basic material behaviour. If one inspects the creep curves (e.g. Figs.3.8 and 3.10) from the step-load cases, the primary creep in the first step is very much different from that found in the subsequent steps. This inconsistency is caused by the lack of mechanical conditioning as referred by Alfrey (1948) in his discussion of Leaderman's (1943) work on high polymers. Nielsen (1972) referred to that first creep curve as virgin creep curve. If the material is not mechanically conditioned to rid its virgin creep, the superposition will not give the correct responses due to varying excitations.

4.1.3 Isochrone Technique

Isochronous curves are constructed from the moment-deflection-time surface. The non-dimensionalized results are plotted in Figures 4.15 to 4.18. The following procedures are used in obtaining the data points:

1. Calculate the average fractional deflections from each level of constant-sustained load. Determine the fractional deflection values corresponding to the specified elapsed times using the cubic-spline technique.
2. Non-dimensionalize the instantaneous moment-deflection curve by setting the values of moment and deflection to one for the first load step. (The scheme can be verified by checking the linearity of the load-

displacement curves from the short-term test results or of the instantaneous results from each load step.)

3. The isochrones are created by multiplying 2 and 3 above.

The isochronous moment-deflection curves further demonstrate that the OSB and SSP's time-dependent behaviour practically follows that of an idealized linear viscoelastic material.

4.2 Prediction of the Long-Term Flexural Behaviour of OSB Stressed Skin Panels

There are a few questions that must be answered before the time-dependent behaviour of this composite panel can be modeled:

1. As described earlier, OSB is basically made from three layers of flakes. The orientation of the core layer is orthogonal to that of the surface layers. Should these layers be differentiated in the SSP model? If the answer is yes, then how can one determine the flexural modulus of each layer when only the composite flexural stiffness of the OSB panel is known? If the answer is no, then how can one account for the contribution of the OSB panel (when only EI of the panel itself is known) to the composite flexural stiffness of the SSP?
2. Can one extend the spring analogy, used in the linear elastic problem, to a linear viscoelastic problem?

3. Since different viscoelastic materials are used to construct the SSP, can the model be simple enough to ignore the effects of stress redistribution due to differential creep rates? (Since the lumber creeps slower than the OSB, it will restrain the OSB from creeping at a rate corresponding to unrestrained conditions. Thus, the current stress in the OSB is actually lower than the initial stress and reverse condition is true for the lumber.)

4.2.1 Flexural Moduli of the OSB Layers

It was decided that the answer to the first question posed above is to distinguish the layered structure in the OSB. The SSP used in the prediction is therefore made of three components. The first component is the S-P-F lumber. The second component represents the surface layers of the OSB which have a parallel-to-grain orientation. The third component represents the core layer of the OSB which has a perpendicular-to-grain orientation. The time-dependent behaviour of each component will be characterized by the flexural creep test results. The OSB's parallel-to-grain results would be used to characterize the second component's long-term behaviour. The OSB's perpendicular-to-grain results would apply to the third component. Although the perpendicular-to-grain tests for the OSB specimens are delayed by about 8 days, the same results are used in the prediction for both environments due to lack of better data.

Now, the flexural modulus of each layer (surface and core) must be determined. The solution may be approximated with the following reasoning. If a panel is subjected to two separate bending moments which are orthogonal to each other. The average flexural stiffness for each direction (parallel- and perpendicular-to-grain) can be evaluated. The flexural moduli of the surface(S) and core(C) layers can be approximated using the formulation shown below:

$$\begin{bmatrix} I_S & I_C \\ I_C & I_S \end{bmatrix} \begin{Bmatrix} E_S \\ E_C \end{Bmatrix} = \begin{Bmatrix} EI_A \\ EI_B \end{Bmatrix} \qquad [10]$$

The first matrix on the left side of Eq.10 represents the moment of inertia terms for the surface and core layers. The right side of Eq.10 contains the flexural stiffness terms obtained from tests. Subscripts A and B stand for parallel- and perpendicular-to-grain respectively. The unknowns are E_S for the surface layers and E_C for the core layer. In obtaining the solutions, it is assumed that the alignment of the grains in the surface layer is parallel to that of the bending stresses.

The calculation of moment of inertia terms require the knowledge of shelling ratio. Judging from the compression results shown in Table 3.4, it is reasonable to state that the shelling ratio for the OSB panels is about 0.5. Based on the results (Table 3.1) from panels 13 to 15, and assuming that perfect matching of samples exists, the flexural modulus of the core (E_C = 2440 MPa) is about 1/3 of that for the surface (E_S = 8200 MPa).

By applying the spring model (Figure 1.8), modified to respresent three components, the contributiuons of the first, second, and third components are 31 %, 53 %, and 16 % respectively. The modulus of elasticity of lumber is taken as 10 000 MPa in the calculation.

4.2.2 Application of Correspondence Principle

The solution to the second question can only be tested by applying the correspondence principle (Flugge 1967). The principle states that a linear viscoelastic problem may be evaluated using the method developed for a linear elastic problem by replacing the elastic constants with the appropriate viscoelastic operators.

Now, if one rearranges Eqs. 6A and 8, the resulting expression is shown below:

$$\frac{P}{\Delta(t)} = \frac{K2}{FD(t)} \qquad [11]$$

When comparing above expression with Eq.1A, the application of the correspondence principle becomes apparent. The time-dependent flexural stiffness of the SSP can be calculated as before but the elastic constant of each component is reduced by the corresponding fractional deflection function.

Thus, the composite viscoelastic problem can be dealt with using the spring analogy. Recall that for elastic analysis, each material's behaviour is represented with a spring. Now, each spring is replaced with a Maxwell-Voight element as shown in Figure 4.19. It is not necessary to determine the values of all the constants shown in the figure. If we examine the arrangement of the elements, the time-dependent deflection of the SSP can be calculated by modifying the right side of Eq.11 as follows:

$$\Delta(t) = P \Big/ \sum_{i=1}^{n} \frac{K_i}{FD_i(t)} \qquad [12]$$

The SSP model shown in Figure 4.19 also indirectly answers the third question outlined earlier. If we evaluate the load history of each Maxwell-Voigt element, load redistribution among the components of the SSP is apparent.

The prediction of long-term flexural behaviour has been carried out for both environments. A typical calculation example is shown in Appendix B. The results, in fractional deflection format, are shown in Figures 4.20 and 4.21. The maximum difference between the predicted and test values is about 6 % for the controlled environment and 13 % for the uncontrolled environment.

4.3 Application of the Prediction Method to a Full-Scale Specimen

A similar experiment is currently conducted by the Forest Products Testing Laboratory of Alberta Research Council as illustrated in Figure 4.22. The SSP specimens are constructed with two thickness of OSB skin (9.5 mm and 15.5 mm) and four 38 x 140 mm S-P-F lumber webs. The top (compression) skin has a thickness of 15.5 mm. Each creep specimen is simply supported and is subjected to third-point loading as shown in Figures 4.23 and 4.24. The test spans are about 4800 and 1065 mm for the SSP and OSB respectively. The flexural load applied to each SSP is equivalent to that resulted from a gravity load of 1.9 kPa.

The prediction technique used here is virtually identical to that used before. The only exception is that the core material in the OSB panel (perpendicular-to-grain) has been ignored in calculating the composite stiffness due to lack of data (the flexural modulus of this idealized OSB panel must therefore be adjusted to account for the absence of the core material). The results are illustrated in Figure 4.25. Exclusion of the contribution from the core layer of the OSB in the calculations seems do not create an erroneous prediction appreciably. This may indicate that the contribution of the core material, in both elastic and viscoelastic terms, to the composite behaviour is not as significant as the other components.

4.4 Environmental Effects

The creep experiments were conducted in both controlled and uncontrolled environments. The effects of relative humidity and to a lesser extent, temperature, on the time-dependent flexural behaviour had been observed.

When comparing the results from the two different environments, one definite conclusion can be drawn; that is, fluctuating climatic conditions worsen the creep deformation as demonstrated in Figures 3.14 and 3.15 for the lumber and Figures 4.2 and 4.3 for the OSB.

Based on the results from the controlled environment, it seems that the temperature range encountered during the experiment does not have a dominating effect on the creep behaviour as for the humidity. Therefore, the discussion hereon is based on the assumption that temperature is not a factor.

As the humidity changes, a material's creep rate will alter in order to establish a new creep path corresponding to the new environment (Nielsen 1972). A change in the moisture content of the material may also change the micro-strucuture permanently. As a result, the creep behaviour is altered. The rate at which a material reaches a new equilibrium moisture is affected by the size of the specimen. This may explain, in part, why the predicted results are higher than that meausured for the SSP tested under uncontrolled environment.

The impacts of environmental variables on the creep behaviour of wood-based materials is not fully understood yet. Results are mostly empirical in nature. Spring-dashpot models are very restrictive and cannot be used, reasonably, to predict the creep deformation especially under fluctuating climatic conditions. Sophisticated modelling requires a better understanding of the microscopic behaviour. Also, it is more difficult to evaluate the parameters of the model as it becomes more complicated.

The flexural creep experiment is still continuing as this document is being prepared; however, when can one be satisfied that the data collected are adequate for the development of design guidelines?

Under steady-state environmental conditions, an accurate account of the creep behaviour of a given material can be obtained in a relatively short time. The 'final' deformation of that material can then be estimated using the graphical technique as shown in Figure 4.26. This technique is an attempt to linearize the creep curve. The fractional deflection function (or total deflection if desired) for SSP specimen 1 has been plotted on a log-log scale. Under sustained load condition, the final fractional deflection is obtained by extending the last portion of the creep curve to the desired time. One can then estimate the deflection by multiplying the extrapolated value to the elastic deflection.

Under non-steady-state environmental conditions, one may establish the creep behaviour using accelerated tests with the fluctuating variables set at the anticipated extremes. However, the response of the material may no longer behave in a linear manner (Nielsen 1972). The problem is further complicated by the creep rupture phenomenon associated with fluctuating environment. It is therefore difficult to predict the ultimate deflection using the simple technique just presented.

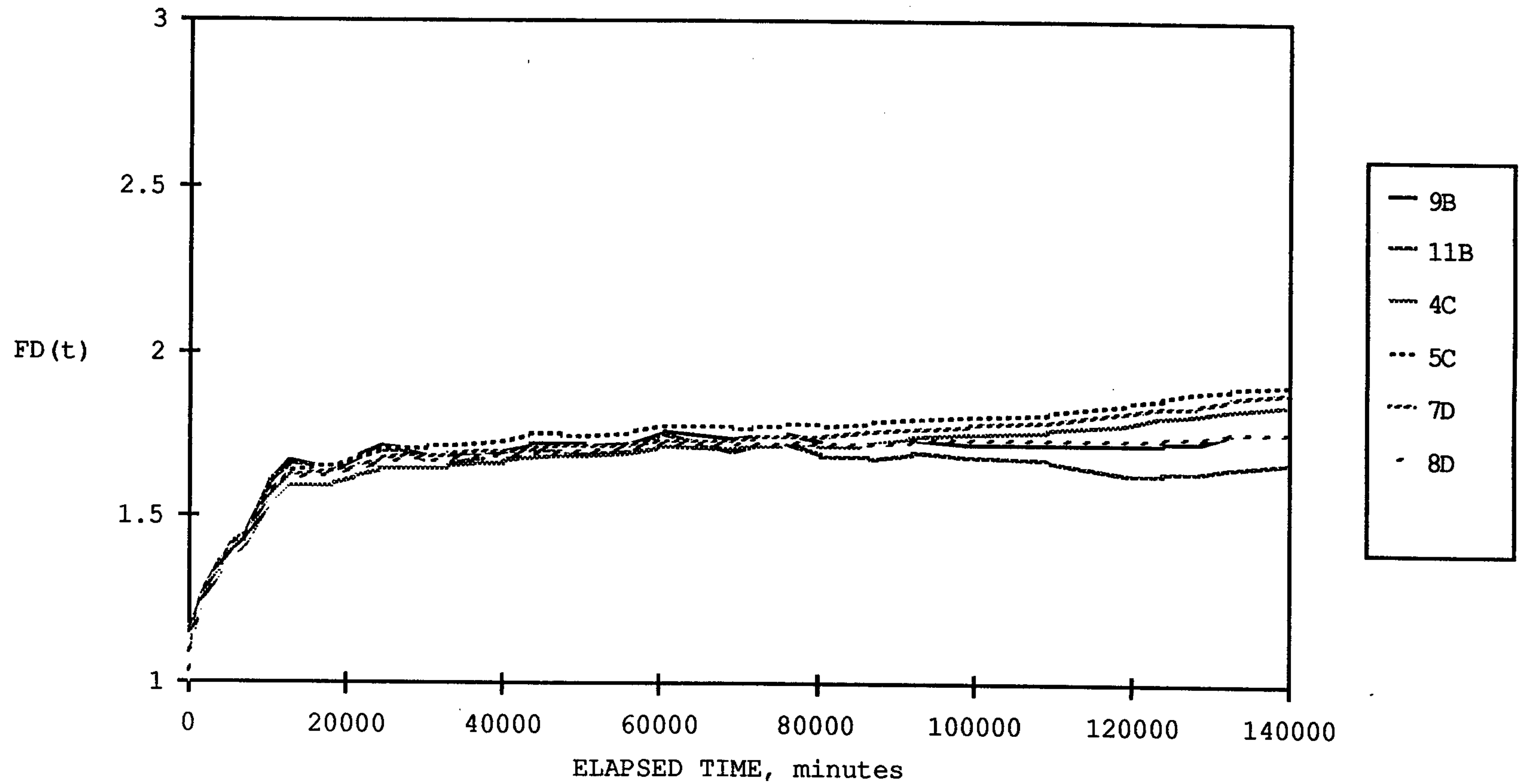


FIGURE 4.1 FRACTIONAL DEFLECTION HISTORIES OF SSP SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

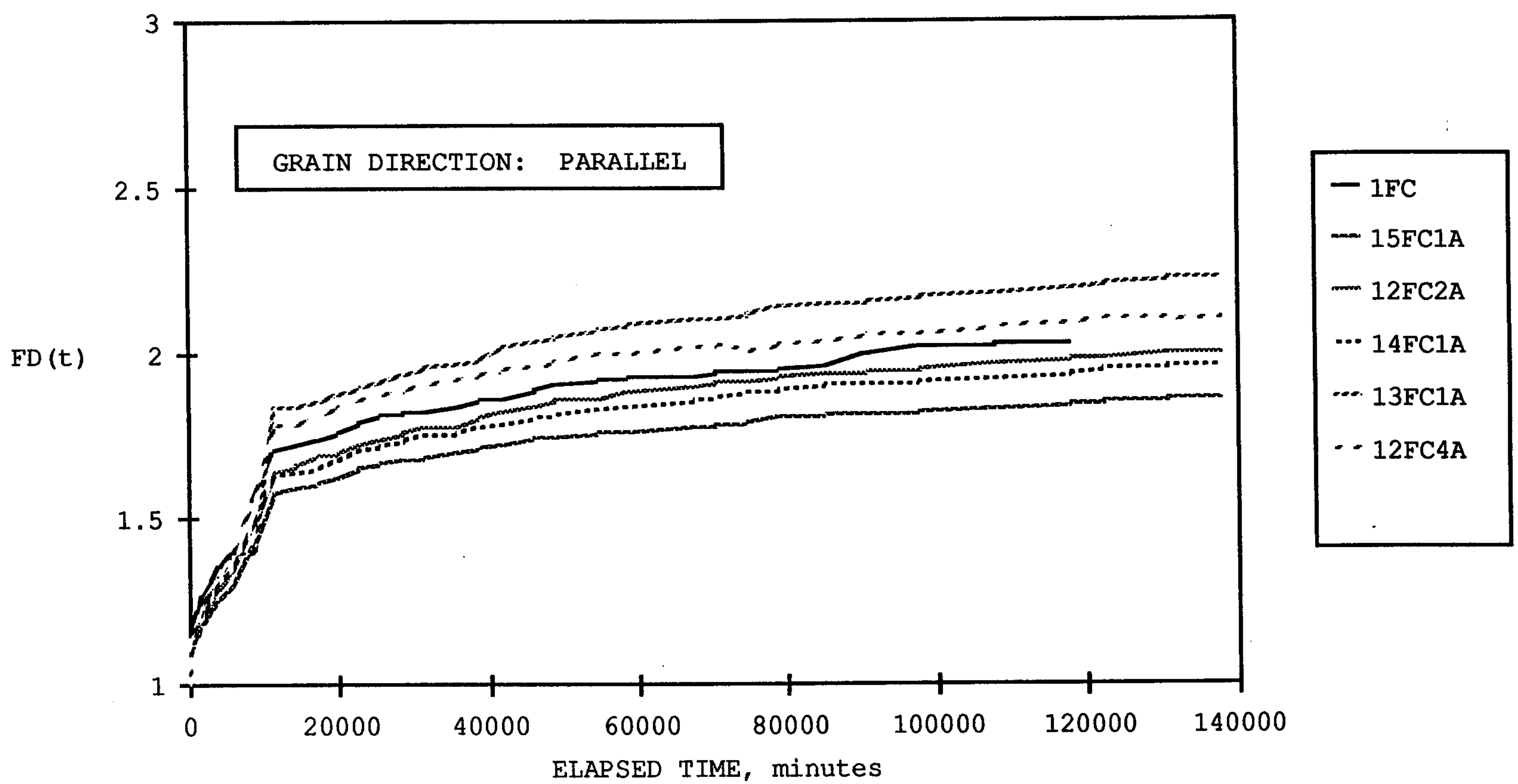


FIGURE 4.2 FRACTIONAL DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER CONTROLLED ENVIRONMENT

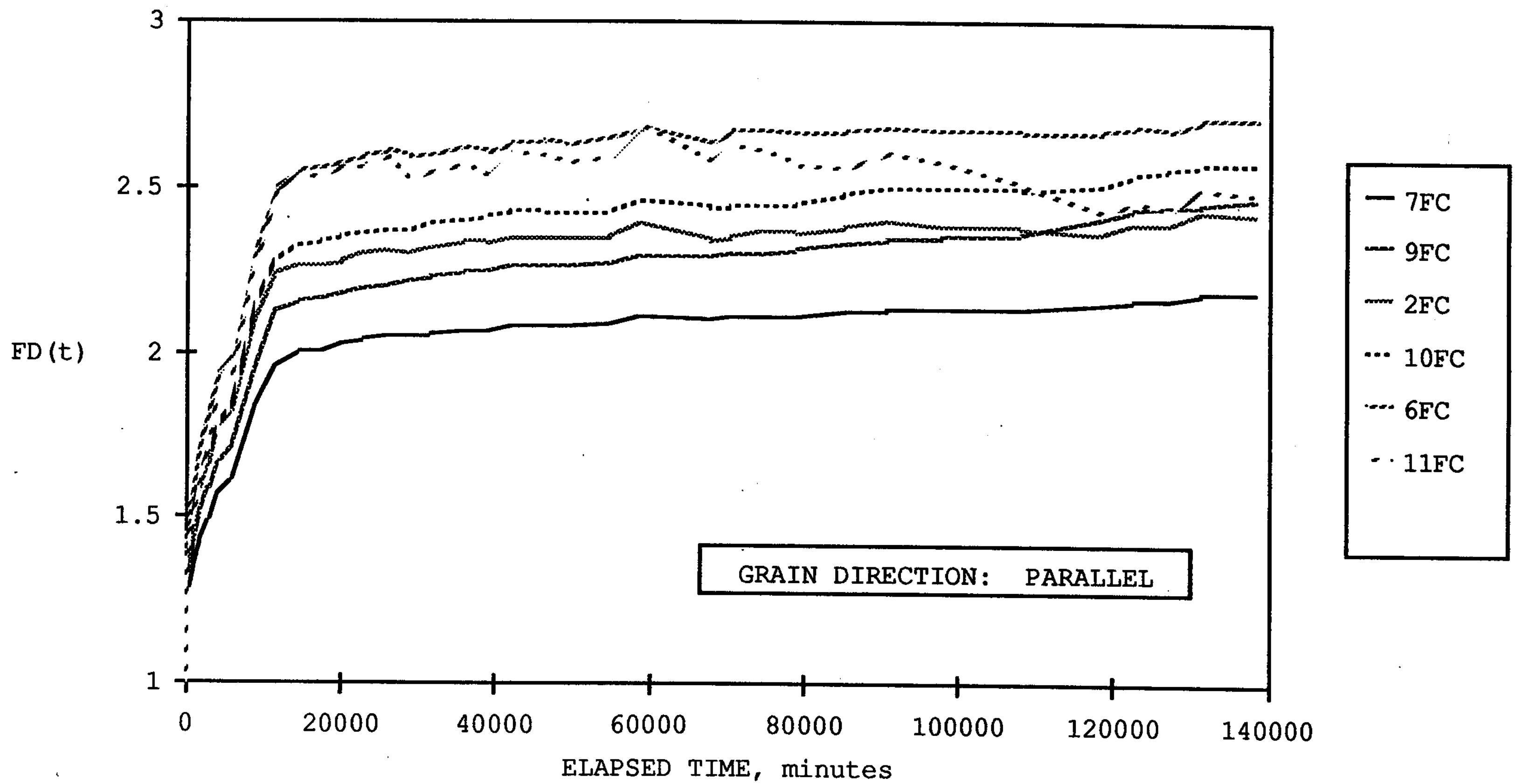


FIGURE 4.3 FRACTIONAL DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

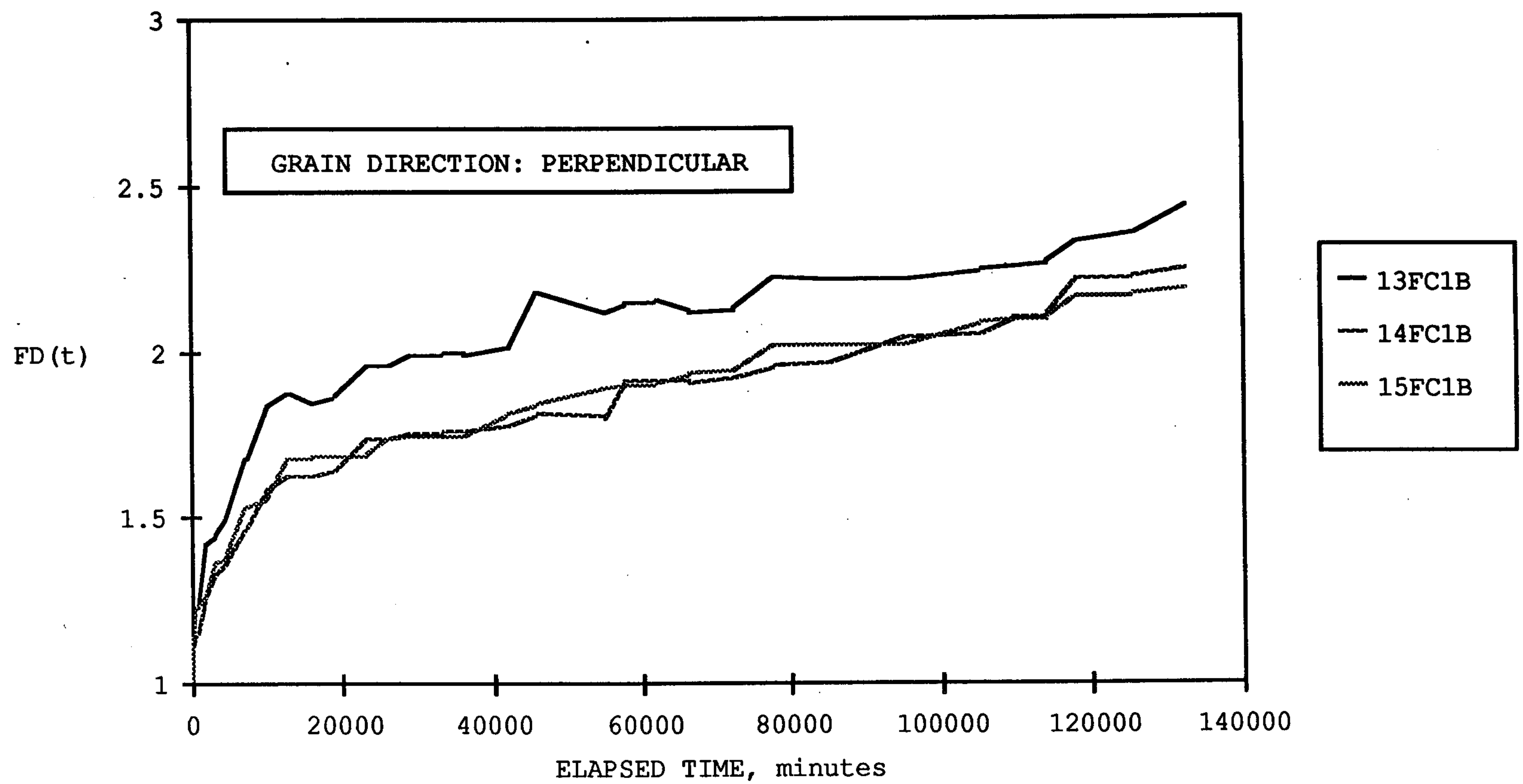


FIGURE 4.4 FRACTIONAL DEFLECTION HISTORIES OF OSB SPECIMENS SUBJECTED TO CONSTANT-SUSTAINED MOMENTS UNDER UNCONTROLLED ENVIRONMENT

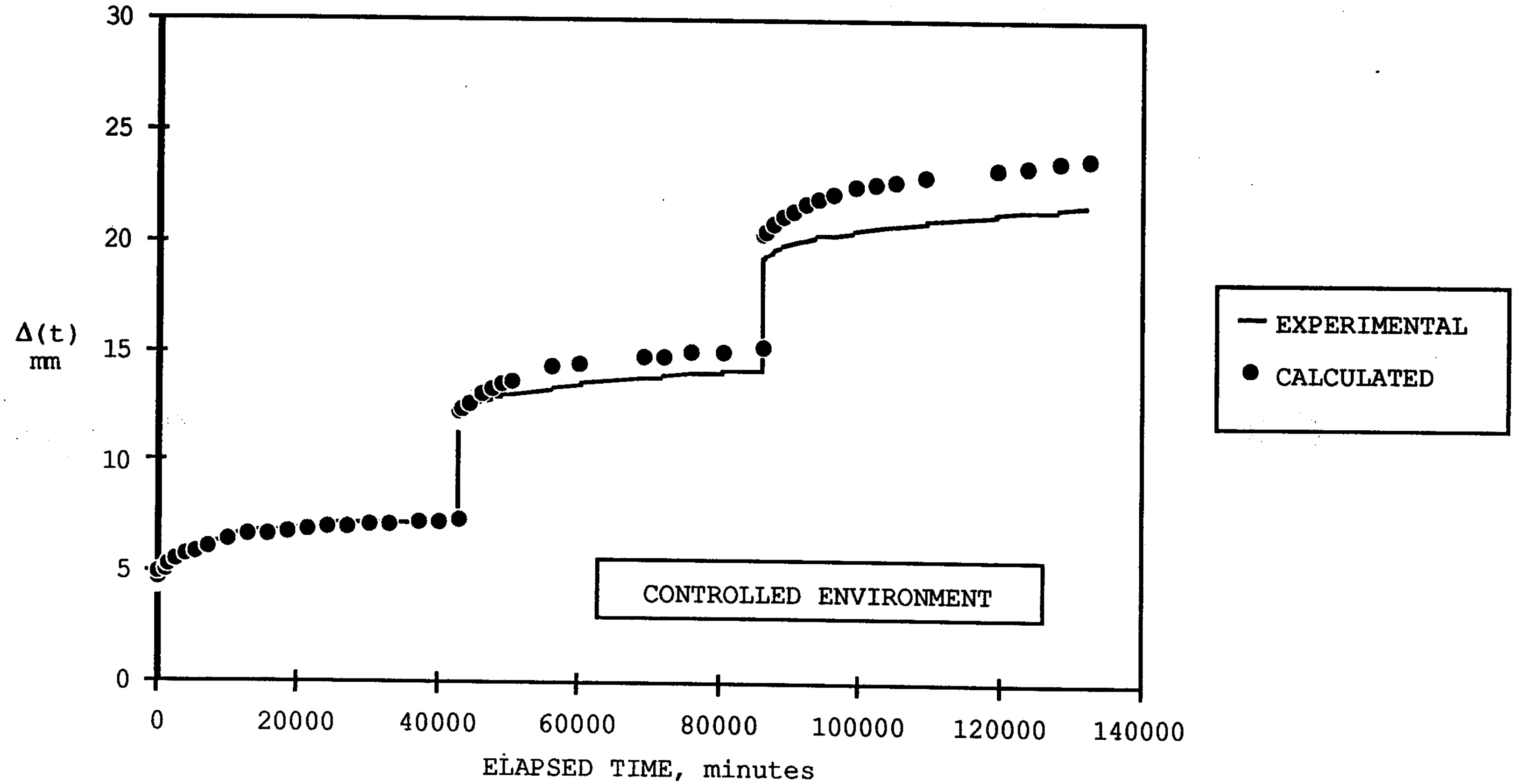


FIGURE 4.5 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON SSP SPECIMEN 2A

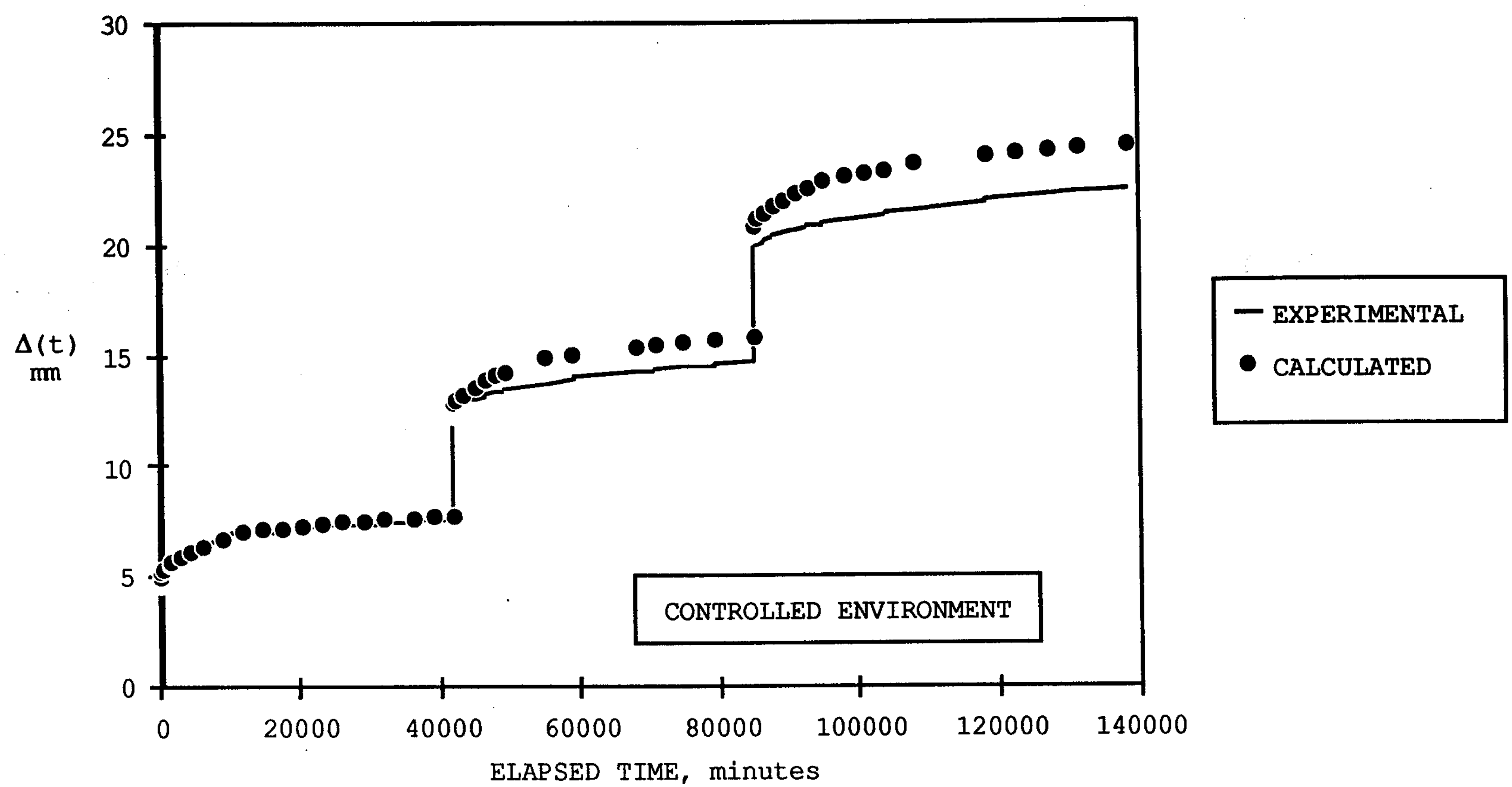


FIGURE 4.6 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON SSP SPECIMEN 3A

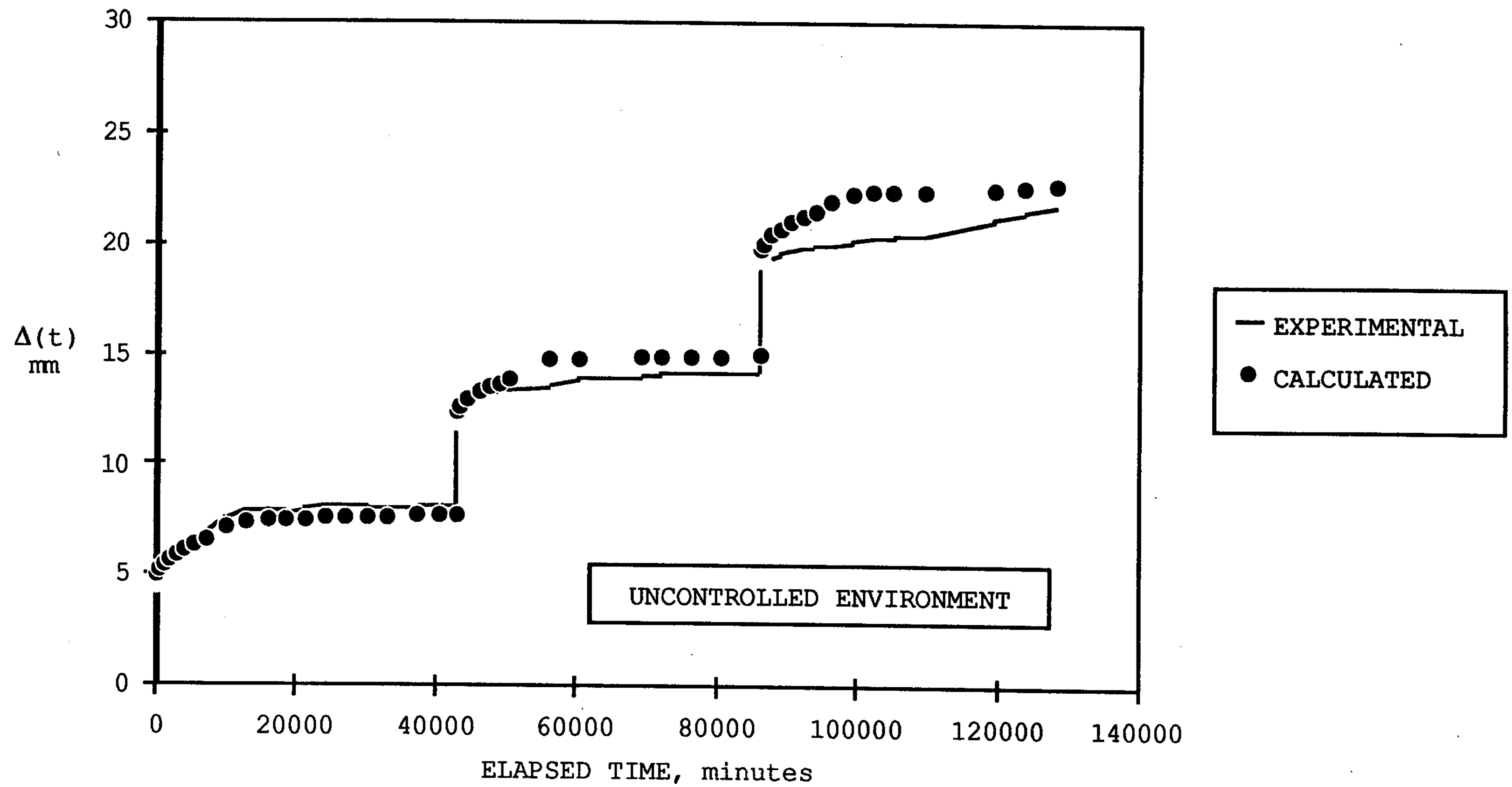


FIGURE 4.7 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON SSP SPECIMEN 6A

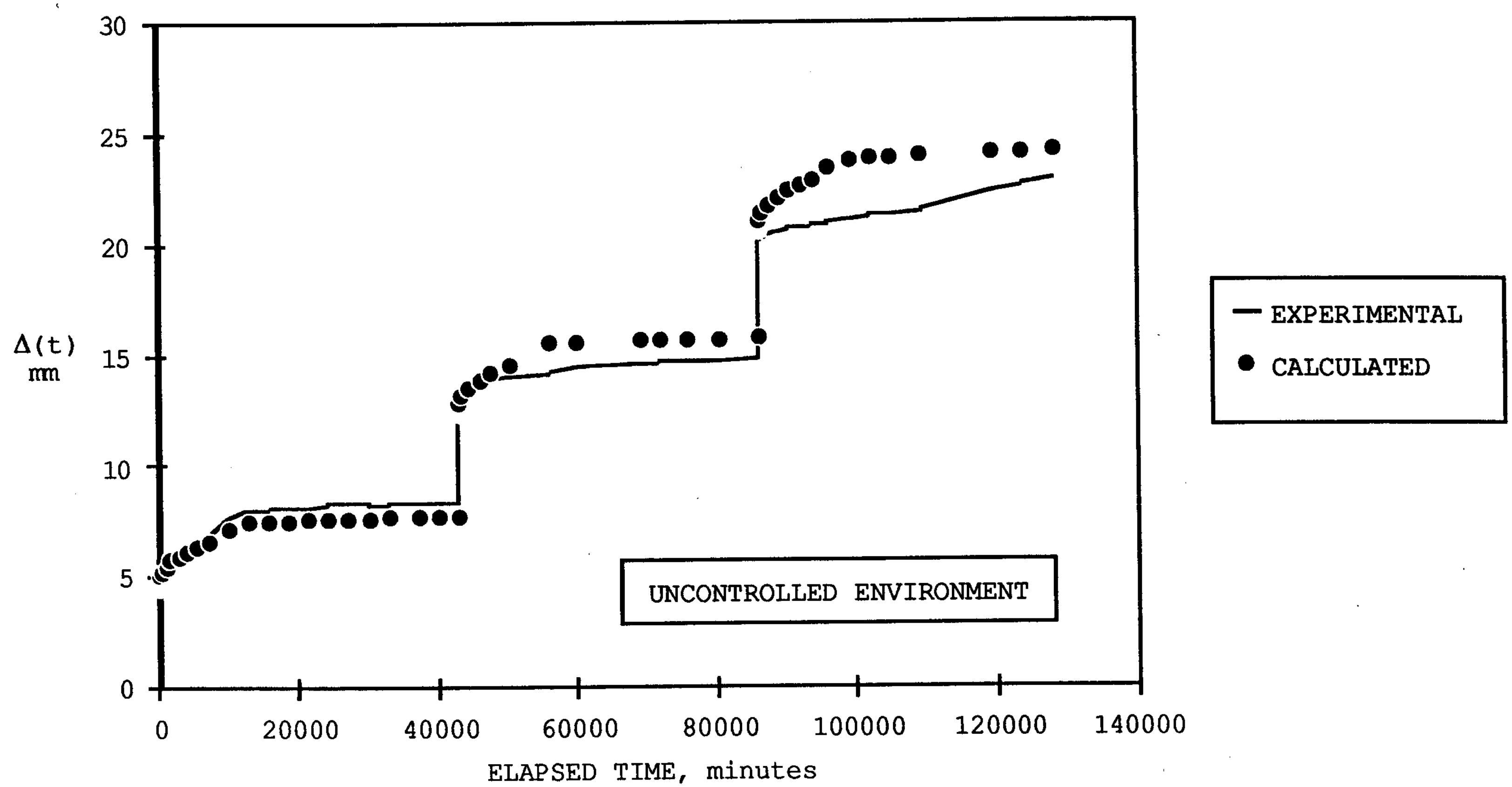


FIGURE 4.8 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON SSP SPECIMEN 10A

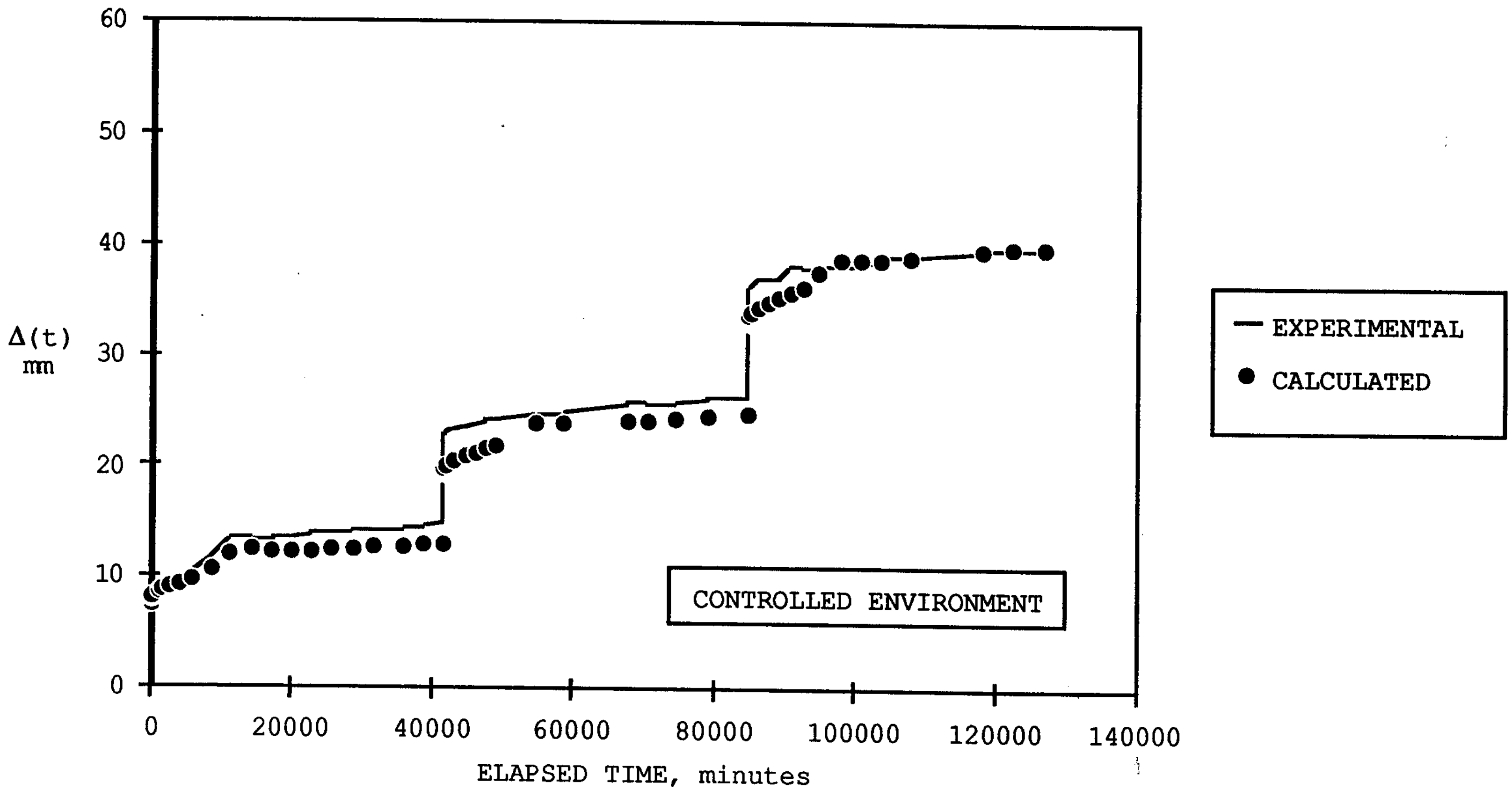


FIGURE 4.9 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON OSB SPECIMEN 4FC

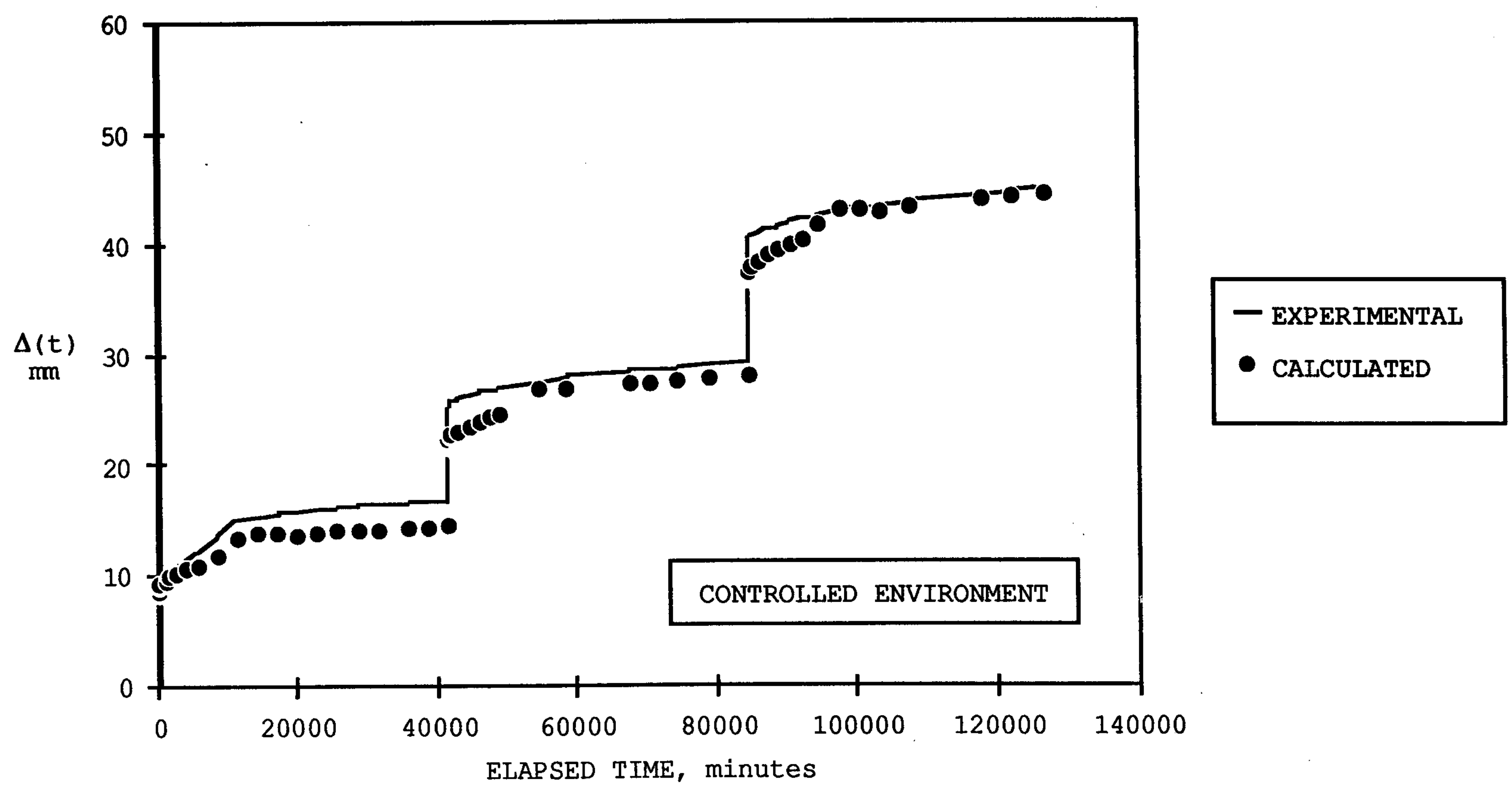


FIGURE 4.10 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON OSB SPECIMEN 5FC

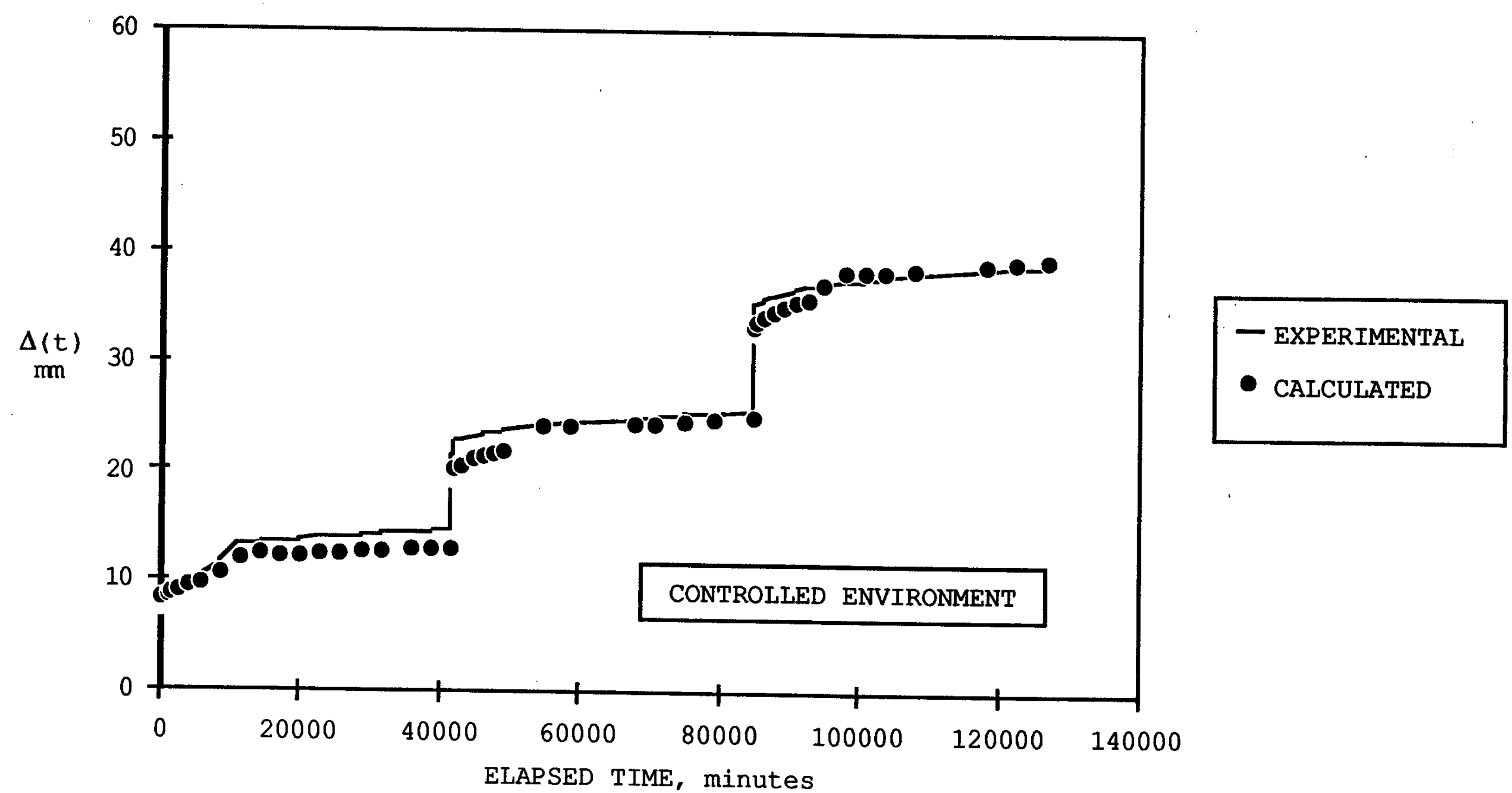


FIGURE 4.11 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON OSB SPECIMEN 12FC3A

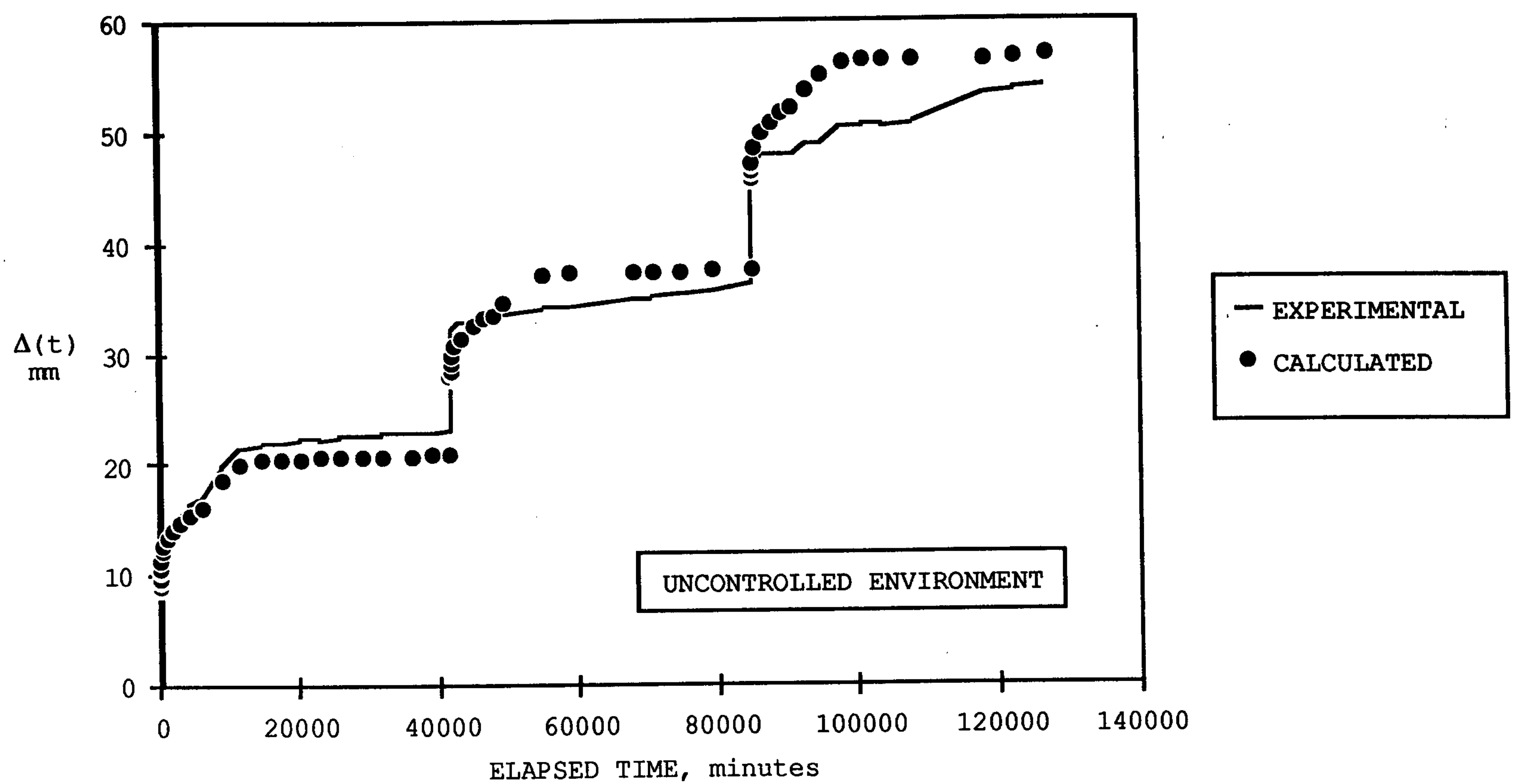


FIGURE 4.12 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON OSB SPECIMEN 3FC

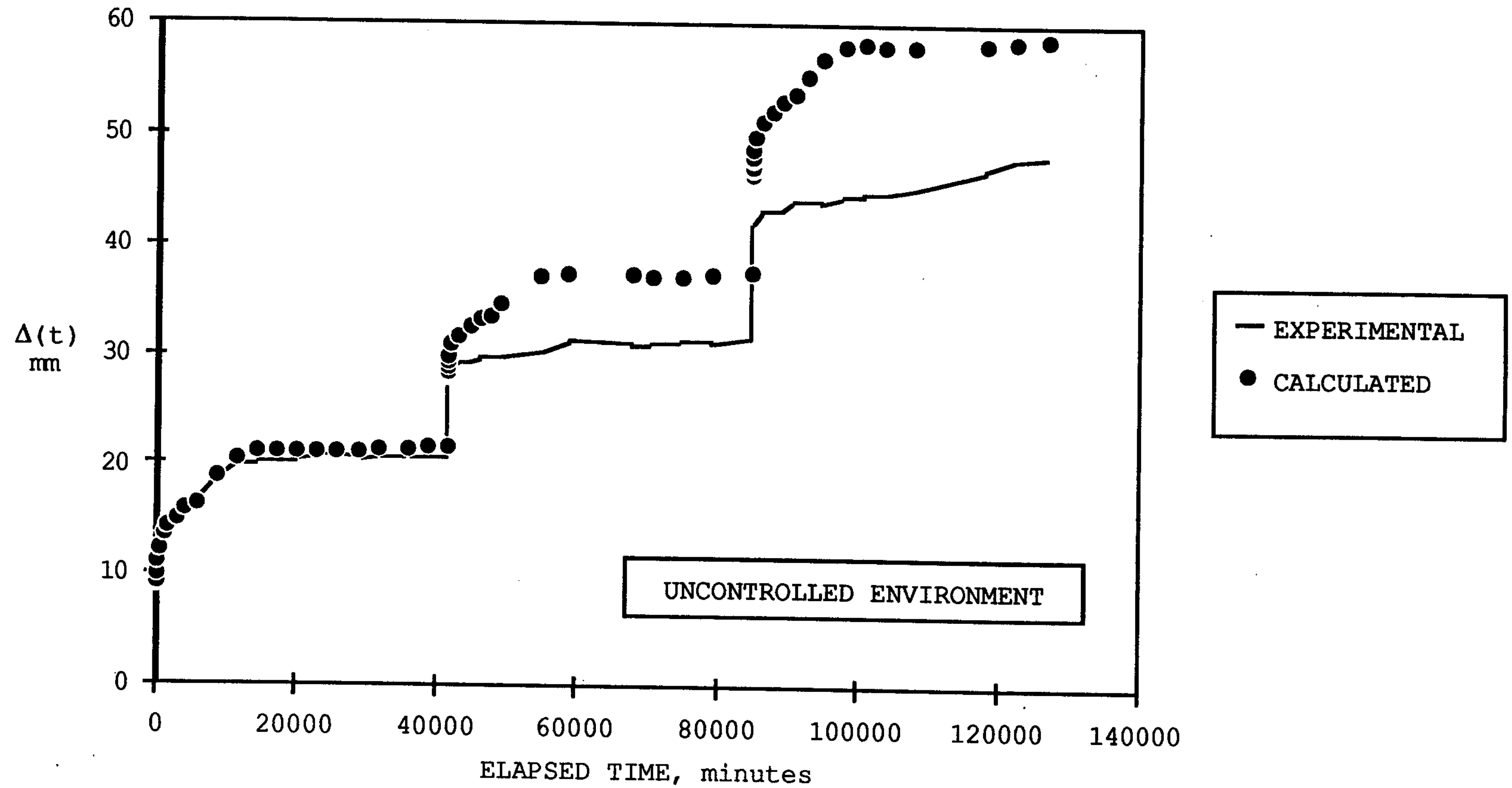


FIGURE 4.13 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON OSB SPECIMEN 8FC

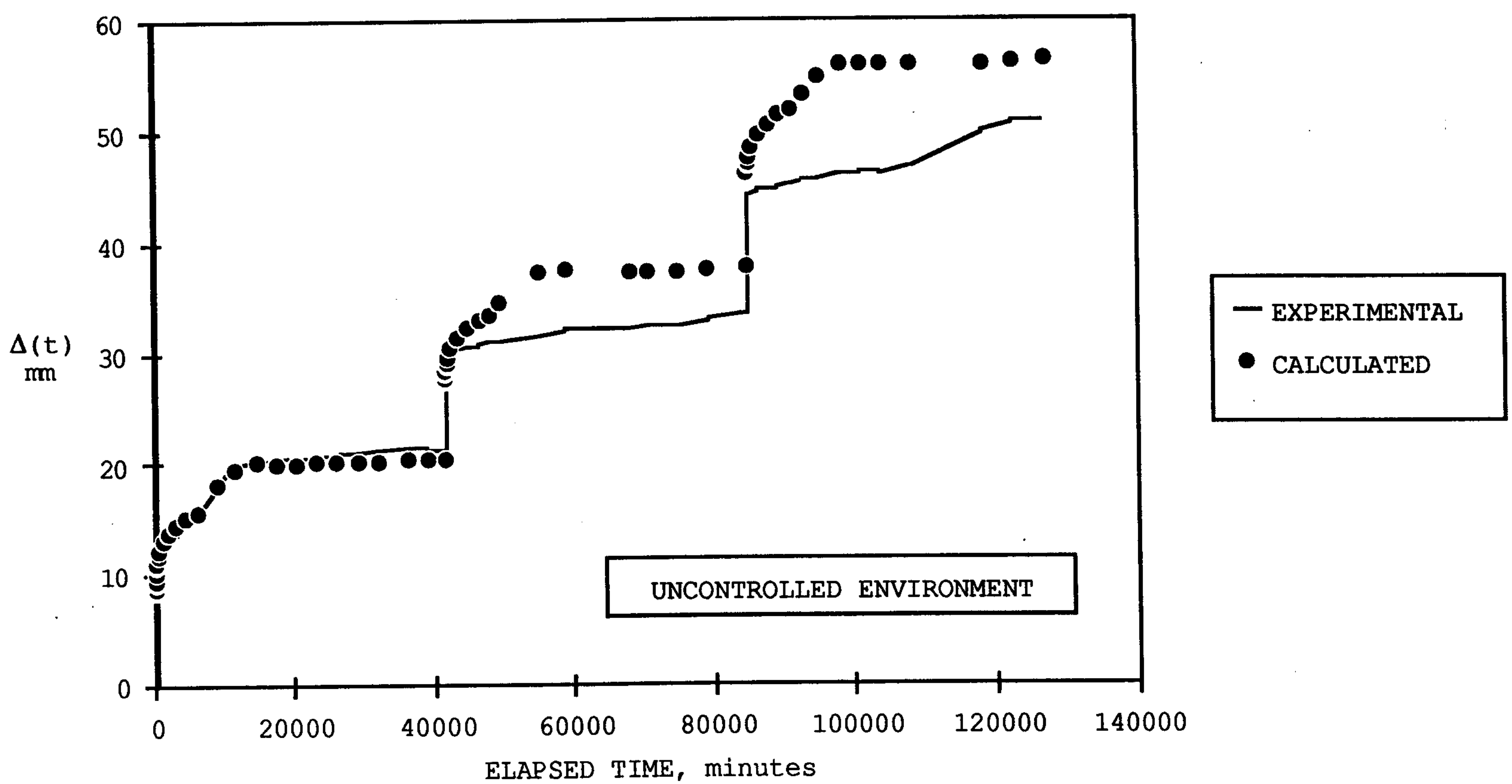


FIGURE 4.14 APPLICATION OF BOLTZMANN'S PRINCIPLE OF SUPERPOSITION ON OSB SPECIMEN 12FC1A

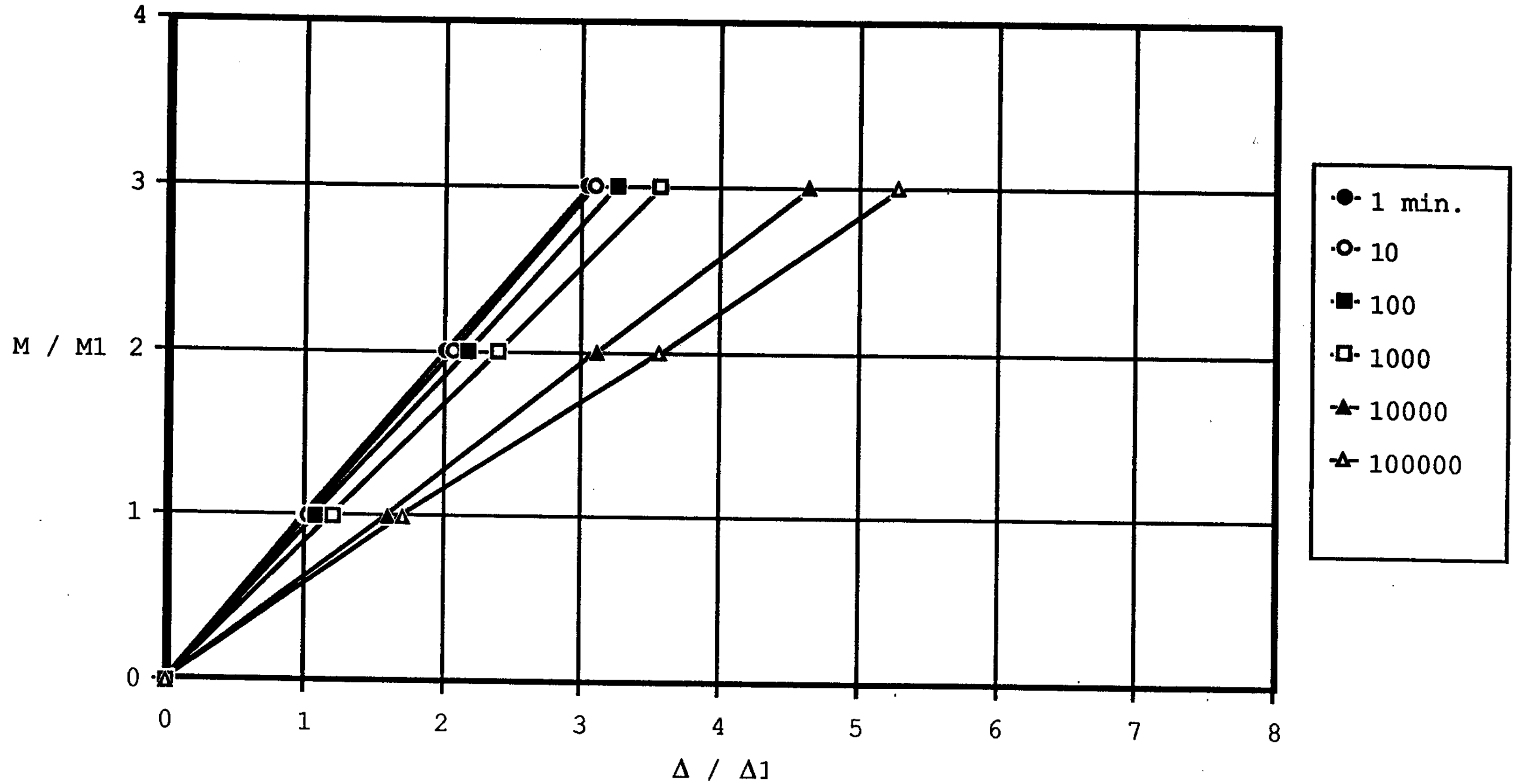


FIGURE 4.15 NON-DIMENSIONALIZED ISOCHRONOUS MOMENT-DEFLECTION CURVES FOR SSP TESTED IN UNCONTROLLED ENVIRONMENT

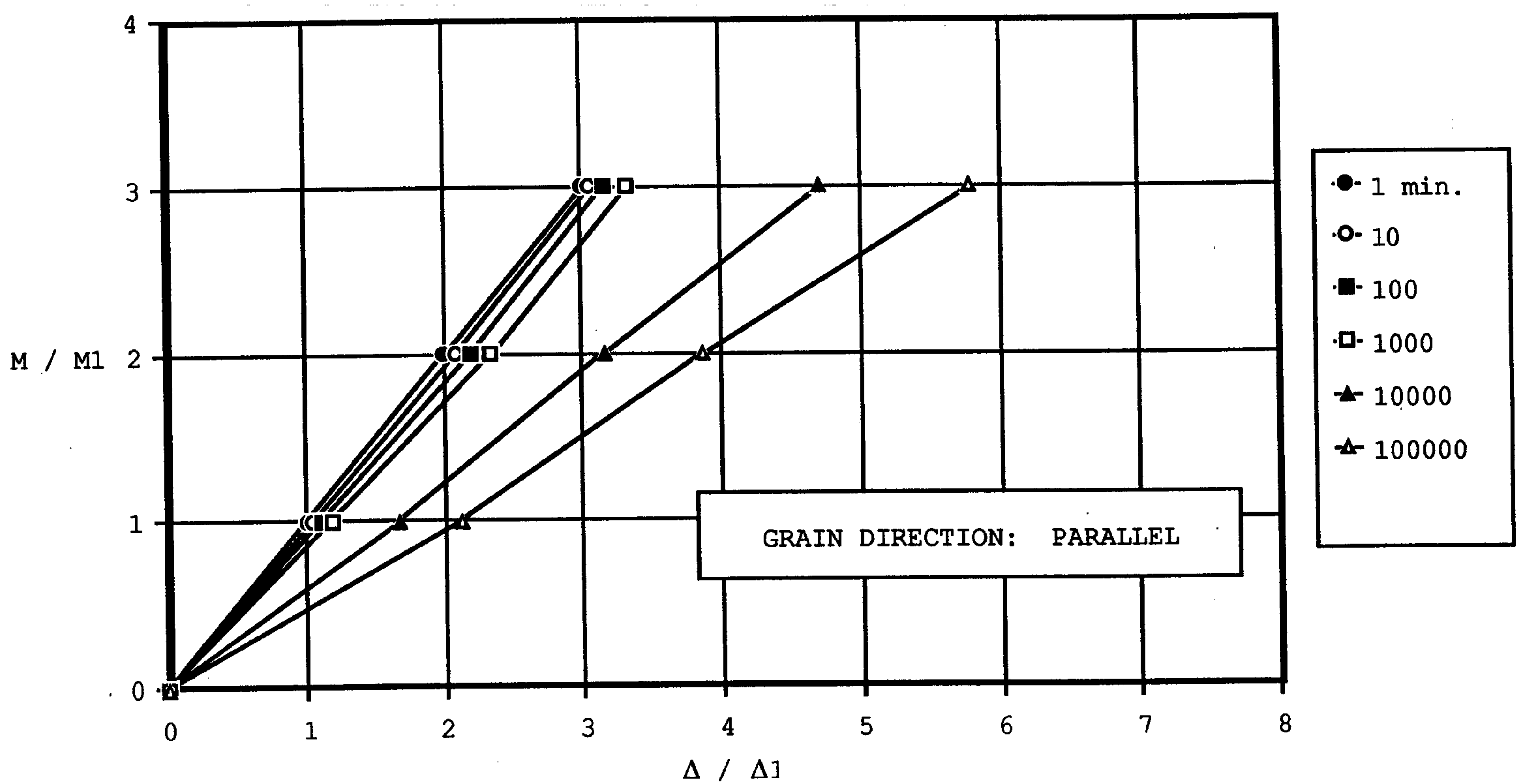


FIGURE 4.16 NON-DIMENSIONALIZED ISOCHRONOUS MOMENT-DEFLECTION CURVES FOR OSB TESTED IN CONTROLLED ENVIRONMENT

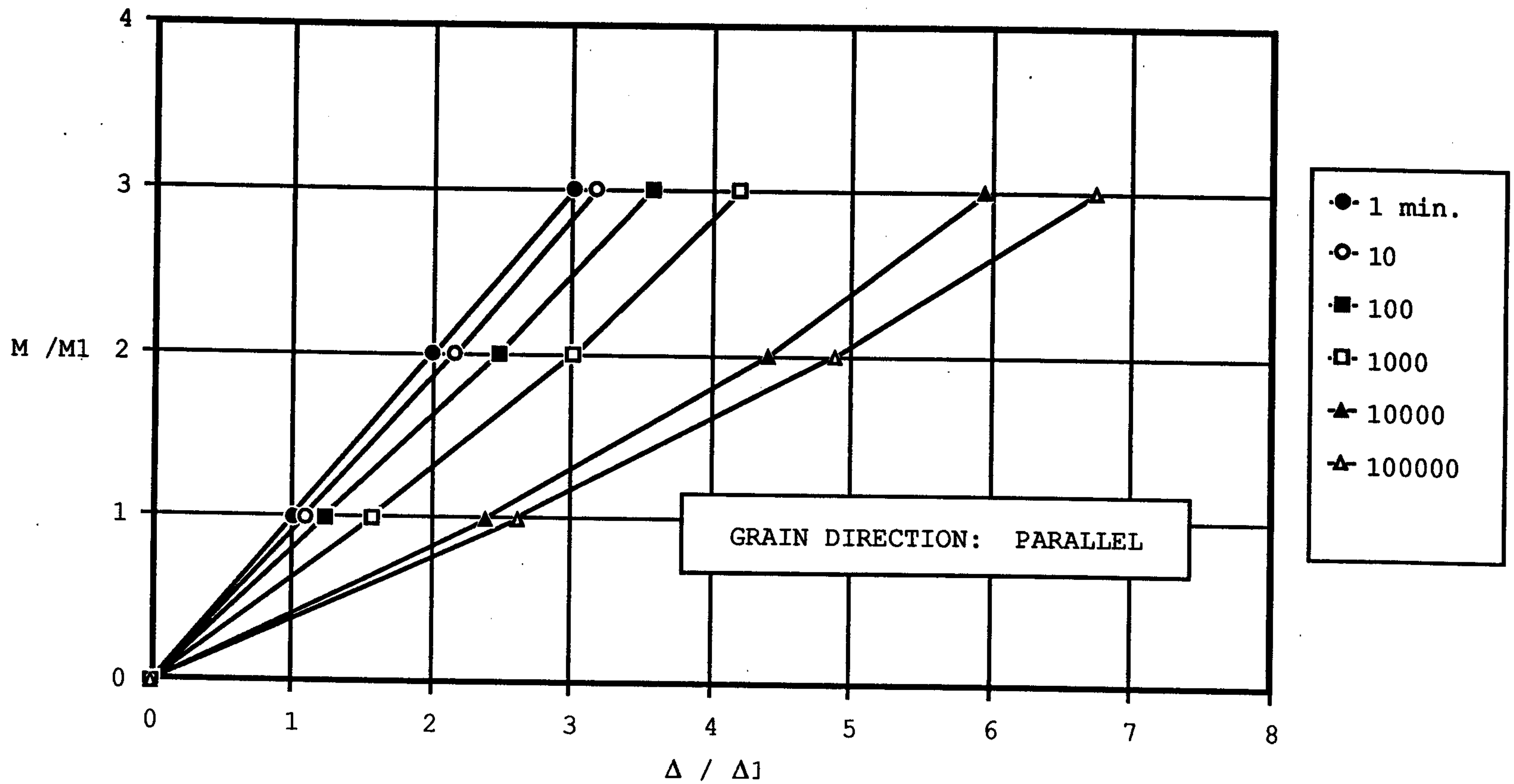


FIGURE 4.17 NON-DIMENSIONALIZED ISOCHRONOUS MOMENT-DEFLECTION CURVES FOR OSB TESTED IN UNCONTROLLED ENVIRONMENT

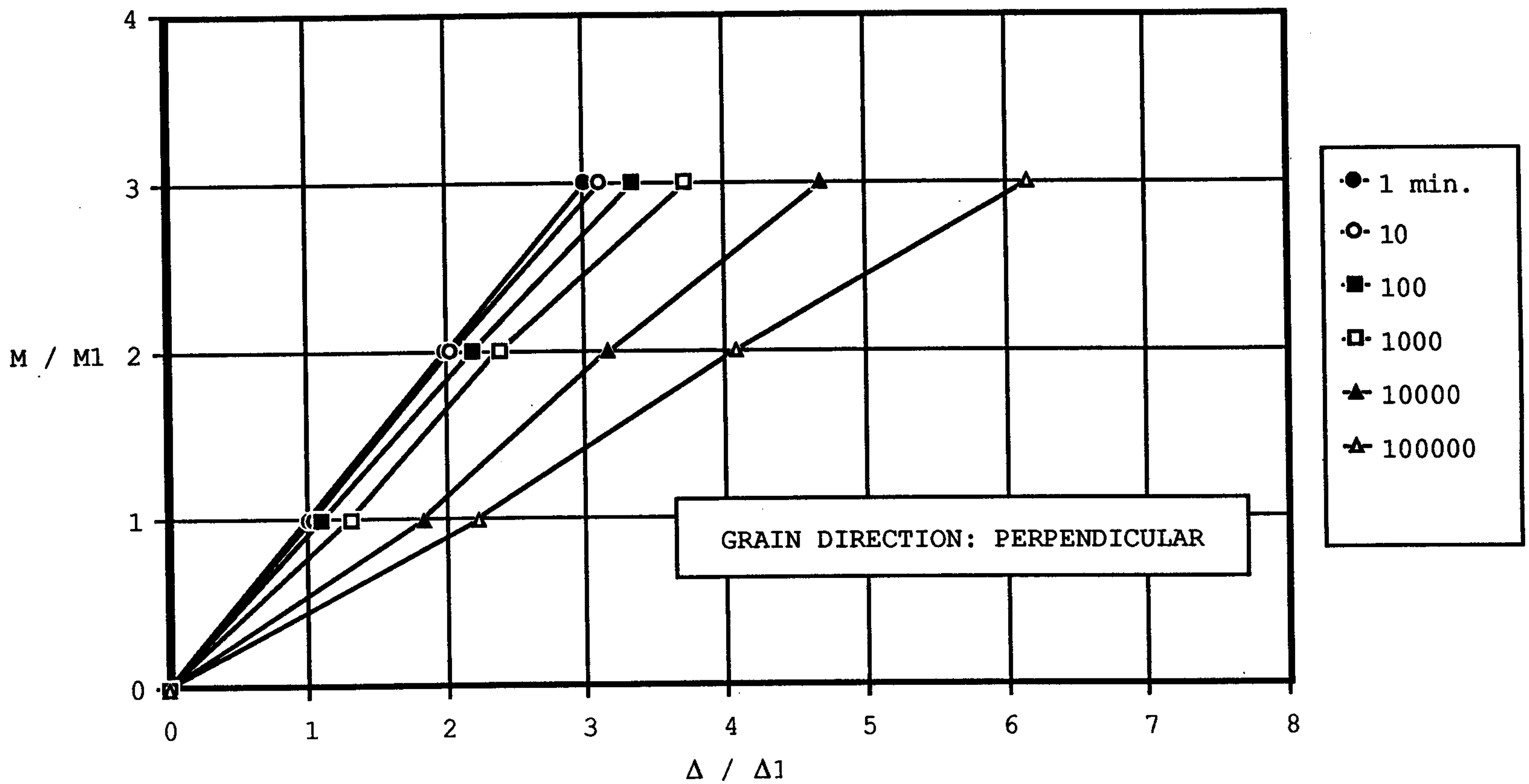


FIGURE 4.18 NON-DIMENSIONALIZED ISOCHRONOUS MOMENT-DEFLECTION CURVES FOR OSB TESTED IN UNCONTROLLED ENVIRONMENT

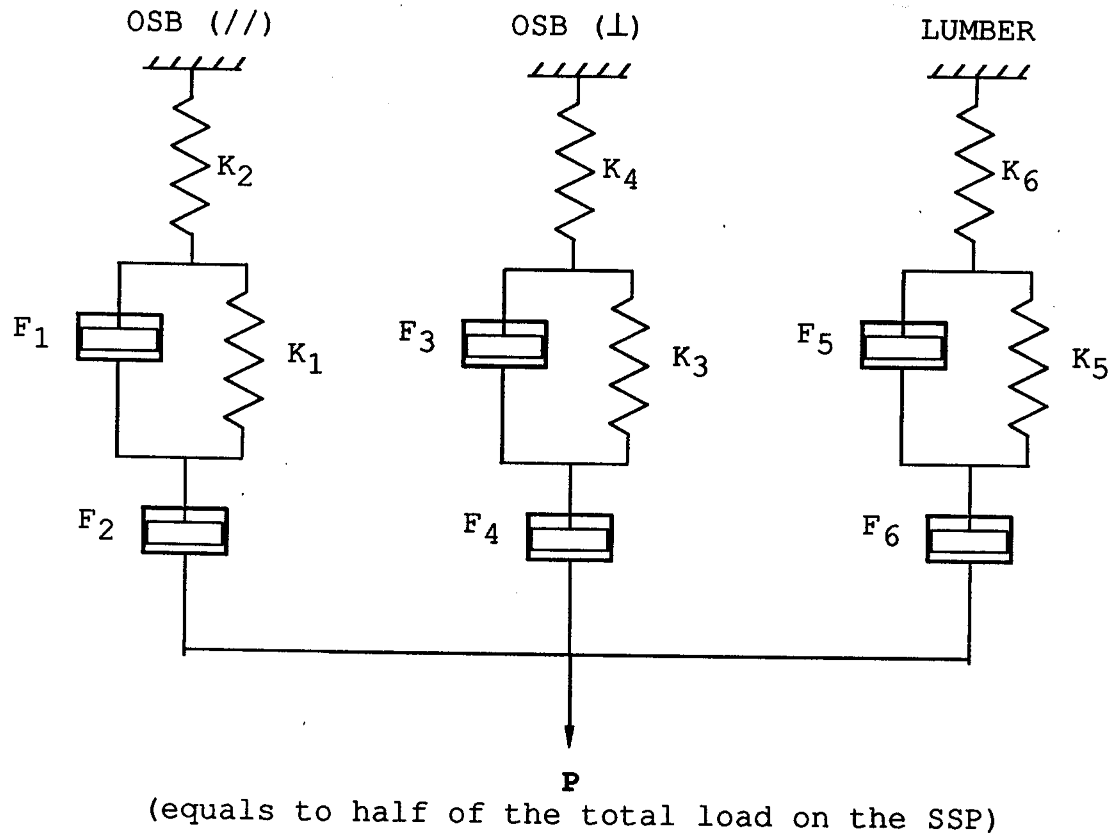


FIGURE 4.19 A COMPOSITE VISCOELASTIC MODEL FOR THE STRESSED SKIN PANEL

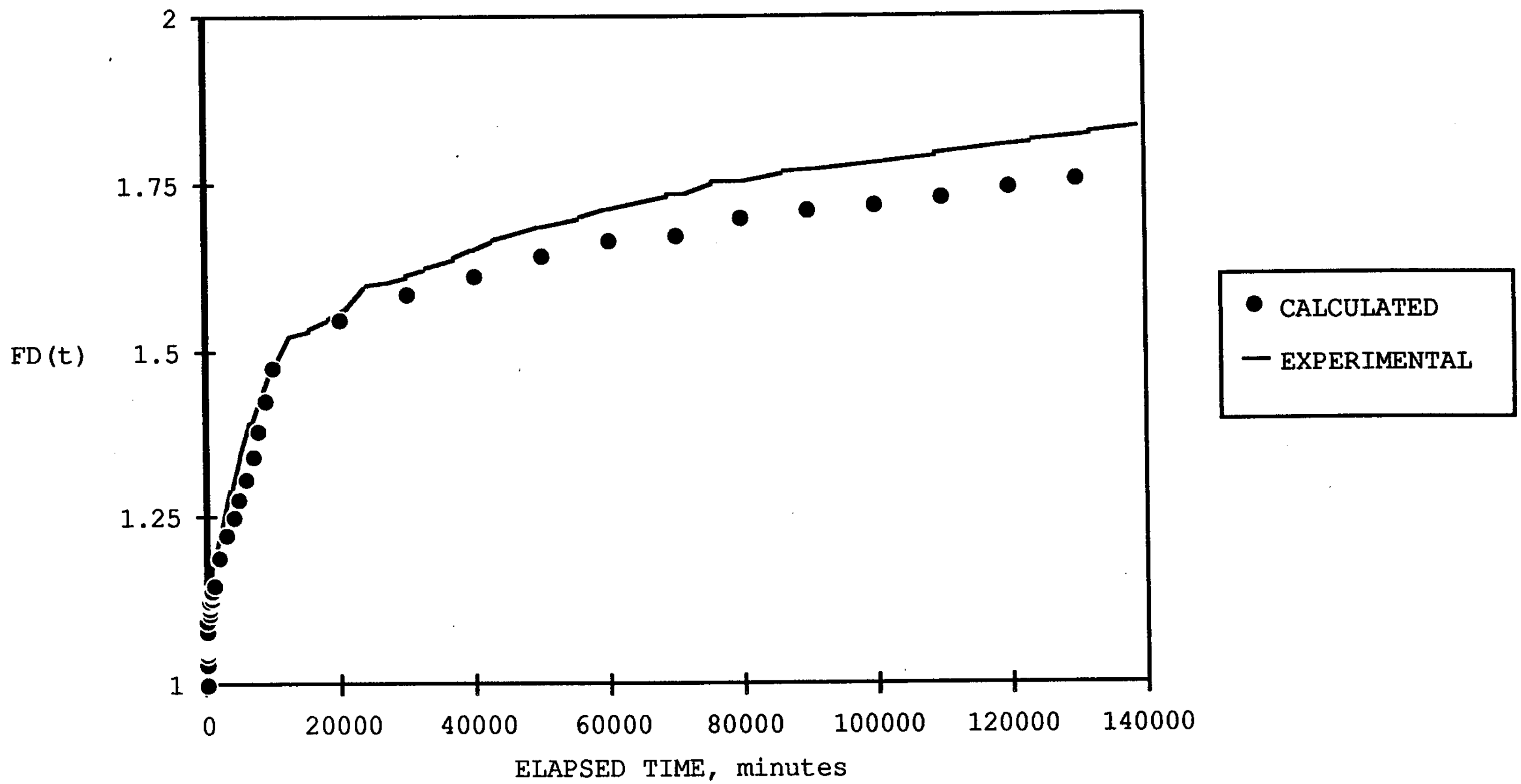


FIGURE 4.20 PREDICTION OF THE FLEXURAL CREEP BEHAVIOUR OF SSP SPECIMEN 1C UNDER CONTROLLED ENVIRONMENT

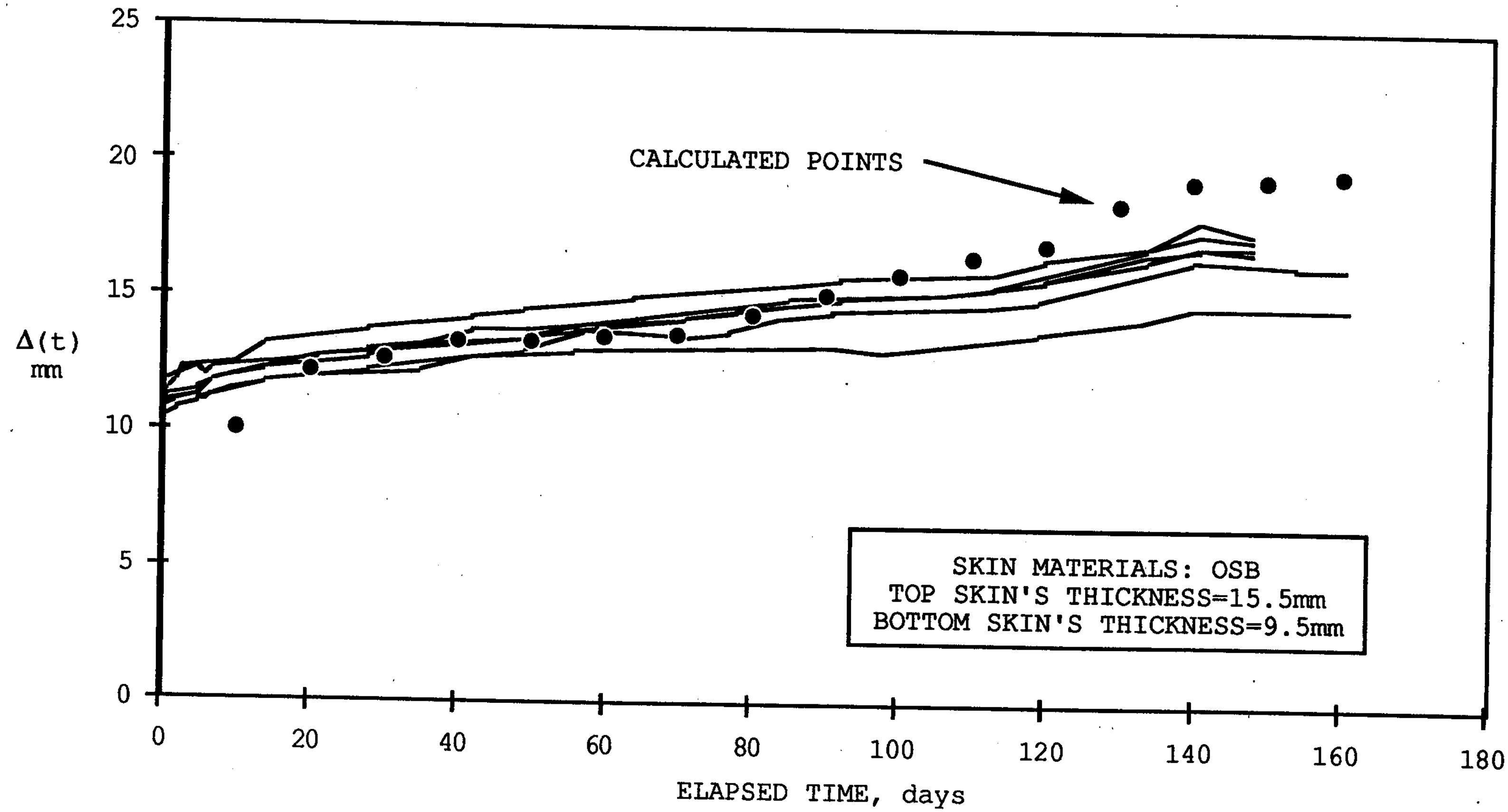


FIGURE 4.25 PREDICTION OF FLEXURAL CREEP DEFLECTION OF FULL-SCALE SSP UNDER UNCONTROLLED ENVIRONMENT

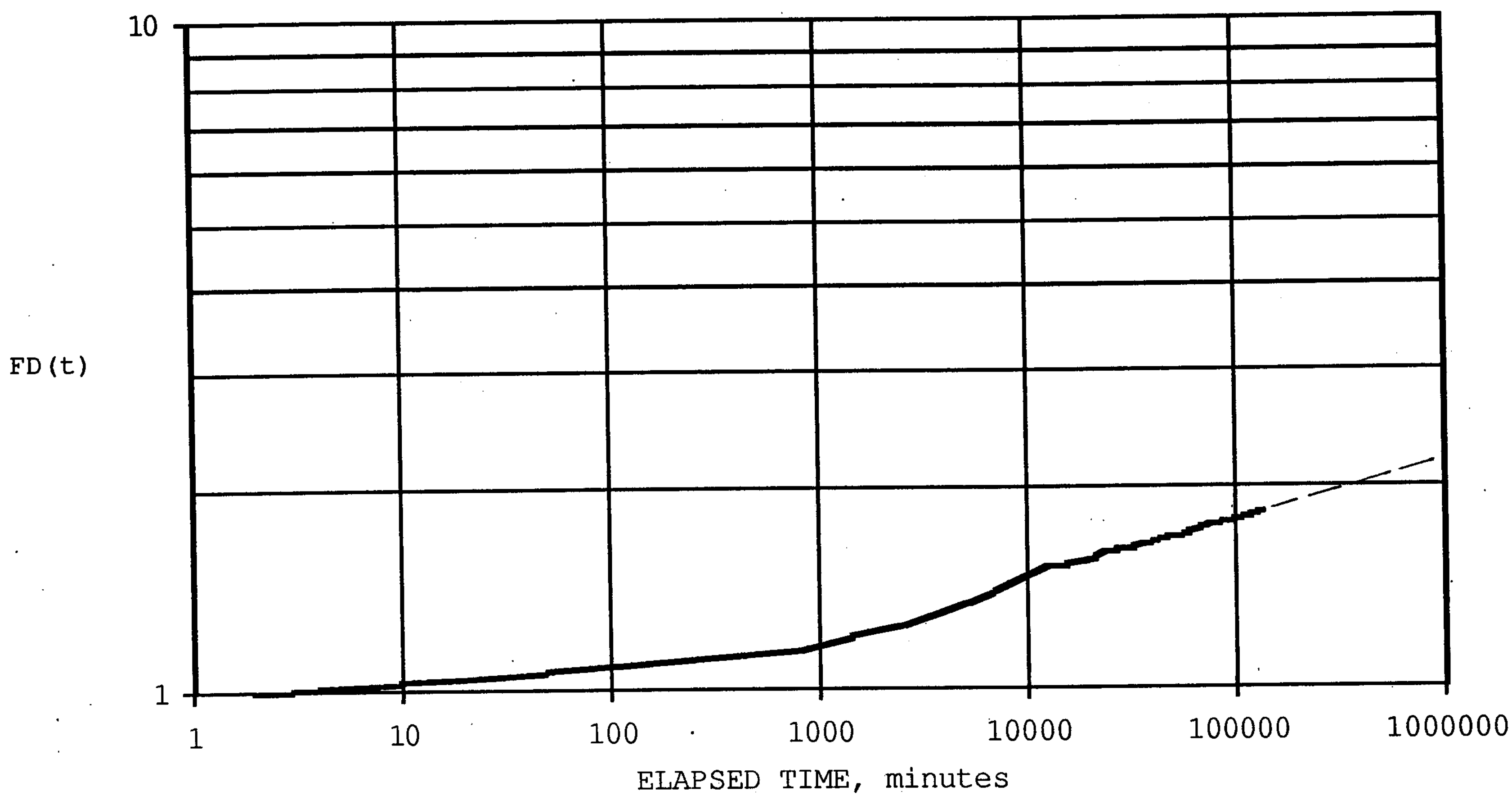


FIGURE 4.26 FRACTIONAL DEFLECTION FUNCTION ON A LOG-LOG SCALE

5. CONCLUSIONS and RECOMMENDATIONS

An experiment was carried out to determine the time-dependent behaviour of oriented strandboards (OSB), S-P-F lumber, and stressed skin panels (SSP) under sustained bending loads. Tests were done indoor under both environmentally controlled and uncontrolled conditions. The test results and subsequent analyses indicate the following:

- The time-dependent flexural behaviour of OSB and SSP can be characterized by linear viscoelastic theories under controlled environment and low stress levels.
- The degree of mechanical conditioning has an influence on the application of Boltzmann's principle of superposition.
- Correspondence principle can be applied to the analysis of the time-dependent deflections of SSP with reasonable accuracy.
- Fluctuating climatic conditions worsen the creep behaviour of OSB and SSP. In an indoor environment, humidity has greater effects on the flexural creep behaviour of the materials than the temperature.

This experiment has verified the applicabilities of some of the basic principles on the flexural creep behaviour of OSB. For the analysis of the time-dependent deflections of SSP, having OSB as skin and lumber as webs, the following recommendation is made:

- The time-dependent flexural deflections of SSP can be evaluated based on the components' flexural moduli. The formulation is the same as that of an elastic one except the elastic modulus of each component is replaced by a creep (fractional deflection) function; the moment of inertia is calculated based on the geometry of the composite cross section.

If OSB or the composite version is used in structural applications such as flooring system, the time-dependent characteristics of this material must be studied from both the strength and the serviceability standpoints. With this in mind, the following recommendations on future research are made:

- Determine whether creep rupture will occur within the expected lifetime of this wood-based product(s) under simulated, fluctuating environmental conditions.
- Study the creep recovery behaviour so that a more completed creep function can be used to model the response of a given system under fluctuating loading conditions.
- Study the short- and long-term properties of OSB in tension and in compression.

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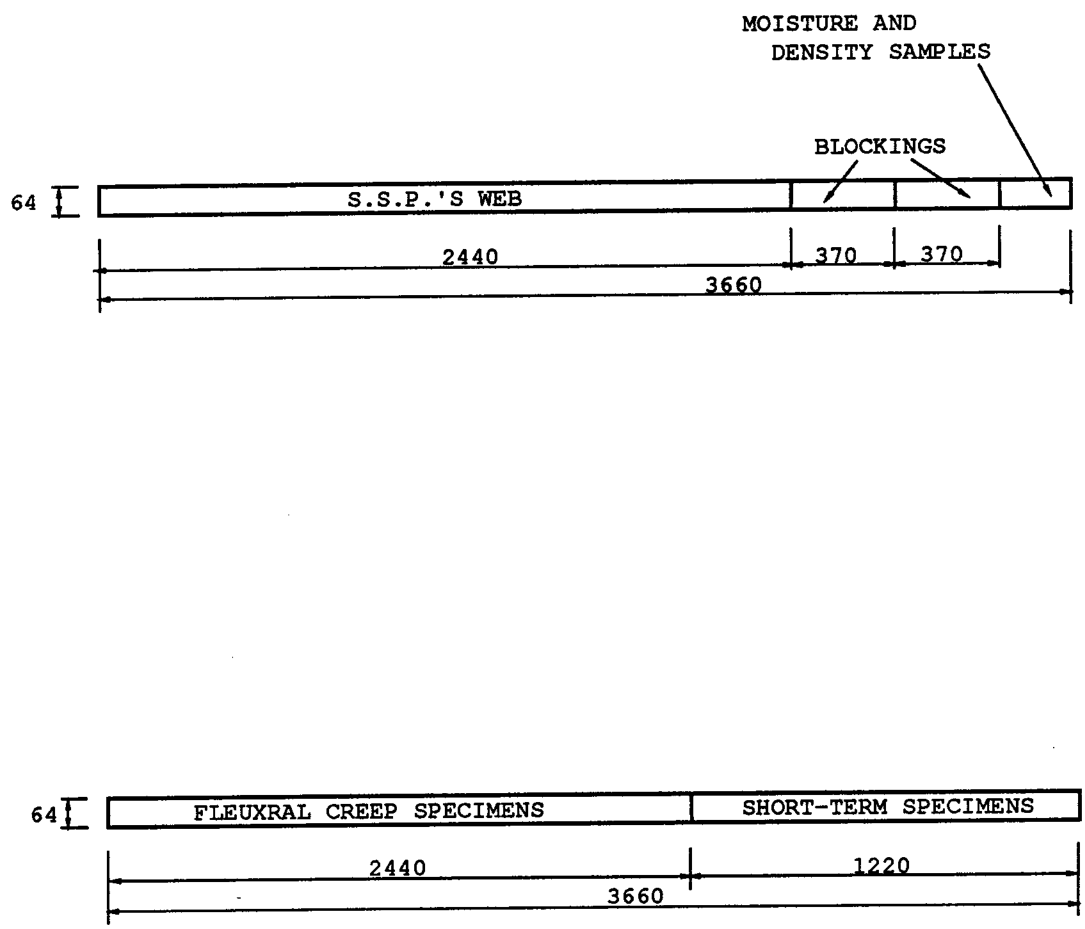
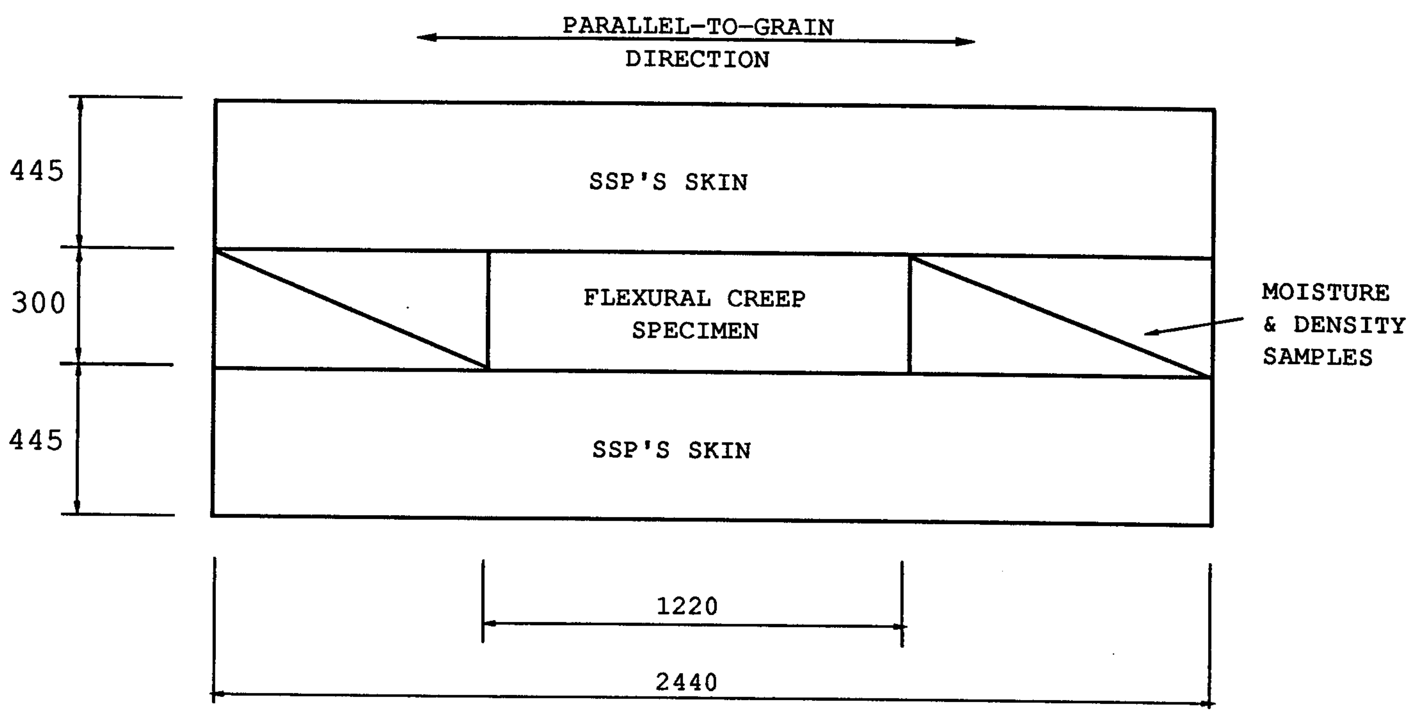
APPENDIX A



NOTES: Diagram is not drawn to scale.
All dimensions are in mm.

FIGURE A1 CUTTING PATTERNS FOR S-P-F LUMBER SPECIMENS



NOTES: DIAGRAM IS NOT DRAWN TO SCALE.
ALL DIMENSIONS ARE IN mm.

FIGURE A2 CUTTING PLAN FOR OSB PANELS THAT WERE DESIGNATED FOR THE USE OF SSP FABRICATION AND FLEXURAL CREEP TESTS

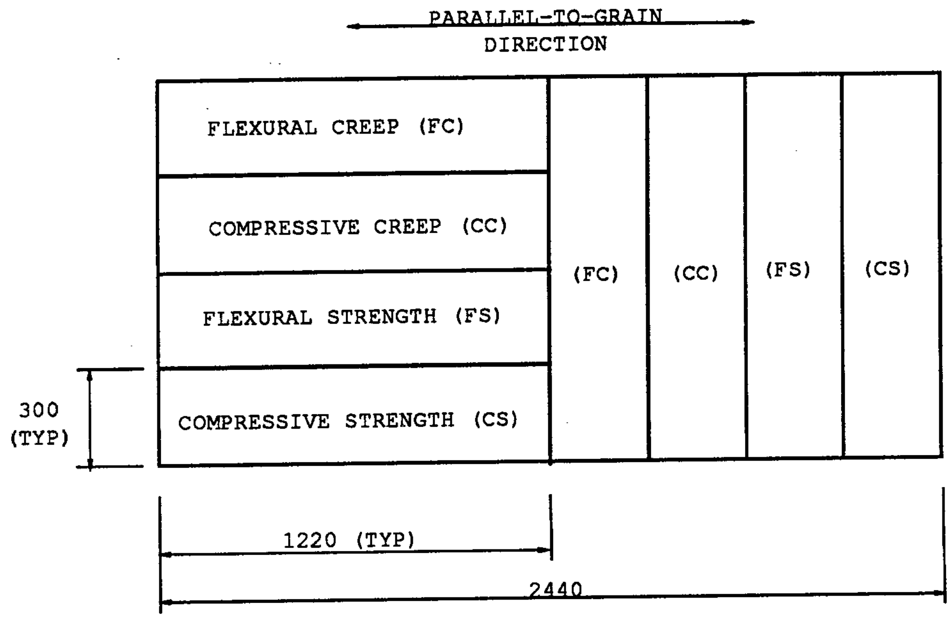


FIGURE A3a CUTTING PLAN FOR OSB PANELS THAT WERE DESIGNATED FOR FLEXURAL & COMPRESSIVE TESTS

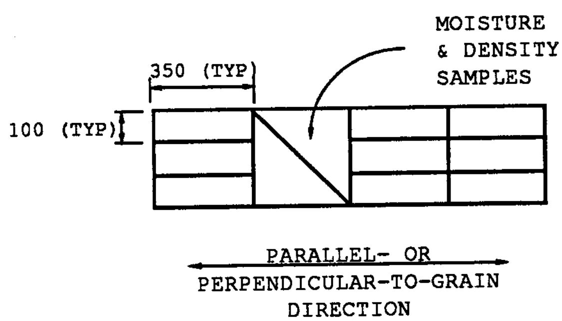


FIGURE A3b CUTTING PLAN FOR OSB COMPRESSION SPECIMENS

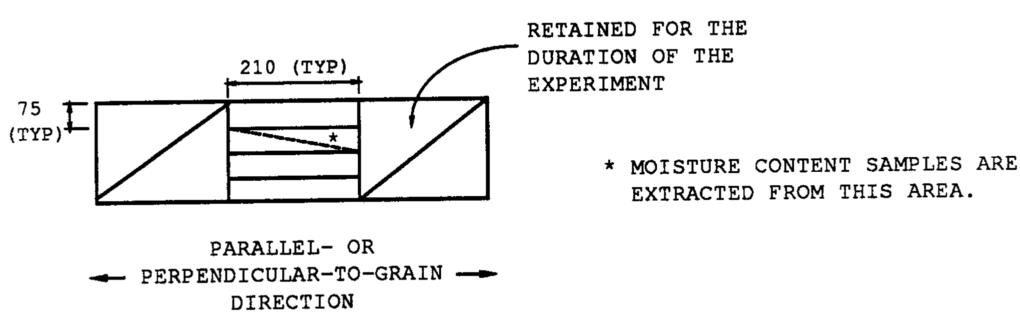
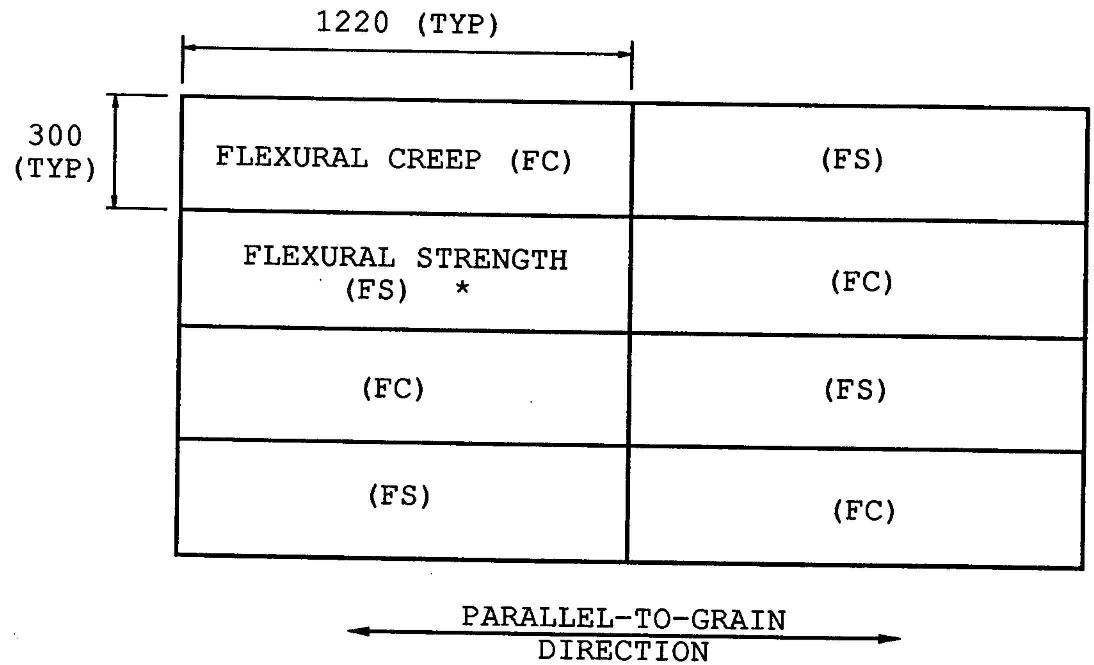


FIGURE A3c CUTTING PLAN FOR OSB FLEXURAL SPECIMENS



* THESE PARTS ARE FURTHER SUBDIVIDED INTO 75 X 210 mm SPECIMENS

FIGURE A4 CUTTING PLAN FOR OSB PANELS THAT WERE DESIGNATED FOR FLEXURAL TESTS ONLY

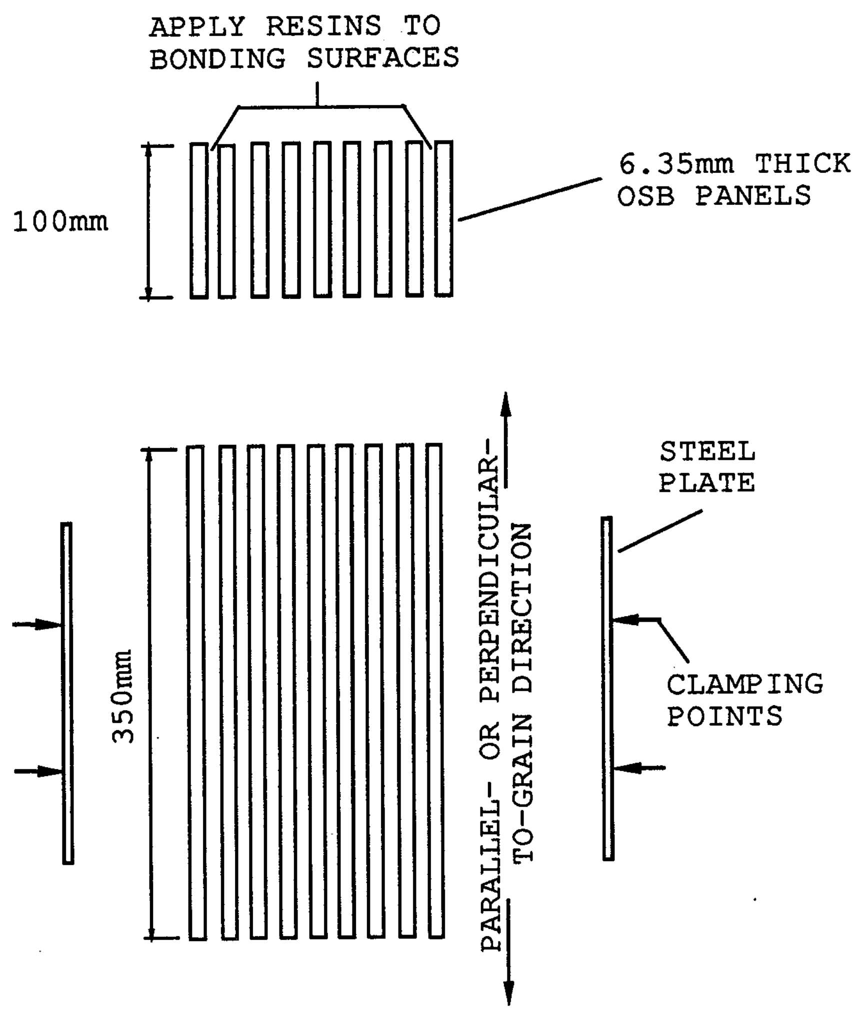


FIGURE A5 FABRICATION OF OSB COMPRESSION SPECIMENS

APPENDIX B

Prediction of SSP's Time-Dependent Deflection

$$\text{Centerline Deflection, } \Delta(t) = \frac{P}{\sum_{i=1}^{n} \frac{K_i}{FD_i(t)}} \qquad [12]$$

where P = point load

n = number of components

K_i = spring constant of the component;

$$\frac{24\ E\ I_t}{a\ (3L^2-4a^2)}$$

E = flexural modulus of the material

I_t = transformed moment of inertia of the component

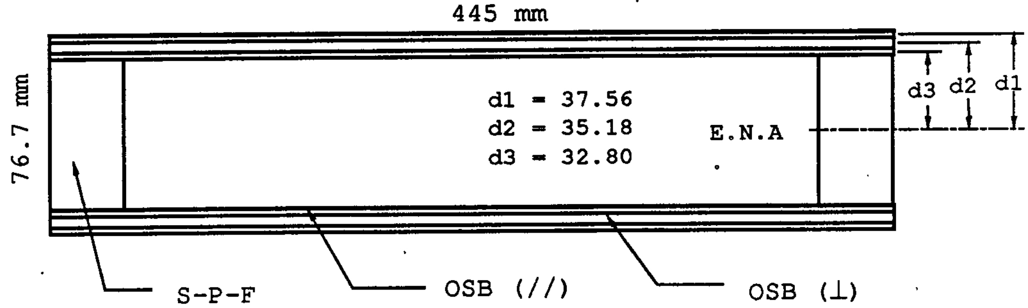
L = span of beam, 2360 mm

a = moment arm, 785 mm

$FD_i(t)$ = material's fractional deflection function

EXAMPLE:

Determine the 100000-minute fractional deflection of the SSP tested under controlled environment.



Note: Shelling ratio for OSB is 0.5.

Components:

surface layers, OSB (//)

$E = 8200$ MPa (Sec. 4.2.1)

$$A = \frac{6.35 \cdot 445 \cdot 0.5}{2} = 706 \text{ mm}^2$$

$$I = \frac{445 \cdot (6.35 \cdot 0.5 / 2)^3}{12} = 148 \text{ mm}^4$$

$$I_t = \sum(A \cdot d^2 + I)$$

$$= 2 \cdot [(706.4 \cdot 37.56^2 + 148.4) + (706.4 \cdot 32.80^2 + 148.4)]$$

$$= 35.1 \text{ X } 10^5 \text{ mm}^4$$

$K_1 = 61.9$ N/mm

$FD_1(100000) = 1.99$ (average of 6 specimens from Table 3.8)

core layers, OSB (⊥)

$E = 2440$ MPa (Sec. 4.2.1)

$A = 6.35 \cdot 445 \cdot 0.5 = 1413 \text{ mm}^2$

$$I = \frac{445 \cdot (6.35 \cdot 0.5)^3}{12} = 1187 \text{ mm}^4$$

$I_t = 2 \cdot (1412.9 \cdot 35.18^2 + 1186.9) = 35.0 \text{ X } 10^5 \text{ mm}^4$

$K_2 = 18.3$ N/mm

$FD_2(100000) = 2.11$ (average of 3 specimens from Table 3.9)

Lumber Web (S-P-F)

$E = 10000$ MPa (Sec. 4.2.1)

$A = 38 \cdot 64 \cdot 2 = 4864 \text{ mm}^2$

$$I = \frac{2 \cdot 38 \cdot 64^3}{12} = 16.6 \text{ X } 10^5 \text{ mm}^4$$

$I_t = I$

$K_3 = 35.6$ N/mm

$FD_3(100000) = 1.31$ (average of 4 specimens from Table 3.11)

<u>Centerline Deflections at 1 and 100000 minutes</u>:

- $\Delta(1) = P / [\ K_1/FD_1(1) + K_2/FD_2(1) + K_3/FD_3(1)\ ]$

  $= 1 \text{ N} / [\ 61.9 + 18.3 + 35.6\ ] \text{ N/mm}$

  $= 0.0086$ mm

- $\Delta(100000) = P / [\ K_1/FD_1(100000) + K_2/FD_2(100000) + K_3/FD_3(100000)\ ]$

  $= 1 \text{ N} / [\ (61.9 / 1.99) + (18.3 / 2.11) + (35.6 / 1.31)\ ] \text{ N/mm}$

  $= 0.0149$ mm

<u>Fractional Deflection at 100000 minutes</u>:

$$FD(100000) = \frac{\Delta(100000)}{\Delta(1)}$$

$$= \frac{0.0149 \text{ mm}}{0.0086 \text{ mm}} = \underline{1.73}$$

compare that to the FD(100000) of SSP 1:

Table 3.6 – (16.57 mm / 9.30 mm) = 1.78

$\therefore$ percent difference = <u>2.8</u>