Duration of Load

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Summary

Although oriented strandboard (OSB) has become increasingly accepted as a structural building product, its application in stressed skin panels has been limited because of a lack of engineering data with respect to short-term and long-term flexural behaviour.

During 1986/87, 24 full scale 165 x 1220 x 4880 mm stressed skin panels were constructed -- twelve with flanges of OSB, six with flanges of Canadian softwood plywood (CSP) and six with flanges of Douglas-fir plywood.

Twelve of these were tested to failure in 1986/87 to determine short-term (elastic) flexural behaviour. It was concluded that current structural design theory for stressed skin panels works effectively for panels made with flanges of CSP plywood and OSB. Many useful preliminary engineering data were provided by this study.

The other twelve stressed skin panels were used to evaluate long-term (sustained loading) flexural (creep) behaviour in a 1000-day study that began in February, 1987. The panel was sustained loaded with 2 kN/m^2 (40 p.s.f.) equivalent in a typical heated Edmonton, Alberta warehouse.

In 1987/88, time-dependent (creep) deflections were measured for the first year of the 1000-day test—both for the stressed skin panels and for the constituent materials.

In 1988/89, the measurement of time-dependent deflections on SSPs continued. A simple model was developed that predicts creep behaviour of stressed skin panels up to 700 days based on 70 days actual data.

In 1989/90 the measurements of the time-dependent flexure on SSPs continued to the 1000 day of loading on which day they were unloaded. The time-dependent flexure recovery after loading was monitored for approximately 50 days prior to destructive short-term loading to destruction.

The testing done shows that the time-dependent flexure of stress skin panels during sustained loading for 1000 days approximately equals the initial elastic deflection observed at uploading.

Further the data shows that the 1000 days sustained load levels applied (13 to 16% of maximum short-term) did not have a damaging effect on the short-term strength of the stress skin panels tested after 50 days creep recovery.

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The financial contribution to the Alberta Research Council's Forest Products Research and Development program from the Alberta Forest Service, Forestry Canada and the Canada-Alberta Forest Resource Development Agreement is greatly appreciated.

1. OBJECTIVES AND GOALS

During 1986/87, 24 stressed skin panels were constructed—six with flanges of Douglas-fir plywood, six with flanges of Canadian softwood (CSP) plywood and twelve with flanges of OSB. Half of these were tested for short-term (elastic) behaviour and the other half for long-term (creep) behaviour.

Short-term (elastic) testing, which was begun and completed in 1986/87, confirmed that current structural design theory for stressed skin panels works reasonably well for panels made with flanges of OSB. Many useful preliminary design data were provided by this study.

Long-term (creep) testing was begun in February, 1987, and continued through to 1989/90.

The objectives for 1989/90, as set out in Schedule "A" of the contract were as follows:

1. Continue measuring and recording test data (deflection, relative humidity and temperature) on the three types of SSP-OSB, spruce plywood, and Douglas-fir plywood.

2. Establish model predictions for each type of load duration set up for each type of SSP (creep curve, statistics, etc.).

3. Compare prediction and experimental results using accepted analytical methods.

4. Based on the comparison indicate whether the models can be used for accurate prediction of time dependent properties of the different SSP.

5. If possible, determine the value of model parameters that can be related to mechanical properties of SSP.

6. Compare the results to those of others; example, the U.S. forest products laboratory and Forintek West.

7. Indicate the practical significance of the results in terms of 'House Performance'.

8. Indicate the implication of the results at the level of various standards."

9. Recommend how stress skin panels can best be made from Alberta's primary wood products.

10. Recommend practical and effective design techniques that includes this load duration information for stress skin panels built with Alberta primary wood products.

11. The project should be brought to a conclusion in the form of a technical report at the end of this fiscal year (1989/90). The final report shall cover the time dependent performance of stress skin panels during the 1000 day duration for creep, and the subsequent 100 day relaxation stages.

2. INTRODUCTION

2.1 Background

Oriented strandboard (OSB) is becoming an increasingly acceptable structural panel product, particularly as a substitute for plywood.

One area in which OSB would seem to be ideally suited is as flange material for stressed skin panels (SSPs). This is an application that traditionally has been reserved for Douglas-fir plywood. So far, the impediment to the use of OSB has been a lack of engineering data (one being knowledge on its time-dependent mechanical behaviour).

During 1986/87 the Alberta Research Council gathered engineering data on the short-term (elastic) flexural behaviour of stressed skin panels made from Alberta-produced wood products. In addition, a 1000-day (three-year) study was begun of sustained loading (creep) behaviour. These tests were continued until November 1989.

The measurement of the time-dependent flexure under sustained loading continued to the 1000th day when they were unloaded. After most of the creep recovery had taken place, the SSPs were tested to destruction in standard short-term ASTM procedures.

2.2 Stressed Skin Panels

A stressed skin panel consists of a frame, or web, constructed of solid lumber, to which top and bottom flanges (or skins), of plywood or other panel materials, are structurally glued. A schematic diagram of a stressed skin panel is shown in Figure 1. There are stressed skin panels without bottom flanges or with T-flanges in place of the bottom flange, but those particular designs are not considered in this study.

The length of the stressed skin panel is typically 4880 mm (16'). The width of the stressed skin panel is typically 1220 mm (4'), which is normal panel width. The spacing of the stringers and the thicknesses of the top and bottom flanges are determined in each instance by design considerations. Headers (at the ends of the web) and blocking (within the web) serve to align the stringers, back up the splice plates, stiffen the panel at points where concentrated loads are anticipated and support the flange edges.

Stressed skin panels are used as roof and floor components in building construction. They are much stiffer than traditional methods of floor and roof construction and can therefore cover greater spans. In addition, they offer the advantage of factory (pre-) fabrication and they can be engineered to cost-effectively suit particular applications.

2.3 Design of Stressed Skin Panels

To ensure maximum stiffness of the stressed skin panel, flanges must be rigidly glued to the web. When the flange is properly secured to the web the whole panel assembly will behave as a composite unit, with direct transfer of forces between flanges and web, the flanges taking most of the bending stress, the web the shear stresses. Where flanges are made of plywood, joints should be scarfed or tongued and grooved, glued and supplemented with splice plates. Panels of oriented strandboard can be made to be the exact length of the stringers so that no joints are required.

For purposes of design calculation, it can be assumed that the stressed skin panel will behave like a composite beam., also bearing in mind the layered structure of OSB and plywood flanges. General flexural formulations can be applied to design the cross-section. In calculating section properties for the stressed skin panel, the designer must take into account the fact that not all materials will have similar moduli of elasticity. These may be reconciled by the use of a transformed section, which is a section of uniform modulus of elasticity. Sections should be designed in such a way that each material is not stressed beyond the safety limits stipulated in the appropriate design codes. For bending, deflection and rolling shear, the panel is "normalized" to the material of the flanges; for horizontal shear, to a material with the properties of the web.

Both the Council of Forest Industries of B. C. (COFI) and the American Plywood Association (APA) have published standard guidelines for engineering design of stressed skin panels with plywood.

Stressed skin panels in Canada are designed in accordance with CSA/CAN3-086 or by proof-loading techniques. A trial section is assumed and then checked for its ability to do the job intended; if the design does not meet the load criteria, it is modified and the process repeated. The design criteria include deflection, bending stress on the bottom flange, bending stress on the top flange, bending stress on the tension splices, rolling shear and horizontal shear. In-plane buckling and shear lag were beyond the scope of this study.

Owing to the structural efficiency possible with stressed skin panels, whereby relatively shallow panels prove adequate for strength, the design is likely to be controlled by the allowable deflection. The first aspect of the assumed section to be checked, therefore, will be deflection. Moment will be checked next, and shear last—since it is least likely to govern.

As the top flange carries the imposed load directly (compression), it is normal for calculations to indicate that it will be thicker than the bottom flange, which is under tension.

2.4 Scope of Creep Study

The scope of this project was to study the effect of sustained loading (1000 day duration) on the time-dependent flexure behaviour of stressed skin panels made with OSB and plywood skins.

Traditionally, in the design of stressed skin panels, little or no attention has been given to time-dependent flexure under sustained loading (creep) at normal design levels. The aim of this study was to make suggestions for design methods that can predict creep deflections for given load assumptions.

From February 1987 to December 1989 a 1,000-day creep test was conducted on twelve stressed skin panels—three with flanges of Douglas-fir, three with flanges of CSP plywood and six with flanges of OSB. The sustained loads applied to the stressed skin panels approximate an uniformly distributed load (UDL) of 2.0 kN/m^2. The stressed skin panels were designed for maximum total deflection of [span/360] after initial loading.

For a rough comparison with the stressed skin panel creep tests, creep tests were also conducted on the constituent materials: OSB, Douglas-fir plywood, CSP plywood and lumber.

A summary of the different specimens—whole stressed skin panels and constituent materials—tested for both short-term and long-term flexure is given in Tables 1. and 2.

Table 1. Dimensions of the SSP specimens flexure tested in short-term and long-term experiments.

Material Stressed Skin Panels with flanges of:	**Short-term Tests**[1]		**Long-term Tests**[2]	
	Number	**Dimensions (mm)**	**Number**	**Dimensions (mm)**
OSB	6 + 6	1220 x 4800 x 165	6	1220 x 4880 x 165
CSP Plywood	3 + 3	1200 x 4800 x 165	3	1220 x 4800 x 165
D. fir Plywood	3 + 6	1200 x 4800 x 165	3	1200 x 4800 x 165

[1] Half of the short-term testing on stressed skin panels was conducted in 1986/87 and the other half in February 1990 after completion of the sustained loading test.

[2] Long-term tests were begun in February 1987 and continued for 100 days to December 1989.

Table 2. Dimensions and test replication number of the constituent monolithic materials of the SSP's tested in short and long term experiments.

Constituent Test Material Tested Individual	**Short-term Tests**[1]		**Long-term Tests**[2]	
	Number	**Dimensions (mm)**	**Number**	**Dimensions (mm)**
OSB Panel (parallel)	3 3	300 x 1220 x 9.5 300 x 1220 x 15.5	3 3	300 x 1220 x 9.5 300 x 1220 x 15.5
CSP Plywood Panel (parallel)	3 3	300 x 1220 x 9.5 300 x 1220 x 15.5	3 3	300 x 1220 x 9.5 300 x 1220 x 15.5
D. fir Plywood Panel (parallel)	3 3	300 x 1220 x 9.5 300 x 1220 x 15.5	3 3	300 x 1220 x 9.5 300 x 1220 x 9.5
Lumber	6	140 x 1220 x 38	3	140 x 1220 x 38

3. METHODS AND MATERIALS

3.1 Design Assumptions

The stressed skin panels used both for long-term and short-term testing were designed to carry a uniformly distributed load of 2.0 kPa (2 kN/m^2 at 40 p.s.f.) with a maximum elastic deflection of [beamspan/360].

3.2 Materials

For the creep portion of this project, 12 stressed skin panels were fabricated in 1986/87 to the same specification as the stressed skin panels used for short-term testing—six with flanges of OSB, three with flanges of CSP plywood and three with flanges of Douglas-fir plywood. The OSB, CSP plywood and lumber material for the webbing were all produced in Alberta. The Douglas-fir plywood originated in British Columbia.

Prior to construction, all materials, both lumber and panels, were tested non-destructively to determine moduli of elasticity. The values determined were then used in the design calculations, together with estimates of specified strength properties.

The overall dimensions of the stressed skin panels were 1220 mm x 4832 mm x 165 mm (4' x 16' x 6.6"). Dimensions of the flange materials are given in Table 3.

Table 3. Stressed skin panels flange dimensions.

Flange Material	Number of SSPs made for short-term tests only.	Number of SSPs made for sustained loading tests.	Thickness (mm)		Flange Panel Dimensions mm x mm
			Top Flange	Bottom Flange	
Oriented Strandboard	6	6	15.5	9.5	1220 x 4880
Douglas fir Plywood	3	3	15.5	9.5	1220 x 2440
CSP Plywood	3	3	15.5	9.5	1220 x 2440

The OSB panels were purchased to match the overall dimensions of the stressed skin panels; thus, no jointing of the flange material was required. Because the plywood panels were shorter than the overall length of the stressed skin panels, tongued and grooved joints and splice plates were required. The tongued and grooved joints were subcontracted. The splice plates were made of the same material used in the flanges—the top splice plates of 15.5 mm plywood, the bottom of 9.5 mm plywood.

The wooden skeleton (webs, headers, blocking) was made with 38 mm x 140 mm (2" x 6") S-P-F, No. 2 or better, kiln-dried, sawn lumber. Only lumber with a moisture content of 15% or less was used.

The glue used in assembly of the stressed skin panels was resorcinol resin. It was applied as per the manufacturer's instructions and cured under constant pressure at room temperature.

3.3 Fabrication

All the stressed skin panels used for short-term and long-term testing were fabricated in 1986/87.

The stressed skin panels were made in three stages:

* first, the skeleton was assembled,

* second, the plywood flanges were spliced together. The splice plates were glued and nailed across the tongued and grooved joints of the flange panels, and clamps were used to close the joints, and
* finally, the flanges were glued and nailed to the skeleton.

Twenty-four (24) stressed skin panels were constructed in cooperation with Western Archrib from materials purchased at lumber yards in Edmonton. The webs of all twenty-four panels were identical in terms of material and design. Only the flanges differed—six of the stressed skin panels had flanges of Douglas-fir, which originated in British Columbia; six had flanges of Alberta spruce plywood; and twelve had flanges of OSB, also made in Alberta product.

The stressed skin panels were assembled according to the standards of the American Plywood Association and the construction diagrams in Figure 2 and Figure 3, with the following dimensions:

* overall length: 4880 mm
* overall width: 1220 mm
* top flange thickness: 15.5 mm
* bottom flange thickness: 9.5 mm
* web constructed from 38 mm x 140 mm (2" x 6") lumber

The plywood joints were tongued and grooved, glued and supported with splice plates. The oriented strandboards were manufactured specifically to match the overall dimensions of the stressed skin panels; therefore, no jointing in the flange sections was required.

All pieces of lumber and all panels were machine stress rated to determine moduli of elasticity. Theses values were used to calculate the overall stiffness of the panels.

Any pieces of lumber with a moisture content over 15% were rejected.

Resorcinol resin adhesive was glued to the flanges to the webs. As there was not a press large enough to handle the stressed skin panels, the flanges were nailed tightly to the webs to allow sufficient time for a solid bond to form.

Blocking was provided at the points where concentrated loads were to be applied.

3.4 Short-term Testing

During 1986/87, twelve stressed skin panels (six with flanges of OSB, three with flanges of Douglas-fir plywood and three with flanges of Alberta spruce plywood), together with constituent materials, were tested for short-term stiffness and strength according to ASTM E72-80: "Standard Methods of Conducting Strength Tests of Panels for Building Construction". The load test set-up is shown in Figure 4a. This is a third point loading arrangement using an airbag. The pressure created inside the airbag was transformed into two line loads that were superimposed onto the test panel. Each panel was subjected to a loading rate of 4410 N per minute. Deflection was measured and plotted against total load. A photograph of the stress skin tester is shown in Figure 4b.

These 12 stressed skin panels were tested to failure. Points of failure were noted and photographs taken showing where the fractures occurred.

Upon completion of each test, moisture samples were taken from webs and flanges.

Twelve identical specimens to the above stressed skin panels were sustained loaded for 1000 days and allowed to recover for 50 days prior to testing to destruction according to ASTM E72-80 in January 1990.

In addition to above 300 x 1200 mm samples of the undamaged skin of the SSPs were cut out and tested for modulus of elasticity in flexure (ASTM D3043-87-C) and modulus of elasticity and ultimate stress in tension (ASTM D3500-86-B).

3.5 Long-Term Testing of Stressed Skin Panels

Time-dependent flexure (creep) testing of 12 stressed skin panels—six with flanges of OSB, three with flanges of CSP plywood and three with flanges of Douglas-fir plywood—was begun in February 1987. This test was carried out for 1000 days to December 1990.

The creep tests were conducted basically according to ASTM E 72-80. The test set-up is shown in Figures 4, 5 and 6. The loading arrangement uses four water-filled drums for each stressed skin panel. The weight of the drums is transformed into two line loads across the test panel. The load was applied fairly quickly to reduce the effects of the rate of loading on the time-deflection curve. Deflection was measured and plotted against elapsed time at regular intervals.

The sustained load for each specimen was applied in less than one minute in order to produce the "instantaneous" loading situation. The mid-span deflections were measured, to the nearest 0.5 mm, regularly. The frequency of data collection was gradually reduced as the duration of the tests increased. The room temperature and humidity were recorded during the experiment.

Throughout the test, the load was constant. The total creep load of 8.7 kN (1956 lb), was applied by a third point loading arrangement, is equivalent to a uniformly distributed load of 2.0 kN/m^2 (40 psf). (The equivalency is based on the fair assumption that equal maximum moments in this case give the same maximum bending stresses and almost the same total deflection in the two load situations.)

The deflection was measured by means of a wire strung alongside the stressed skin panel and a clear plastic ruler attached to a mirror which itself was attached to the stressed skin panel. The wire was supported at both ends of the stressed skin panel and has a tension of approximately 45 N. The wire was supported by bolts located on the neutral axis of the section, directly above the stressed skin panel supports. Measurements are made by lining up the wire with its reflection in the mirror and then taking reading from the ruler. A wire and ruler/mirror arrangement is attached on each side of the stressed skin panel. This arrangement is shown in Figure 7.

The creep testing was conducted in a heated warehouse that is representative of one of the actual conditions under which the stressed skin panels would be used in Alberta. Heating was provided in winter, but humidity was uncontrolled. Indoor temperature and relative humidity was monitored and recorded throughout the testing.

The sustained loading was carried out for 1000 days. Following unloading in approximately one-minute the creep recovery was monitored for 50 days.

3.6 Long-Term Testing of Flange And Web Material

In February, 1987, sustained load (creep) tests were also begun on the (constituent) flange and web materials, to run simultaneously with the stressed skin panel creep tests. This constant load testing uses two simple types of dead load loaded moment arm arrangements. The set-up for testing samples of flange material is shown in Figures 8 and 10, and the set-up for testing samples of webbing material in Figure 9.

3.7 Modelling of Time-Dependent Flexure

Linear visco-elastic behaviour of a material is sometimes represented with phenomenological models. An example of such models is that shown in Figure 11. This is called a Maxwell-Voight (or four-element) model. When the spring and a dashpot are placed in series, the arrangement is called a Maxwell body; when in parallel, a Voight (or Kelvin) body.

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 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 to the Maxwell-Voight model can be derived from statics and is given below:

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

where $\tau = \dfrac{\eta_1}{E1}$

t_0 = time of loading

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

It can be seen from [1] 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:

$$J\,(t) - \frac{\varepsilon\,(t)}{\sigma} \tag{2}$$

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

$$J*\,(t) - \frac{\Delta\,(t)}{P} \tag{3}$$

However, most materials do not follow the behaviour depicted by such a simple model. A more realistic phenomenological model is that shown in Figure 12. 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.

The fractional deflection technique is one way of identifying time-dependent linear behaviour. Fractional deflection for sustained loading is defined as the ratio of the total deflection to instantaneous deflection. Within the linear range, the fractional deflection is the same for all load levels. The ratio is expressed as follows:

$$FD\,(t) = \frac{\Delta\,(t)}{\Delta_{i}} \tag{4}$$

The relationship between the creep compliance function J*(t) and the fractional deflection can be established as follows:

$$FD\,(t) = J^{*}\,(t) * K \geq 1.0 \tag{5}$$

where K depicts the apparent spring constant of the total system

Fractional representation of sustained loading data has been extensively used in this study as it makes engineering predictions fairly simple for the sustained loading case, even when the relative load level and the geometry of the structural members is different.

Analysis of experimental data of log (creep compliance) versus log (time) has shown simple functional relations for most structural building materials. Also, log (fractional creep) versus log (time) is simply related. For linear visco-elastic materials, the following first order model can be used to present experimental data:

$$FD\,(t) = \left(\frac{h}{m}\right) * \exp_{10}\left(\frac{\log\left(\frac{d}{h}\right) * \log\left(\frac{t}{t_1}\right)}{\log\left(\frac{t_2}{t_1}\right)}\right) \tag{6}$$

where
- m = **total deflection at one minute**
- h = **total deflection at time t_1**
- d = **total deflection at time t_2**
- FD(t) = **fractional deflection at time t, expressed as the ratio of total deflection at time t divided by the deflection at one minute**

Geometrically, the analytical formula simply says that the fractional deflection can be obtained by linear extrapolation of the points on a log-log plot.

Although more sophisticated prediction modelling can be attempted, it was decided for the time being to use this approach with 70-day actual creep data.

The model parameters used for trial predictions of creep of sustained loading were based on the deflections "h" (at t_1 = 7 days) and "d" (at t_2 = 70 days).

3.9 Design Prediction of the Long-Term Flexural Behaviour of SSP

The time-dependent flexure of structural components made from visco-elastic materials can be calculated by applying the correspondence principle (Flugge 1967). This principle states that a linear visco-elastic problem may be evaluated using the method developed for a linear elastic problem by replacing the elastic constants with the appropriate visco-elastic operators.

If one rearranges equations 3, 4 and 5, we have:

$$\frac{P}{\Delta\ (t)} = \frac{K}{FD\ (t)} \qquad (7)$$

When examining the above expression 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 visco-elastic problem as a stressed skin element in flexure can be dealt with using the elastic spring analogy, with three spring systems in parallel, two representing the flanges and one the web.

Each spring system in the elastic analogy is replaced with a Maxwell-Kelvin model as shown in Figure 12. 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 as follows:

$$P = \Delta\ (t)\ [\ \frac{K_1}{FD_1\ (t)} + \frac{K_2}{FD_2\ (t)} + \frac{K_3}{FD_3\ (t)}\ ]$$

or

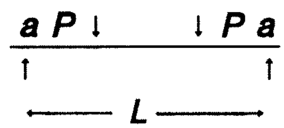
$$\Delta\ (t) = \frac{P}{\sum_{i=1}^{n} \frac{K_i}{FD_i\ (t)}} \qquad (8)$$

where

$$\Delta\ (t) = \textit{centreline of deflection of SSP}$$

$$\Delta\ (t) = \frac{P * a(3L^2 - 4a^2)}{24\ EI} = \frac{P}{EI} \times \frac{a(3L^2 - 4a^2)}{24}$$

P = *two symmetric loads, i.e.*



n = number of components

K_i = spring constant of the component

$$K = \frac{P}{\Delta\ (t)} = \frac{24\ (E * I_t)}{a * (3L^2 - 4a^2)}$$

K = $K_1 + K_2 + K_3$

$$K = C * \left[\frac{E_{ts} \cdot I_{ts}}{FD_1\ (t)} + \frac{E_W \cdot I_W}{FD_2\ (t)} + \frac{E_{bs} \cdot I_{bs}}{FD_3\ (t)} \right]$$

E_t = flexural modulus of the material used for the calculation of the location of the neutral axis

I_t = Moment of Inertia of the transformed section of the SSP

I_{ts} = moment of inertia of the top flange

I_w = moment of inertia of the web

I_b = moment of inertia of the bottom flange

L = span of beam

a = moment arm

$FD_i(t)$ = material's fractional deflection function for sustained loading.

In Appendix C an illustrative example is given.

4. RESULTS AND DISCUSSION

4.1 Short-term Testing of Stressed Skin Panels

During 1986/87, twelve stressed skin panels—six with flanges of OSB, three with flanges of CSP plywood and three with flanges of Douglas-fir plywood—were tested to failure in short term testing sccording to ASTM E72-80.

Twelve identical SSP specimens to the above stressed skin panels were sustained loaded for 1000 days and allowed to recover for 50 days prior to testing to destruction according to ASTM E72-80 in January 1990. The test results from the two test series are reported in Tables 4. and 5.

Average Load/Deflection curves are given in Figure 13. These do not extend into the failure region. Based on a uniformly distributed design load of 2.0 kN/m^2, the failure moments appear very conservative with a factor of safety of 6 or 7. It can also be seen that stressed skin panels made of all three flange materials are well within the maximum allowable live load limit.

It is interesting to note that short-term flexural stiffness performed on SSPs after 1000 days sustained loading had slightly higher stiffness due to lower moisture content of the face material at the time of the testing. The results indicate that the sustained loading did no significant short term flexural stiffness damage. All three flange types (OSB, D.fir and spruce) of stressed skin panels tested had mid-span deflections less than SPAN/360 based on an equivalent uniformly distributed load of 2 kN/m^2 which was used in the long-term flexural tests.

The experimental short-term flexural stiffness of the stressed skin panels (SSPs) are compared with the predicted values in Table 4. The predicted stiffness values of stressed skin panel stiffness values are calculated based on conventional design theory used for plywood (COFI 1976, APA 1987). The theory appears to apply a little better to OSB stressed skin panels than to plywood SSP.

Table 4. Comparison Between the Calculated Flexural Stiffness and that Obtained from the Experiments for the Stressed Skin Panels

Flange Material	Number of Samples	Short Term Flexural Stiffness, EI kN.m²/1220 mm		
		Predicted	Actual Average* No Sustained Load	Actual Average** after Sustained Load
Oriented Strandboard	6 + 6	1,414	1,320	1,413
Douglas-fir Plywood	3 + 3	1,552	1,765	1,772
Spruce Plywood	3 + 3	1,289	1,560	1,613

* Moisture Content 7 - 8%
** Moisture Content 6%

Table 5. Ultimate Maximum Moments Obtained in Short-term Flexure Testing of Stressed Skin Panels

Flange Material on the SSPs Tested	Number of Samples of Full Sized SSPs Tested	Short Term Ultimate Maximum Moment N.m/1220 mm	
		Actual Average* No Sustained Load	Actual Average** After Sustained Load***
OSB	6 + 6	41,160 N.m	42,010 N.m
D. fir Plywood	3 + 3	50,540 N.m	48,546 N.m
CSP Plywood	3 + 3	46,155 N.m	42,527 N.m

* Moisture Content 7 - 8 % at test
** Moisture Content 6% at test
*** 1000 days of sustained loading with a constant moment 6,544 N.m prior to short term test

The failure of OSB faced stressed skin panel during short-term testing is progressive. It usually begins with tensile fracture across the bottom flange. The web members then begin to fail from the bottom and fracture longitudinally. Shear failure along the bottom interface (which is material failure, rather than glue failure) is also evident. All top flanges remain intact. Many fracture lines, in both flanges and webs, intersect knots and initial cracks found in the material.

Failure of the plywood flanges is characterized by a very sudden and dramatic collapse. Two of the stressed skin panels sheathed with plywood exhibited failure at tensile splice points. Failure of OSB flanges is of a slower, progressive nature.

Based on these results, it was concluded that:

- The elastic flexural stiffness of OSB flanged stressed skin panels obtained experimentally agrees fairly well with the conventional designed theory—as for plywood, the layered structure of OSB must be considered

- The ultimate short-term stiffness and strength of stressed skin panels that has been sustained loaded (at 13-16% of ultimate strength) for 1000 days appears not affected when tested according to ASTM E72-80 fifty days after unloading.

4.2 Short-term Testing of Flange and Web Material

The results of short-term testing of flange and web materials are listed in Tables 6. and 7. Considerable variation in material properties due to defects may very well have influence on the test results as the replication number was small.

Table 6. Short-term (elastic) flexural properties of the monolithic flange and web materials.

Mechanical Property	Panel Thickness (mm)	Flange and Web Material* Tested Individually			
		Douglas fir Plywood	CSP Plywood	Oriented Strandboard	S-P-F Lumber
Modulus of Elasticity	15.5 9.5	13270 MPa 12515 MPa	9955 MPa 10010 MPa	8955 MPa 8495 MPa	11390 MPa
Modulus of Rupture	15.5 9.5	37.4 MPa 43.9 MPa	34.1[1] MPa 26.9 MPa	31.8 MPa 24.6 MPa	N.A.
Mass Density	15.5 9.5	445 kg/m³ 465 kg/m³	440 kg/m³ 460 kg/m³	675 kg/m³ 637 kg/m³	N.A.

* MC = 7-8%

Table 7. Short-term elastic flexure and tension properties of the monolithic skin of SSP panels after 1000 days of sustained loading.

Panel Material (Parallel) Tested Individually	Panel Thickness	Flexure MOE	Tension MOE	ULT. Tension Strength	Density	Moisture Content
	mm	MPa	MPa	MPa	kg/m³	%
OSB	9.88 16.13	8154 7823	5645 5567	13.4 12.7	676 665	5 5
CSP Plywood	9.80 15.33	10010 8507	7035 8267	14.8 13.4	504 428	6 6
Douglas fir Plywood	9.83 15.23	12.348 9020	7405 10737	20.5 13.5	587 454	6 6

4.3 Long-term Testing of Stressed Skin Panels

A total of twelve stressed skin panels was subjected to sustained bending loads in a typical heated warehouse environment in Edmonton, Alberta. The mid-span moment induced was equivalent to that resulting from a uniformly distributed load of 2 kPa (40 psf).

The sustained load for each specimen was applied in less than one minute in order to produce the "instantaneous" loading situation. The mid-span deflections were measured, to the nearest 0.5 mm, regularly. The frequency of data collection was gradually reduced as the duration of the tests increased. The room temperature and humidity were recorded during the experiment.

The sustained loading was carried out for 1000 days. Following unloading in approximately one-minute the creep recovery was monitored for 50 days.

Table 8. Fractional Deflection of Stressed Skin Panels Sustained Loaded for 1000 Days plus 50 Days of Creep Recovery Following Unloading.

Type of SSP (165x1220x4880 mm)	OSB	CSP Plywood	D.fir Plywood
Sustained Moment* (N.m/1220 mm)	6544	6554	6570
Full Span Deflection 1 minute after uploading	10.08 mm	8.42 mm	8.92 mm
Elapsed time from uploading	Fractional Deflection		
1 minute	1.00	1.00	1.00
10 minutes	1.02	1.01	1.01
10^2 minutes	1.06	1.03	-
10^3 minutes	1.10	1.09	1.04
10^4 minutes	1.16	1.18	1.11
10^5 minutes	1.39	1.41	1.31
10^6 minutes	1.90	1.66	1.60
1000 days = T	2.04	1.72	1.66
Unloading	Unloading	Unloading	Unloading
T + 1 minute	0.91	0.61	0.57
T + 10 minutes	0.89	0.61	0.57
T + 10^2 minutes	0.87	0.58	0.53
T + 2 · 10^3 minutes	0.83	0.52	0.51
T + 10^4 minutes	0.74	0.48	0.45
T + 50 days	0.62	0.39	0.36

* The stress level was approximately 13 - 16% of ultimate short term maximum

The average long-term flexural behaviour of stressed skin panels for 1000 days is tabulated in Table 8 and plotted in Figures 5a and 5b. Fractional deflection, FD(t), is defined as the ratio of total deflection and the one-minute deflection. It can be seen that the fractional deflection of the stressed skin panels reached "2" by the end of the 1000-day experiments for OSB, slightly higher than for similar SSPs faced with plywood.

After unloading, creep recovery (visco-elastic) took place during the first 50 days of creep recovery. The data obtained showed that approximately ⅔ of the time-dependent-flexure under sustained loading was non-recoverable (viscous). However the short term stiffness and strength (as mentioned above) did not appear to have changed significantly due to 1000 days of sustained loading at the 13 - 16% of maximum short time level.

4.4 Long-Term Testing of Flange and Web Material

Data from 1000-day creep tests on the constituent materials (Douglas-fir plywood, CSP plywood, OSB and S-P-F lumber) are presented in Table 9, Figure 15 and Appendix A. This data indicates that the monolithic OSB materials creep more than the OSB faced stressed skin panel.

Table 9. Fractional deflection of sustained flexure loaded samples during 1000 days of testing according to CSA 325.1 see 5.29.

Material	Spruce Plywood		D. fir		Oriented Strandboard		Lumber
Thickness (mm)	15.5	9.5	15.5	9.5	15.5	9.5	38
Stress Level (%) MOE (MPa) MOR (MPa)	14.8 9955 34.1	18.2 10010 26.9	13.5 13270 37.4	13.9 12515 43.9	11.9 8955 31.8	19.9 8495 24.6	- - -
Elapsed Time from Uploading	Average Fractional Deflection (Relative to One-Minute Deflection						
1 minute	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10^2 minutes	1.02	1.02	1.02	1.03	1.02	1.04	1.00
10^2 minutes	1.04	1.03	1.04	1.04	1.08	1.08	1.05
10^3 minutes	1.06	1.06	1.06	1.05	1.12	1.13	1.08
10^4 minutes	1.11	1.07	1.08	1.07	1.21	1.25	1.13
10^5 minutes	1.21	1.16	1.17	1.13	1.51	1.61	1.28
4.10^5 minutes	1.32	1.31	1.41	1.24	2.31	2.23	1.71
10^6 minutes	1.38	1.34	1.46	1.29	2.55	2.52	1.92
1000 days	1.63	1.53	1.51	1.31	2.76	2.71	1.97

4.5 Temperature and Relative Humidity

The temperature and relative humidity were recorded throughout the test period. This data, which is shown in Figure 18, is similar to most heated warehouses in Edmonton during winter months. From the literature, "Flexural Creep Behaviour of OSB Stressed Skin Panels" Bach, Wong & Cheng 1988., and other experiments it appears that local environmental changes influence the rate of creep.

4.6 Model Prediction

Models can be very useful for prediction of events beyond the experimental time scale.

In this study, actual data from the first 70 days (0.2 years) of testing were used, example wise, to predict time-dependent deflection of the SSPs after 1.9 years sustained loading. In a similar fashion predictions were made of the time-dependent fractional deflections of the constituent materials (used for the web and flanges) loaded individually for 1.5 years.

This data, which is presented in Tables 10 and 11, show that predictions can be off up to 20%. These results are interesting, considering that the time-dependent deflection predictions are based on experimental values obtained in a time period only about one tenth of the prediction time.

Table 10. Model Parameters for fractional deflection prediction of sustained flexure loaded SSPs.

Flange Material on SSPs	h/m	d/h	Fractional Deflection After 694 Days of Sustained Loading		
			Model*	Actual	Difference
OSB	1.16	1.198	2.30	1.90	+ 21%
Spruce Plywood	1.18	1.195	1.685	1.66	+ 2%
D. fir Plywood	1.11	1.180	1.546	1.62	- 5%

* $FD(t) = (h/m) * (d/h)^{\log(t/t_1)}$ for t_1 = 6.94 days and t = 694 days, h = 6.94 days deflection, d = 69.4 days deflection m = 1 min. deflection

Table 11. Model Parameters for fractional deflection prediction of sustained flexure loading of flange and web materials.

Flange Material on SSPs	h/m	d/h	Fractional Deflection After 555 Days of Sustained Loading		
			Model 9	Actual	Difference
OSB	1.23	1.268	1.93	2.46	- 21%
Spruce Plywood	1.090	1.087	1.278	1.33	- 4%
D. fir Plywood	1.075	1.070	1.22	1.45	- 16%
Lumber	1.130	1.133	1.43	1.73	- 17%

* $FD(t) = (h/m) * (d/h)^{\log(t/t_1)}$ for t_1 = 6.94 days and t = 555 days, h = 6.94 days deflection, d = 69.4 days deflection m = 1 min. deflection

5. CONCLUSIONS

After three years of testing, the following conclusions have been reached:

- The current structural design theory for stressed skin panels works effectively for the panels made with flanges of CSP plywood and OSB and short-term duration of load.

- Sustained loading of SSPs made with flanges of OSB, CSP plywood and Douglas fir plywood demonstrates substantial time-dependent deflection relative to the pure elastic deformation that is due to initial loading. The differences in time-dependent behaviour can, however, be accounted for in the design stage.

- OSB flanges can be recommended for stressed skin panels provided that time-dependent (creep) flexures are considered by the designer.

Specific Conclusions Relevant to the Contract

5.1 The fractional deflection under sustained loading for 1000 day (with a U.D.L. load equivalent of 2 kN/m^2) gave maximum fractional deflections of OSB faced material 2.04 in comparison 1.72 and 1.66 for CSP and Douglas-fir plywood when tested in a normal heated warehouse in Edmonton, Alberta.

5.2 Model prediction of time-dependent flexure of SSPs under sustained loading is possible. It is recommended to use transformed section theory and multiply the elastic deflection with the fractional creep obtained from the test reported.

A simple model has been suggested suitable for prediction of creep behaviour e.g. 700 days, based on 70 days of testing.

5.3 Comparison of the experimental short-term stiffness agree fairly well with the analytically predicted values. The creep predicted by the model based on the available data is within 20% of the actual creep experienced. The accuracy of the model would appear sufficient for most engineering design applications.

5.4 In general use the prediction model is suggested to predict the time-dependent flexure of SSPs assuming the same load and environmental exposure as in this study.

5.5 The model parameters most closely related to the mechanical properties of the SSPs investigated are section geometry, load, time, material and environment.

5.6 Comparison of available results from elsewhere is only indirectly possible as we found only flexure creep data for the skin material OSB and plywood. The creep properties of individual tested OSB appears significantly larger than for structural components of the same material.

5.7 The practical significance of the testing done at ARC is that we now have "in-house-performance" indications that OSB installed as web in SSPs exhibit less creep fractional creep when creep tested "alone" according to e.g. CSA 325.1-88 Section 5.29 as done in the environmental conditions we have in Alberta warehouses.

5.8 The work done on sustained loading at ARC suggests that CSA 086 considered introduction of design recommendations that accounts for time effects with regards to serviceability. ASTM E-72 may be expanded to include sustained loading test methods for structural components just like the test performed in this project.

5.9 It can be recommended that stress skin panels utilizing OSB be made with tension flange material where both face and core layers have strand orientation parallel to the service span.

5.10 A practical design technique for evaluation of time-dependent flexure under sustained loading of SSPs is to use standard engineering principles (as in e.g. COFI and APA technical report) for short-term elastic deflection and assume the maximum deflection will be double with time.

6. RECOMMENDATIONS

In order to facilitate acceptance of OSB among engineers and architects additional SSP testing, covering different SSP designs, different environmental exposure, and different load situations should be undertaken to make more economical serviceability design possible. A reliability approach to serviceability with OSB as a structural material should also be explored.

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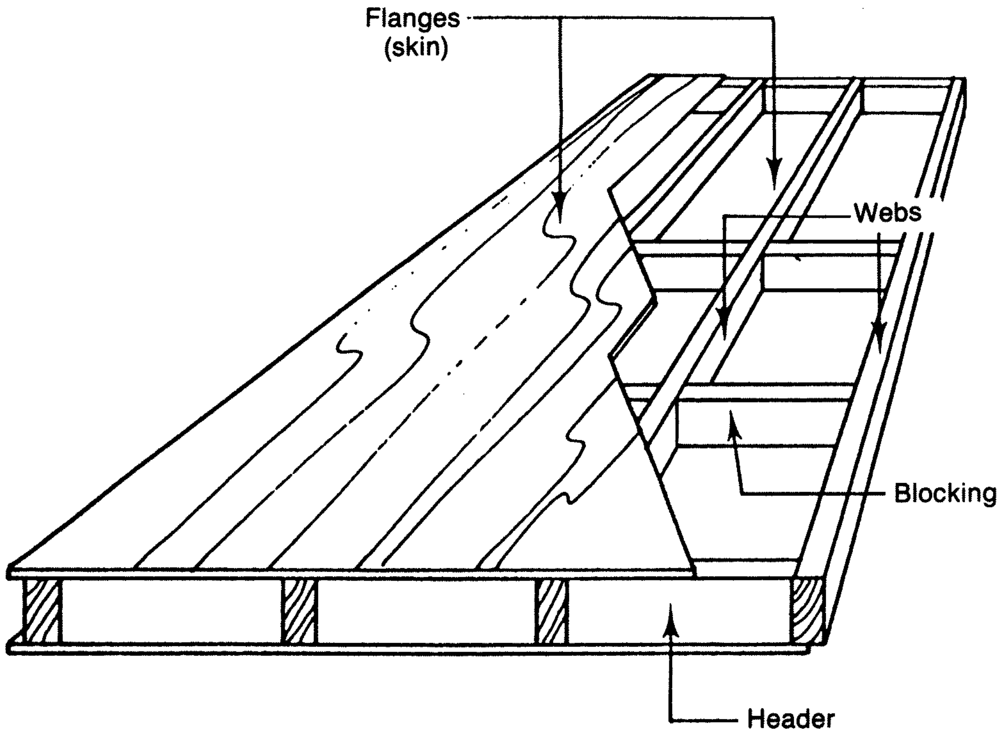

Figure 1. Schematic diagram of stressed skin panel.

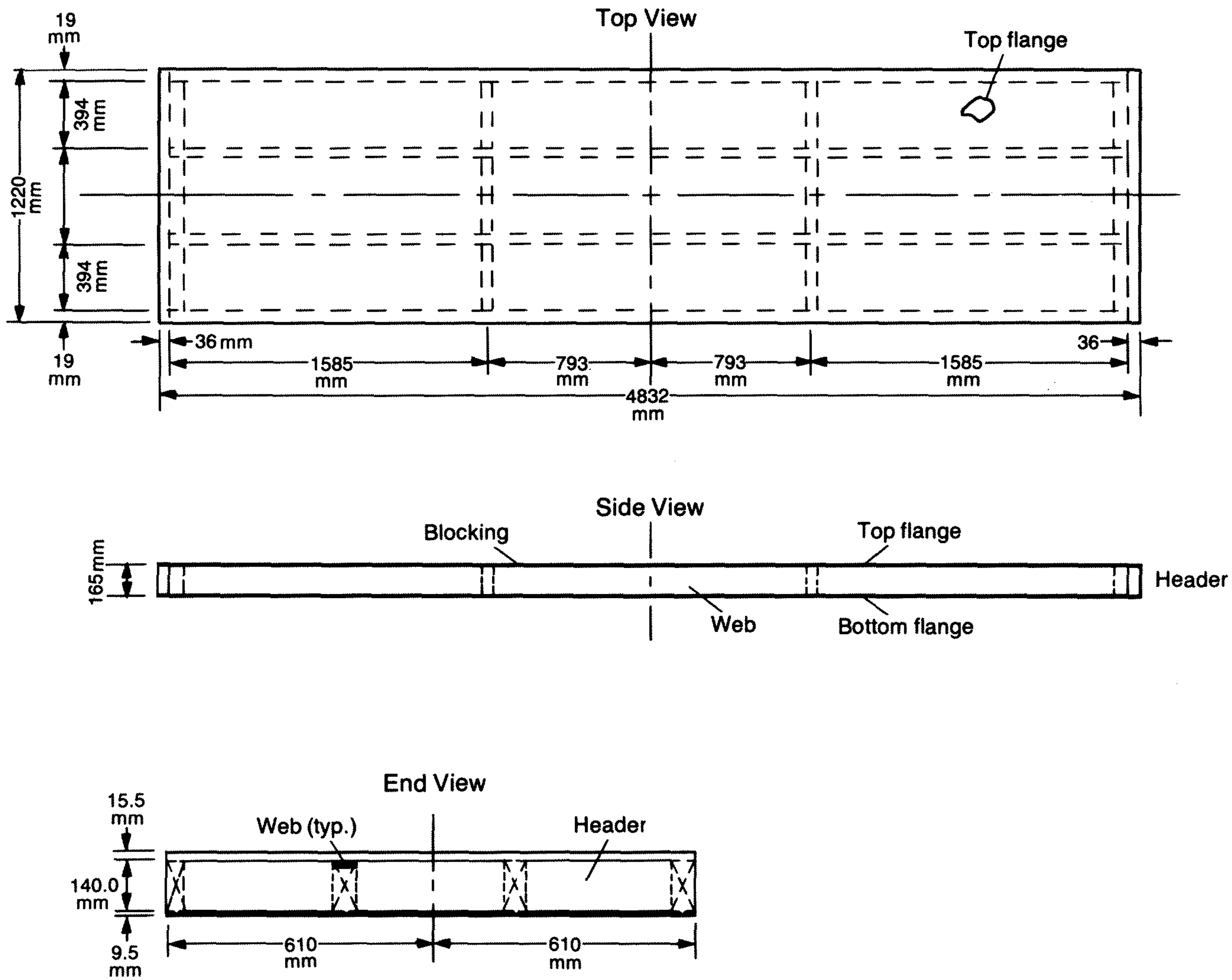

Figure 2. Construction drawing for stressed skin panels.

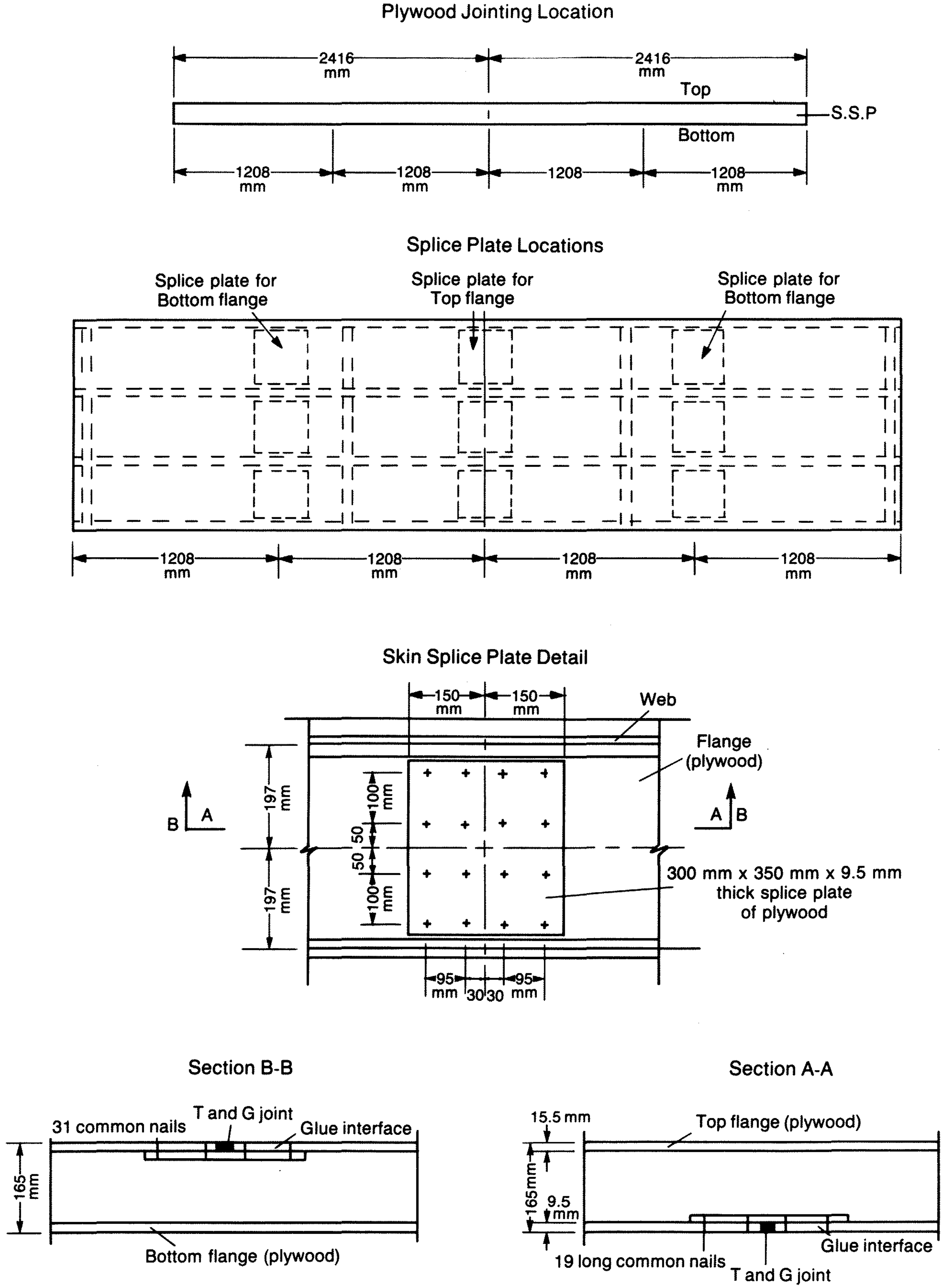

Figure 3. Splice plate drawing for stressed skin panels.

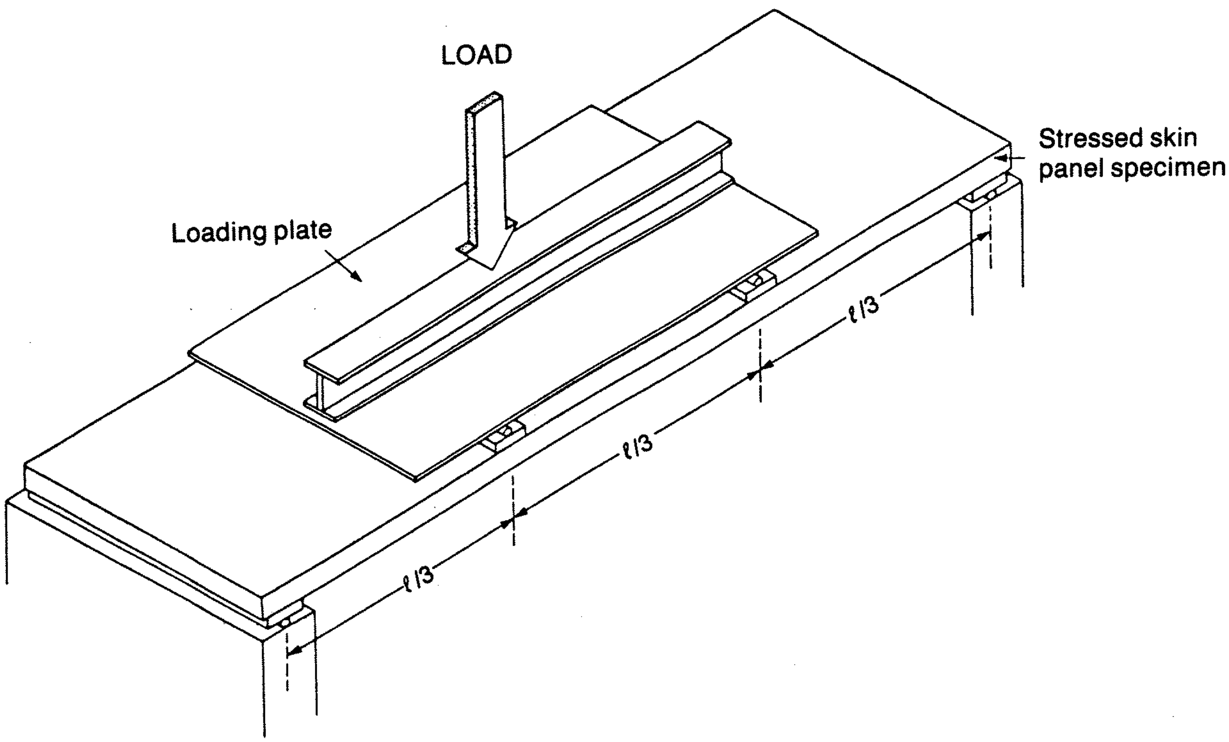

Figure 4a. Load test arrangement for short-term and long-term testing of stressed skin panels.

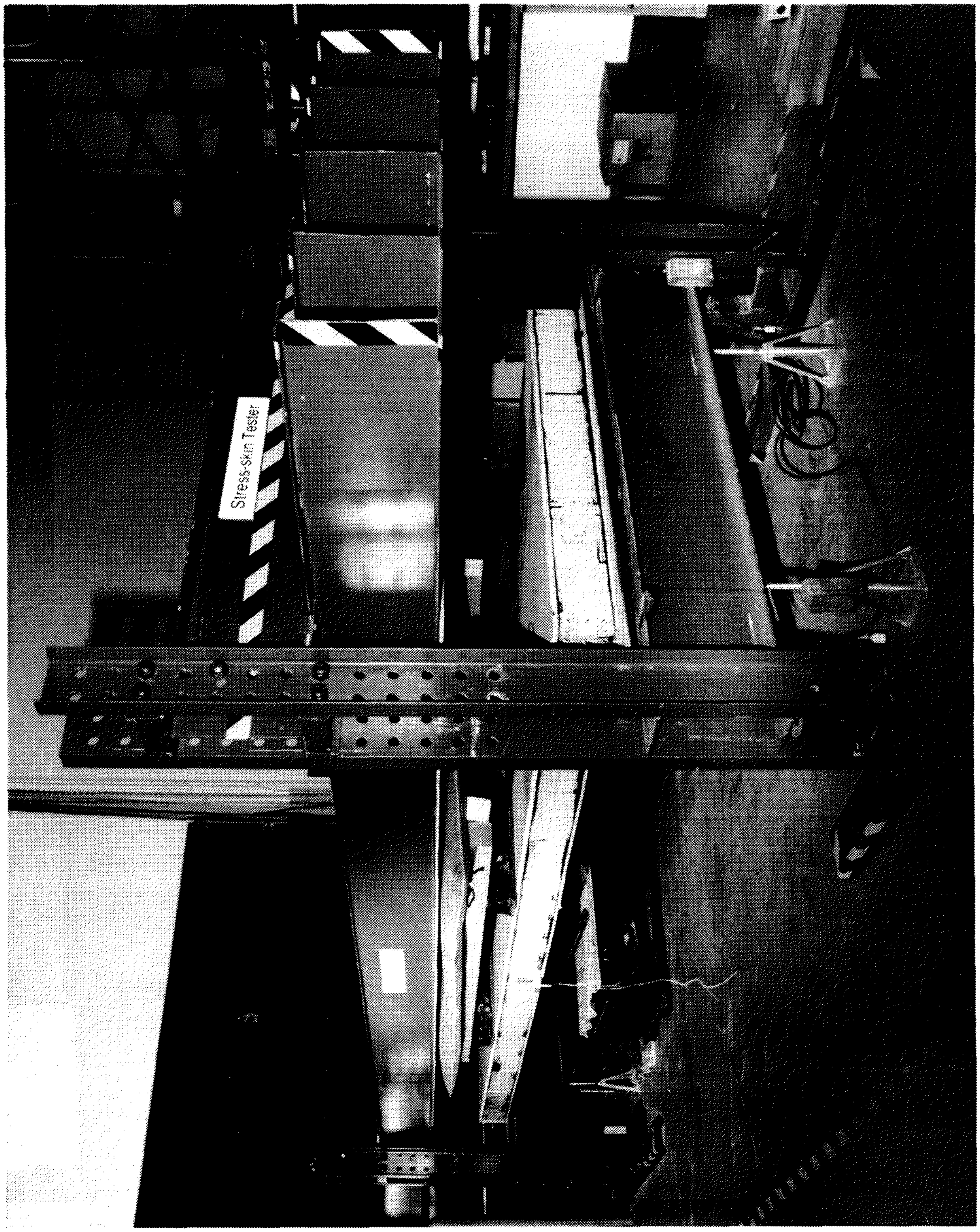

Figure 4b. Stressed skin panel tester.

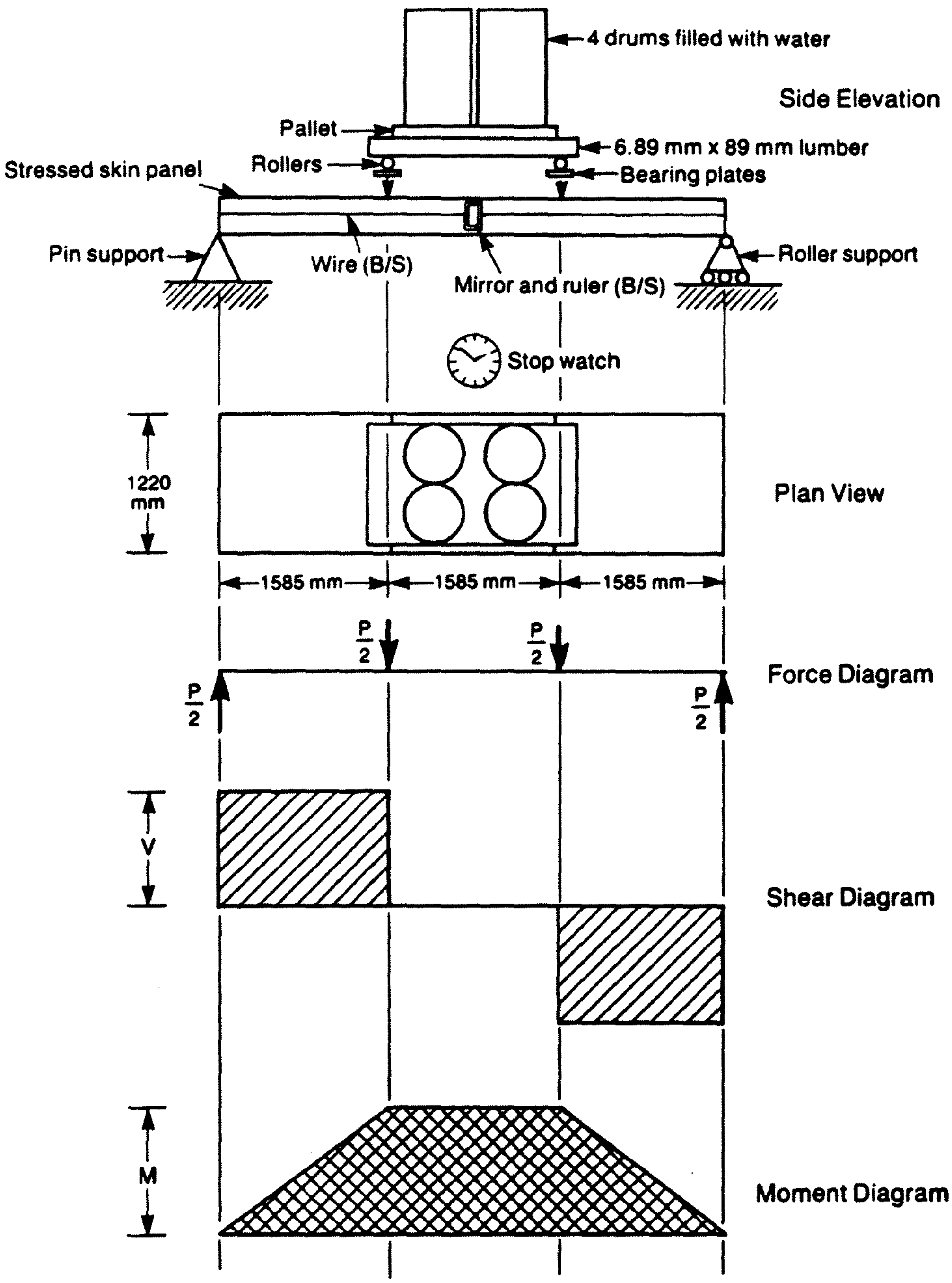

Figure 5. Principal load and measurement set-up for creep testing of stressed skin panels.

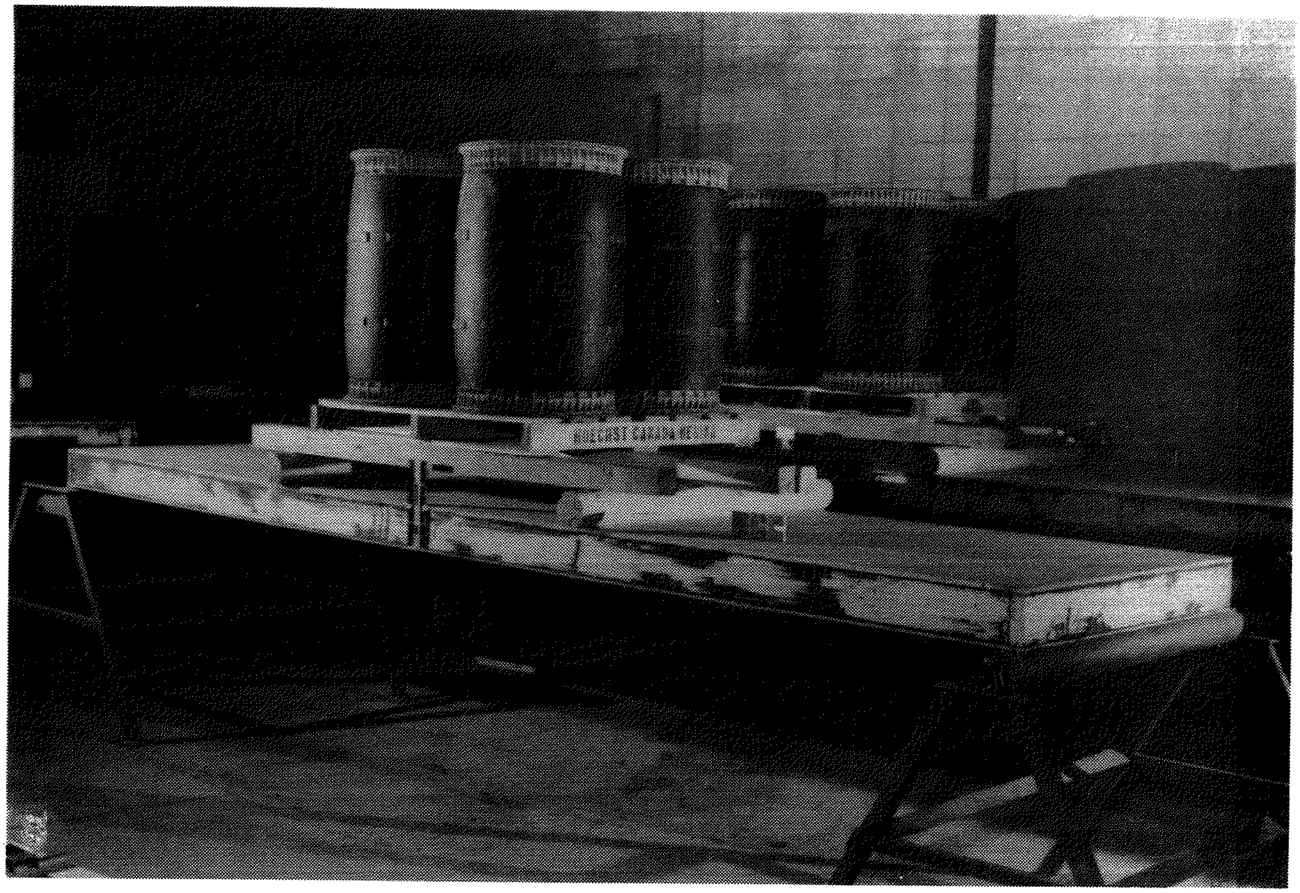

Figure 6. Stressed skin panel with OSB flanges subjected to sustained maximum moment load equivalent to 2 kN/m^2.

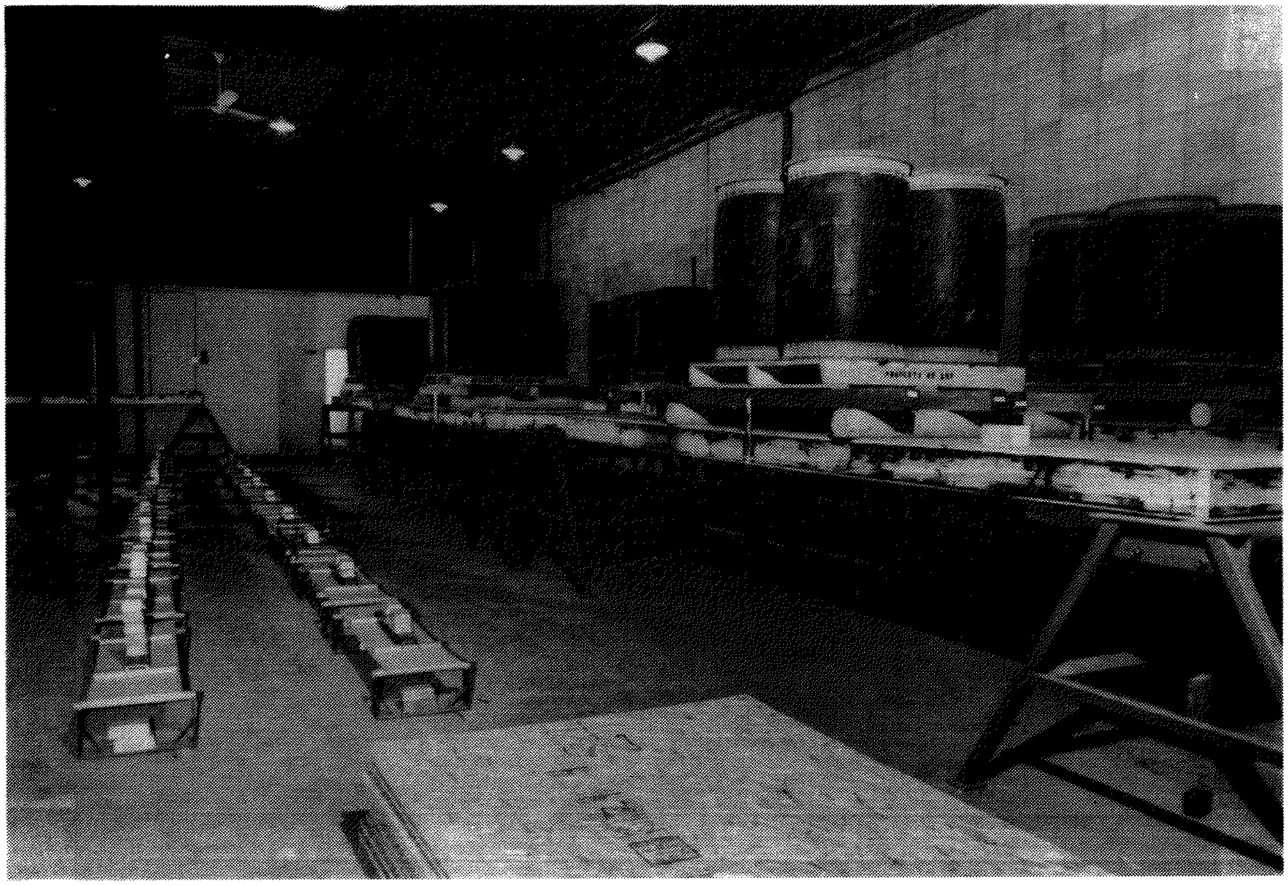

Figure 7. Measuring apparatus for creep testing of SSPs.

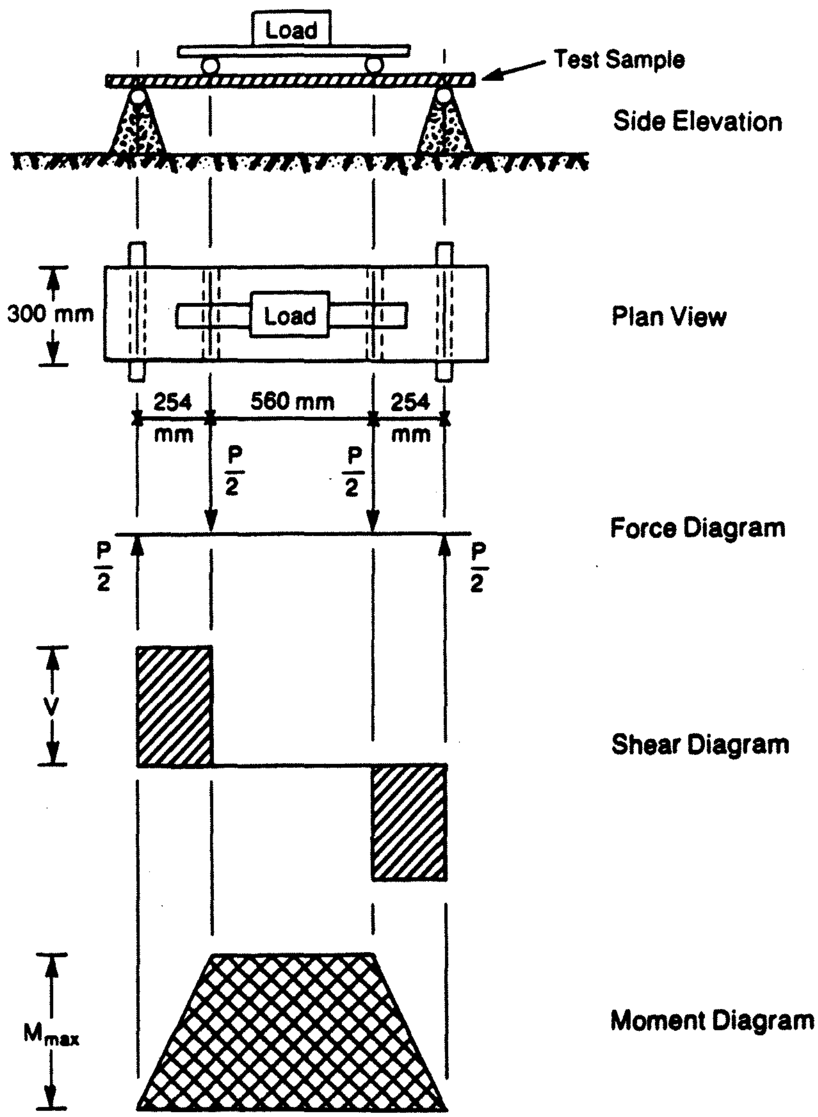

Figure 8. Testing apparatus for creep testing of constituent material specimens (OSB, Spruce and Douglas fir plywood).

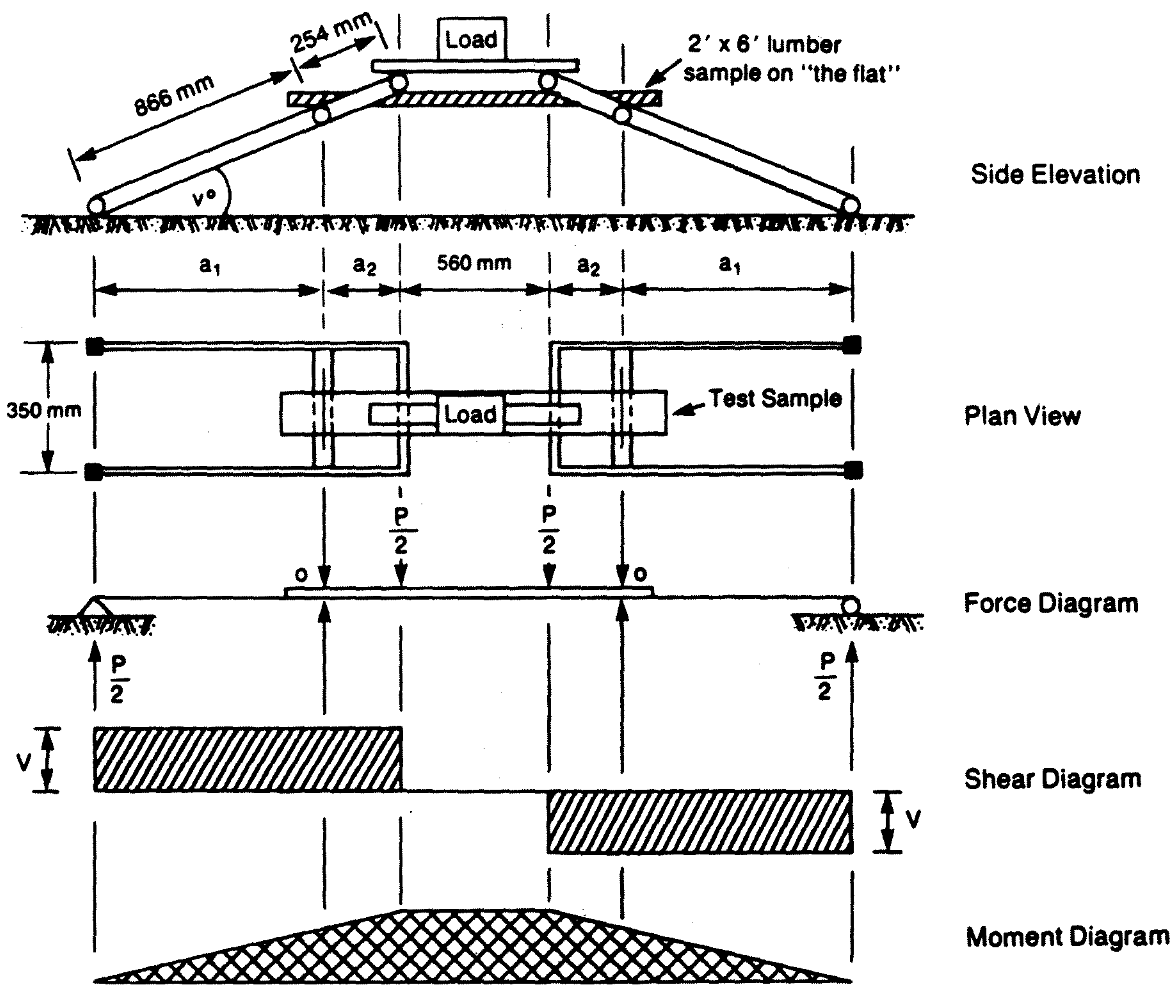

Figure 9. Testing apparatus for creep testing of 2' x 6' lumber on "the flat".

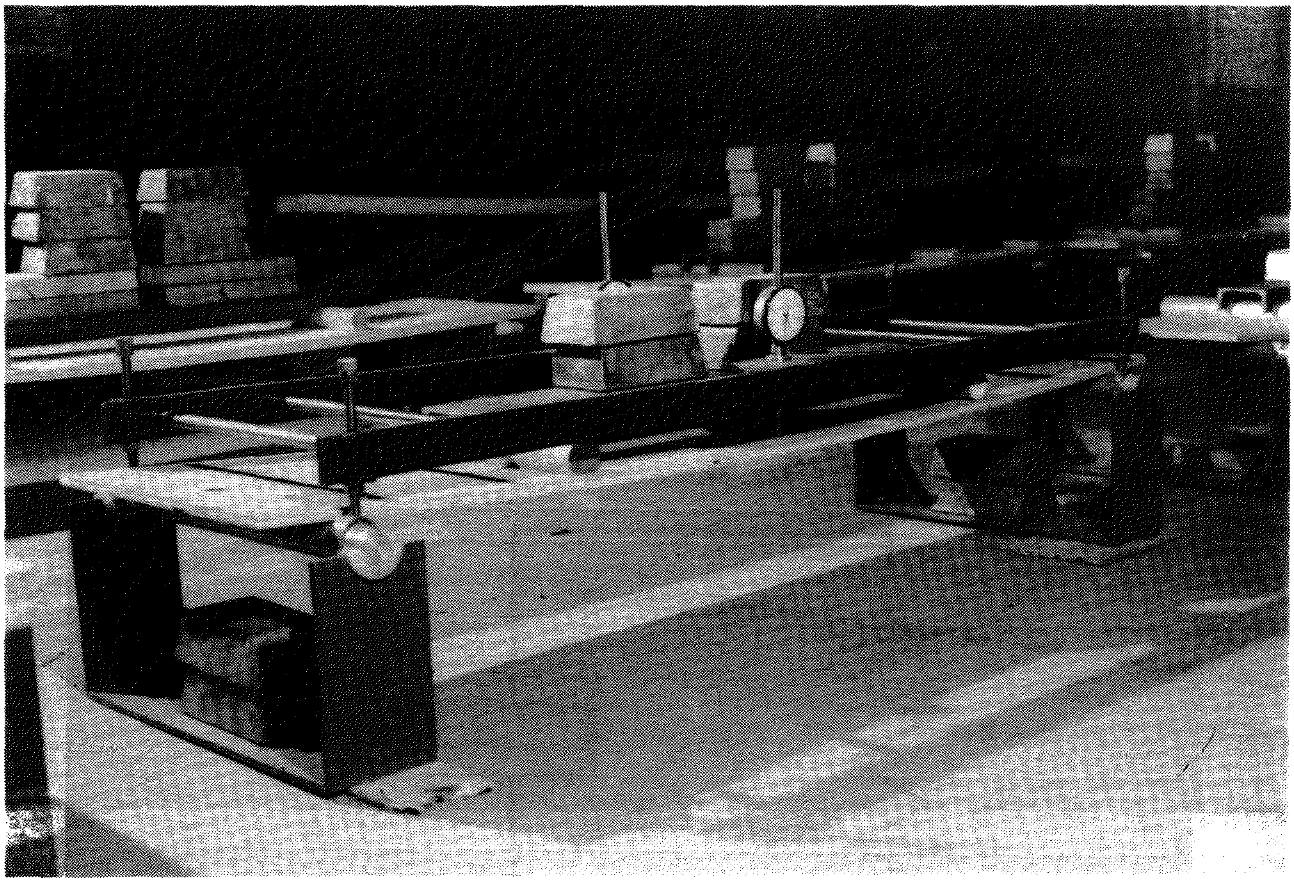

Figure 10. Creep testing of flange materials of the stressed skin panel.

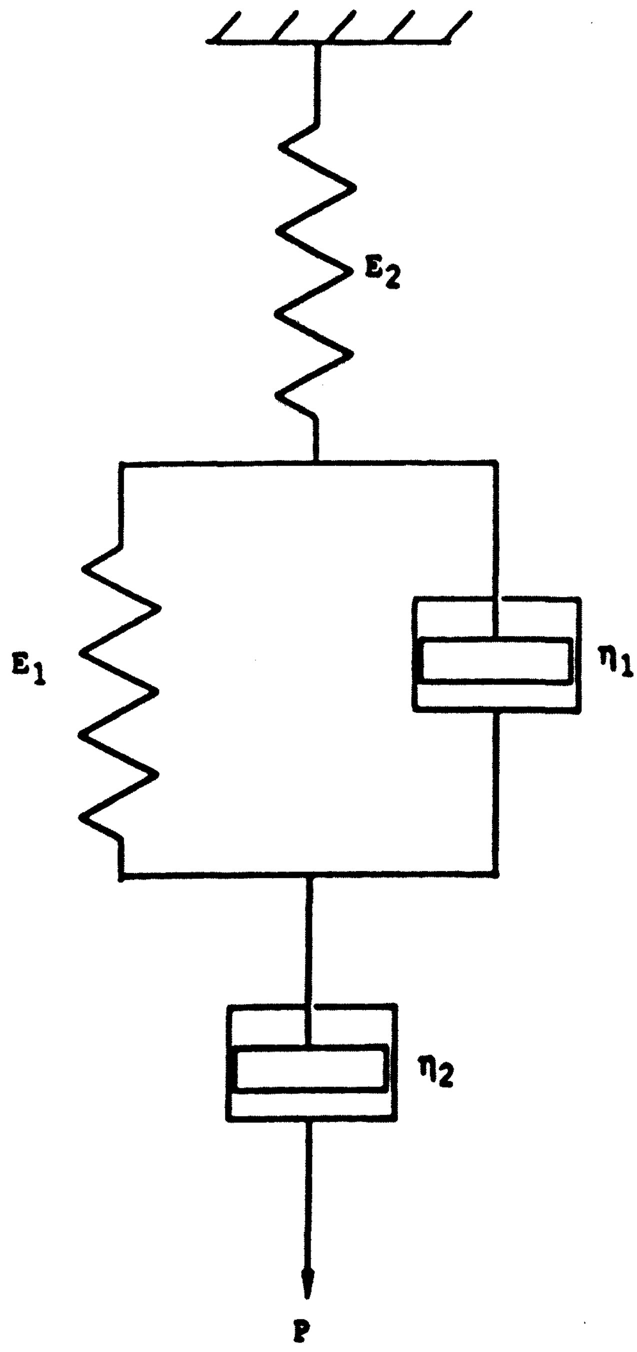

Figure 11. Maxwell-Voight model.

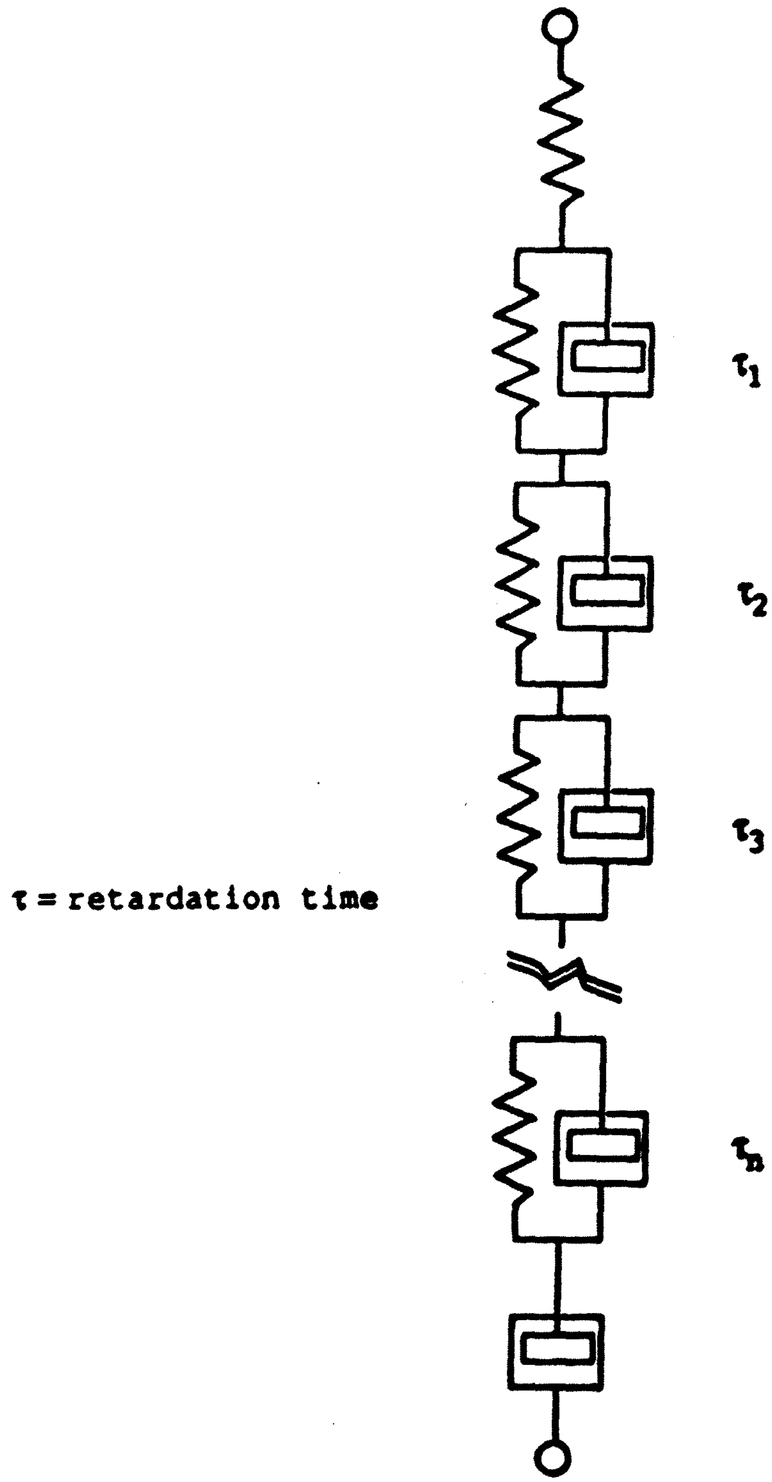

Figure 12. A Maxwell element in series with multiple number of Kelvin elements.

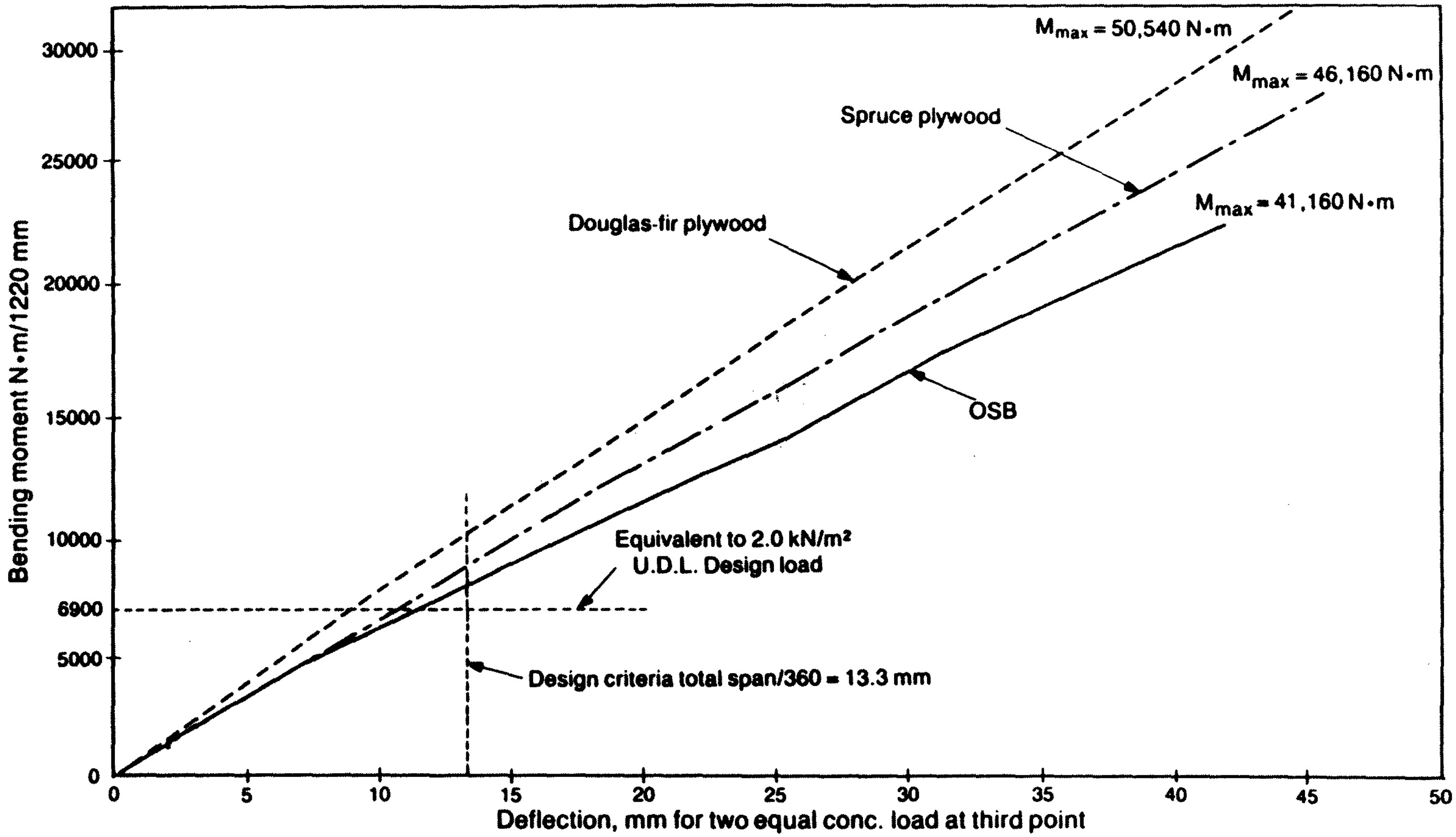

Figure 13. Load/deflection curves for stressed skin panels made with flanges of different materials.

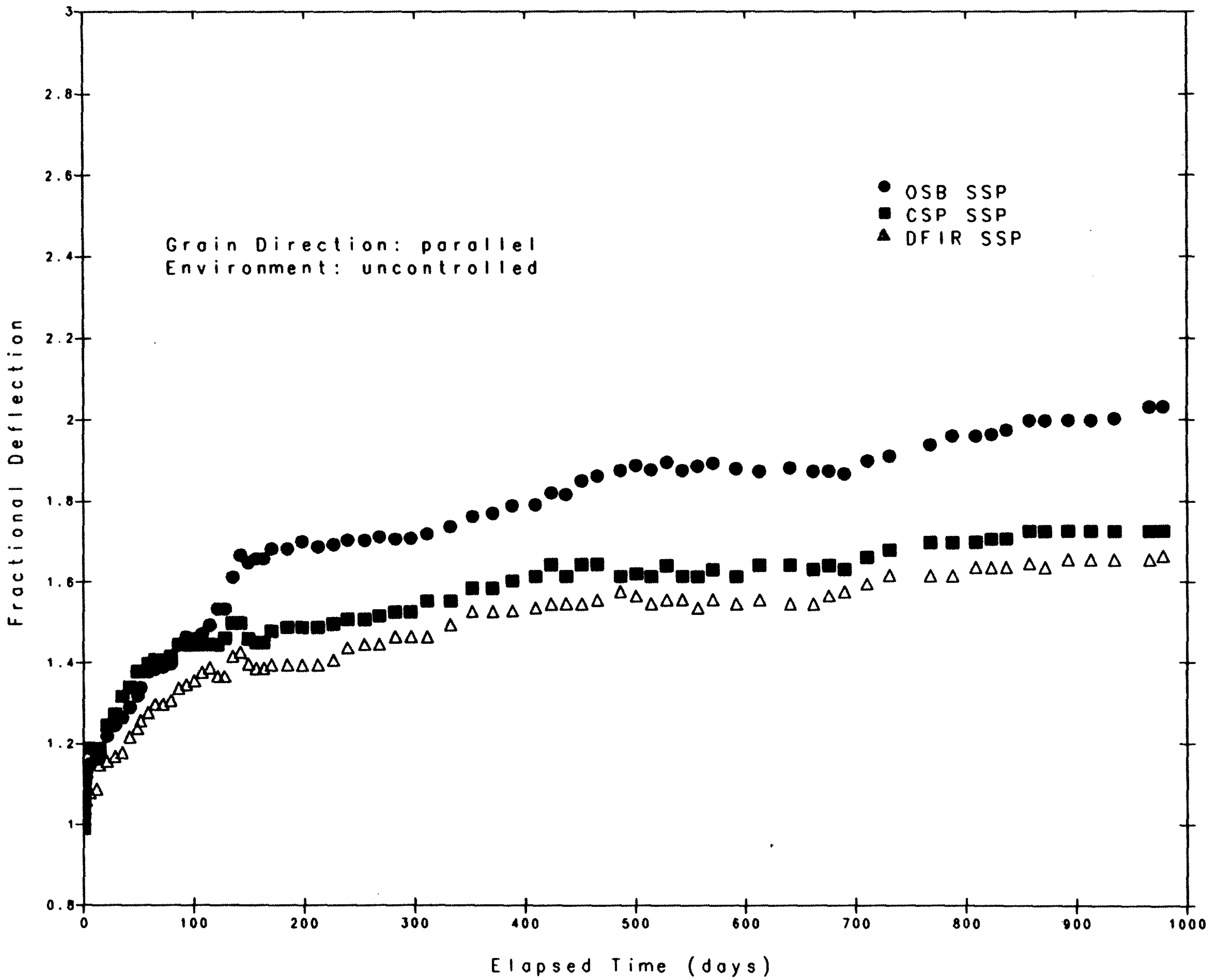

Figure 14. Fractional deflection vs. time for OSB, Spruce and Douglas-fir stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

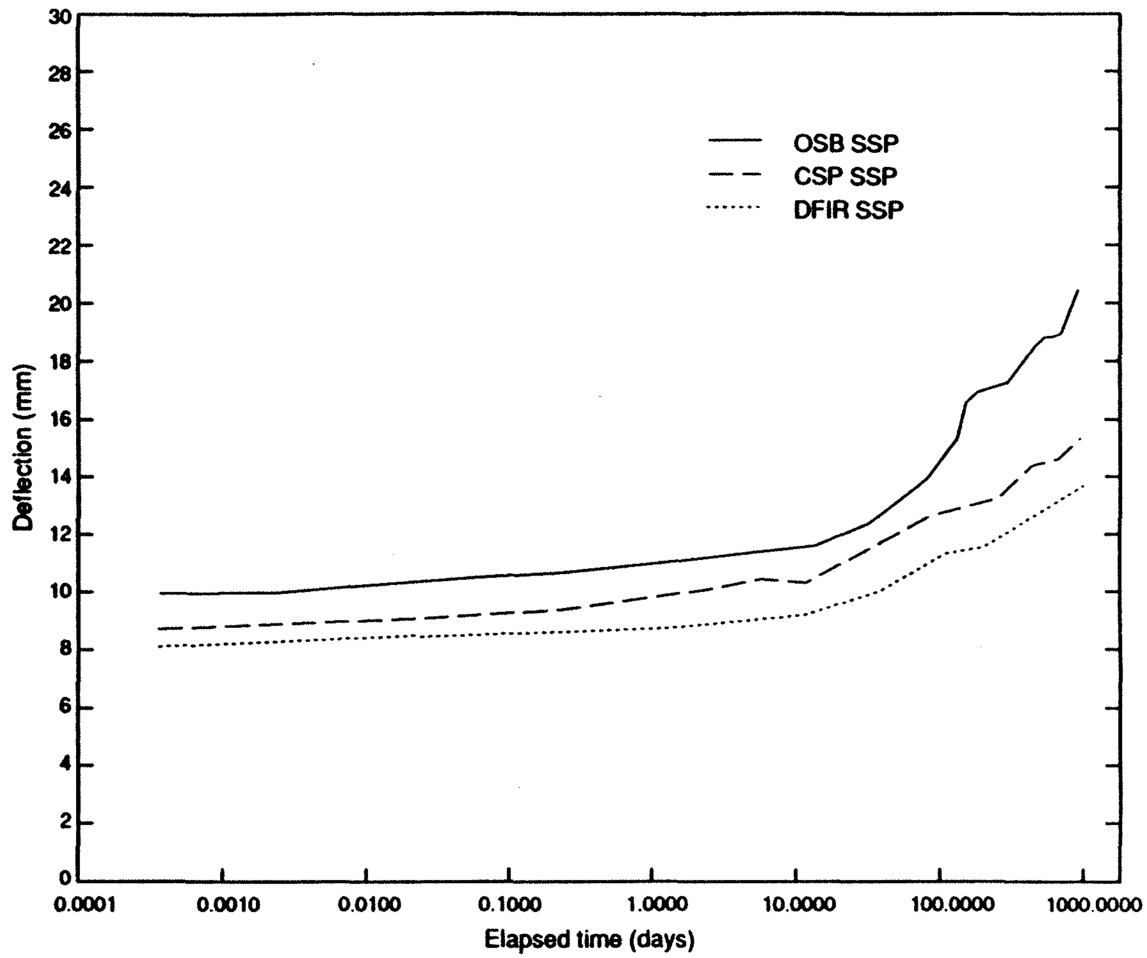

Figure 15. Deflection vs. log time for OSB, Spruce and Douglas-fir stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

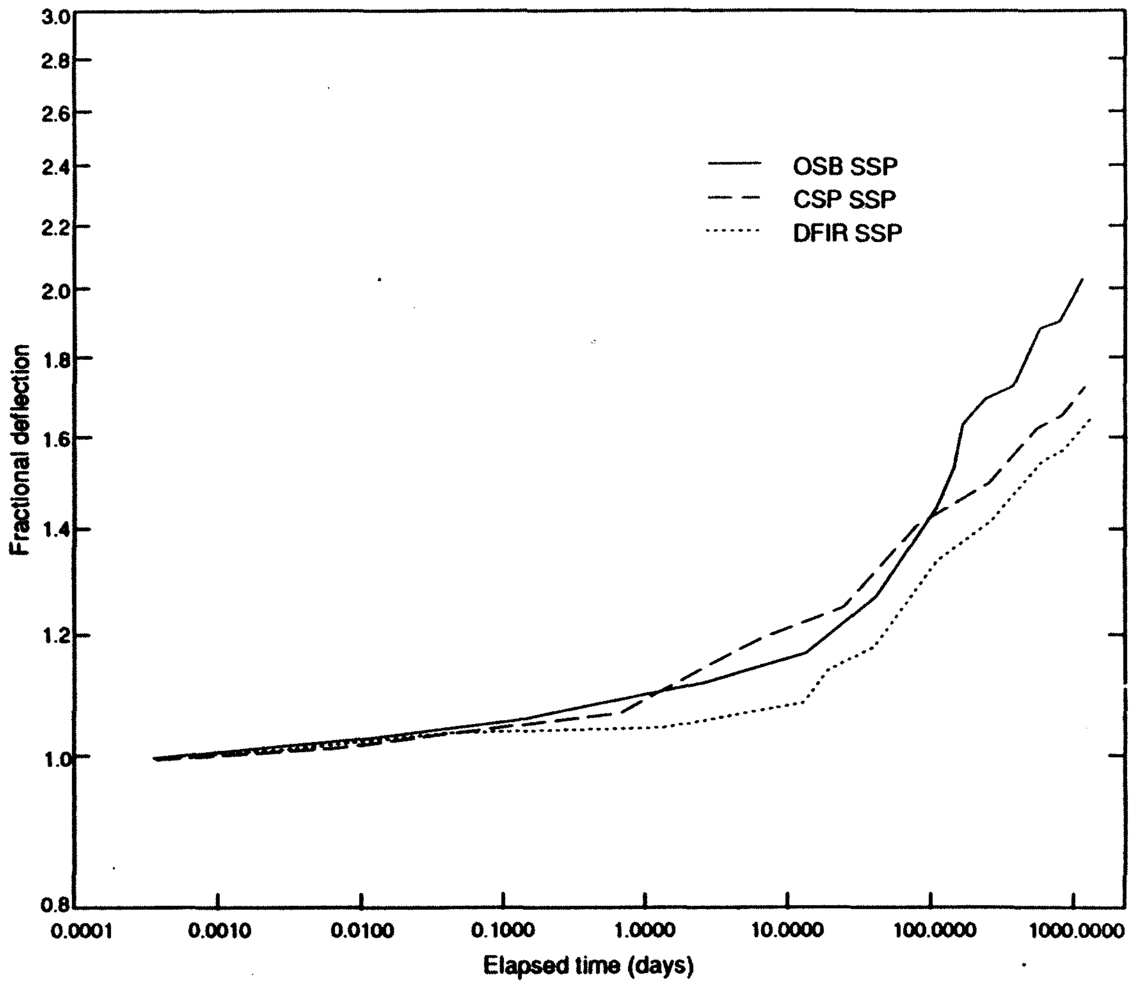

Figure 16. Logarithmic fractional deflection vs. time for OSB, Spruce and Douglas-fir stressed skin panels subjected to equal sustained moments equivalent to 2 kPa U.D.L.

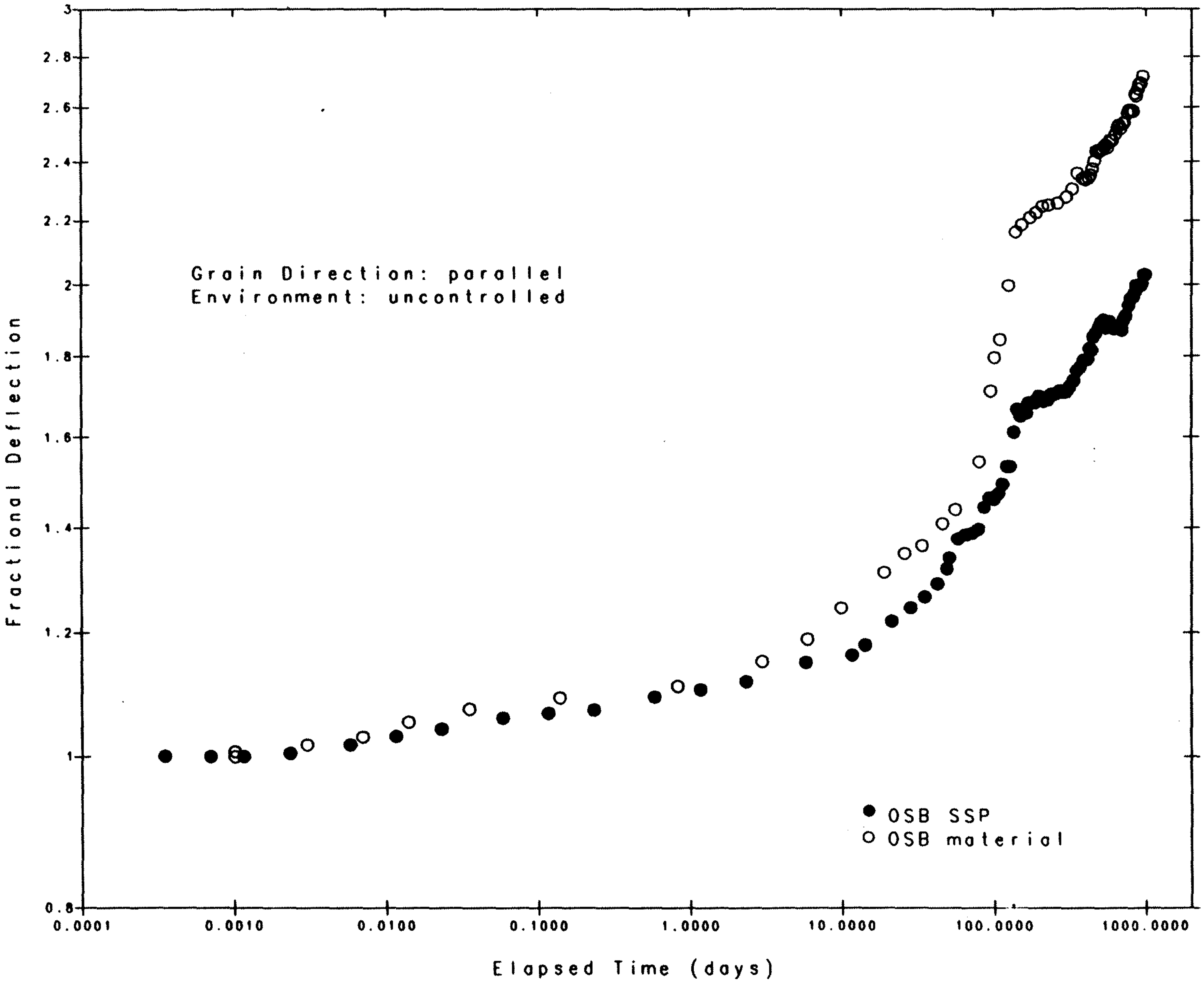

Figure 17. Comparison of fractional creep of OSB SSP with OSB material.

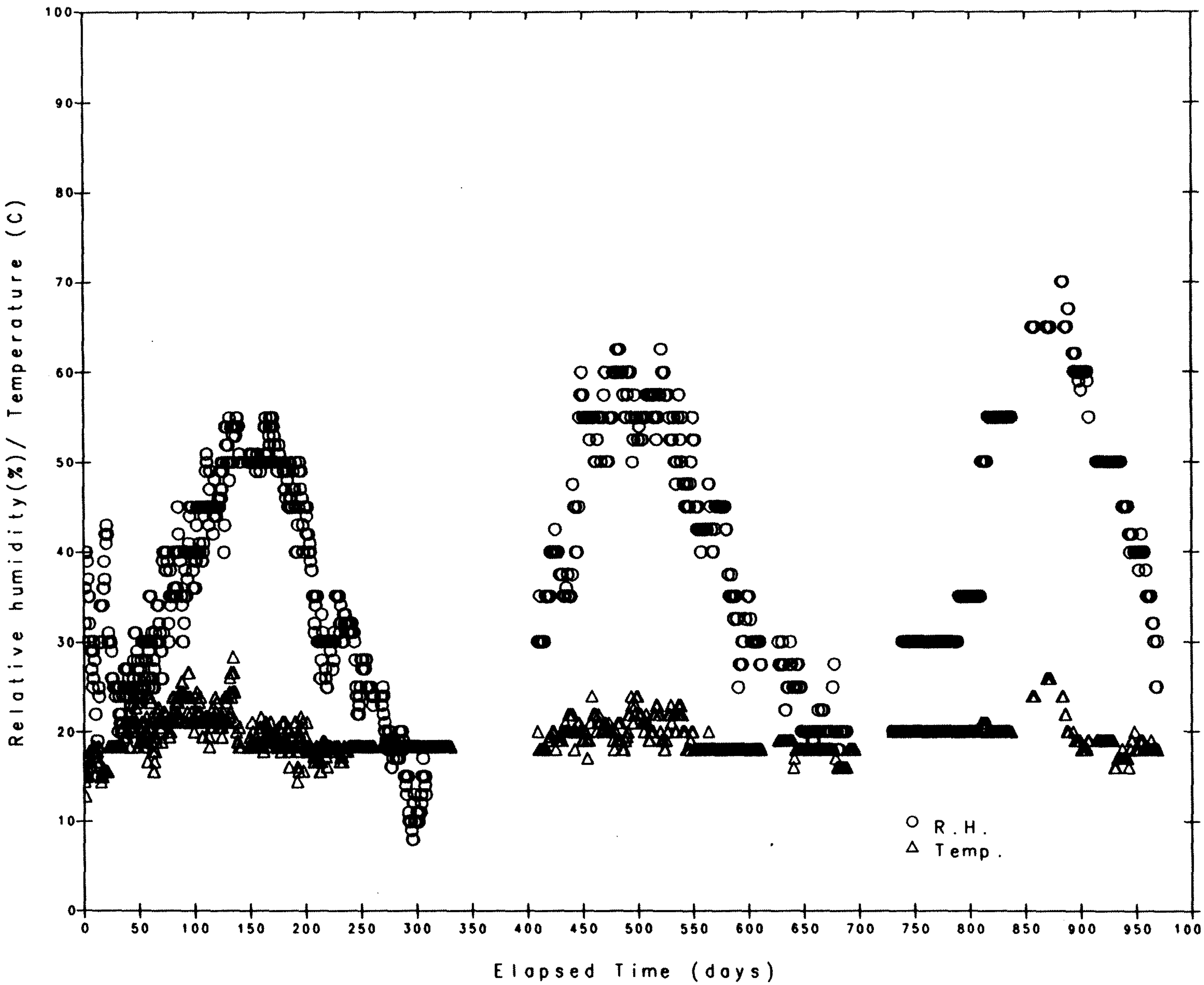

Figure 18. Temperature and relative humidity changes in the warehouse during the 1000 days sustained loading tests were conducted.

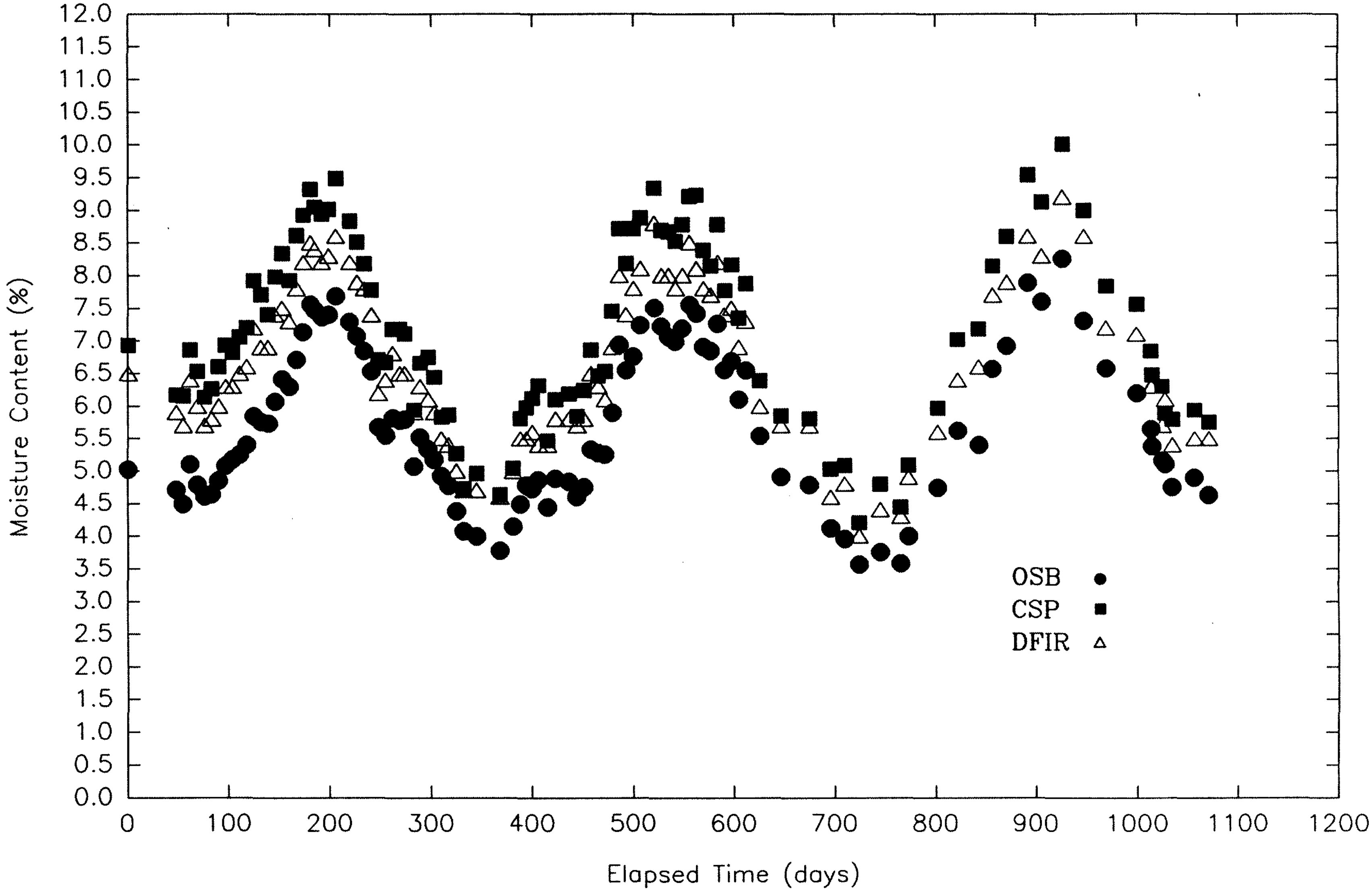

Figure 19. Moisture content (%), based on oven dry weight, of panel samples stored in warehouse with conditions in Figure 18.

Appendix A

Creep Full Sized Stressed Skin Panels
Subjected to Equal Sustained Bending Moments
Equivalent to 2 kN/m^2 U.D.L.

Table A-1. Creep

Average Fractional Deflection Values of
Stressed Skin Panels Subjected to Sustained Moments

Client : A.R.C.
Test Date : December 14, 1989
Proj. Ref.: 40601700

Test Material: CSP, D.FIR, and OSB
Dimensions: 165 mm x 1220 mm x 4832 mm
Conditioning: Uncontrolled Environment
Moment arm: 1586 mm

Type of SSP		CSP		D.Fir		OSB	
Quantity		3		3		3	
Flexural Stiffness		1560 kN-sq.m		1765 kN-sq.m		1320 kN-sq.m	
Ultimate Moment		46160 N-m		50540 N-m		41160 N-m	
Load Level (%)		14.2		13.0		15.9	
Elapsed Time		Average Fractional Deflections (Relative to One-Minute Deflection)					
Days	Minutes	Deflection (mm)	Fractional Deflection	Deflection (mm)	Fractional Deflection	Deflection (mm)	Fractional Deflection
0.001	1	8.92	1.000	8.42	1.000	10.08	1.000
0.001	2	9.00	1.010	8.50	1.010	10.08	1.000
0.003	5	9.00	1.010	8.50	1.010	10.18	1.010
0.007	10	9.00	1.010	8.50	1.010	10.29	1.020
0.014	20	9.08	1.010	8.50	1.010	10.39	1.030
0.035	50	9.08	1.010	8.67	1.030	10.59	1.050
0.069	100	9.08	1.030	8.84	1.050	10.69	1.060
0.139	200	9.38	1.060	8.75	1.040	10.79	1.070
0.347	500	9.46	1.070	8.75	1.040	10.89	1.080
0.694	1000	9.63	1.090	8.75	1.040	11.09	1.100
1.389	2000	9.94	1.130	8.84	1.050	11.19	1.110
3.472	5000	10.25	1.180	9.09	1.080	11.39	1.130
6.944	10000	10.48	1.180	9.34	1.110	11.70	1.160
13.889	20000	10.58	1.190	9.76	1.160	12.30	1.220
34.722	50000	12.13	1.320	10.44	1.240	13.01	1.290
69.444	100000	12.50	1.410	11.03	1.310	14.02	1.390
138.889	200000	13.33	1.500	12.04	1.430	16.74	1.660
208.333	300000	13.33	1.490	11.87	1.410	17.04	1.690
277.778	400000	13.54	1.520	12.46	1.480	17.24	1.710
416.667	600000	14.58	1.641	13.17	1.565	18.29	1.814
555.556	800000	14.33	1.612	12.83	1.525	18.92	1.877
694.444	1000000	14.75	1.659	13.50	1.604	19.13	1.898
763.889	1100000	15.08	1.696	13.67	1.626	19.54	1.939
833.333	1200000	15.17	1.704	13.67	1.626	19.88	1.972
902.778	1300000	15.33	1.723	13.83	1.645	20.13	1.997
978.000	1408320	15.33	1.723	13.92	1.653	20.46	2.030
1000.000	1440000	15.33	1.723	13.95	1.657	20.56	2.039

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Table A-2. Creep Recovery

Average Fractional Deflection Values of
Stressed Skin Panels Subjected to Sustained Moments

Client : A.R.C.
Test Date : December 14, 1989
Proj. Ref.: 40601700

Test Material: CSP, D.FIR, and OSB
Dimensions: 165 mm x 1220 mm x 4832 mm
Conditioning: Uncontrolled Environment
Moment arm: 1586 mm

Type of SSP		CSP		D.Fir		OSB	
Quantity		3		3		3	
Flexural Stiffness		1560 kN-sq.m		1765 kN-sq.m		1320 kN-sq.m	
Ultimate Moment		46160 N-m		50540 N-m		41160 N-m	
Load Level (%)		14.2		13.0		15.9	
Elapsed Time		Average Fractional Deflections (Relative to One-Minute Deflection)					
Days	Minutes	Fractional Recovery Deflection	Actual Deflection (mm)	Fractional Recovery Deflection	Actual Deflection (mm)	Fractional Recovery Deflection	Actual Deflection (mm)
0	0	1.73	15.33	1.66	13.92	2.03	20.46
0.00069	1	0.61	5.42	0.57	4.75	0.91	9.21
0.00139	2	0.61	5.42	0.57	4.75	0.91	9.13
0.00347	5	0.61	5.42	0.57	4.75	0.90	9.04
0.00694	10	0.61	5.42	0.57	4.75	0.89	9.00
0.01389	20	0.60	5.33	0.54	4.50	0.89	8.96
0.03472	50	0.59	5.25	0.54	4.50	0.87	8.79
0.06944	100	0.58	5.19	0.53	4.44	0.87	8.75
0.13889	200	0.57	5.03	0.53	4.41	0.86	8.66
0.34722	500	0.55	4.94	0.53	4.35	0.85	8.55
1.04167	1500	0.54	4.79	0.51	4.33	0.83	8.36
1.38889	2000	0.52	4.57	0.51	4.30	0.83	8.31
3.47222	5000	0.50	4.47	0.48	4.02	0.78	7.89
6.94444	10000	0.48	4.27	0.45	3.79	0.74	7.47
10.41667	15000	0.45	3.99	0.45	3.80	0.74	7.42
13.88889	20000	0.44	3.92	0.43	3.58	0.69	6.99
17.36111	30000	0.43	3.78	0.42	3.57	0.67	6.76
20.83333	40000	0.41	3.66	0.42	3.53	0.65	6.51
34.72222	50000	0.40	3.58	0.40	3.40	0.64	6.41
41.66666	60000	0.41	3.50	0.39	3.27	0.63	6.34
50.00000	72000	0.39	3.46	0.36	3.05	0.62	6.27

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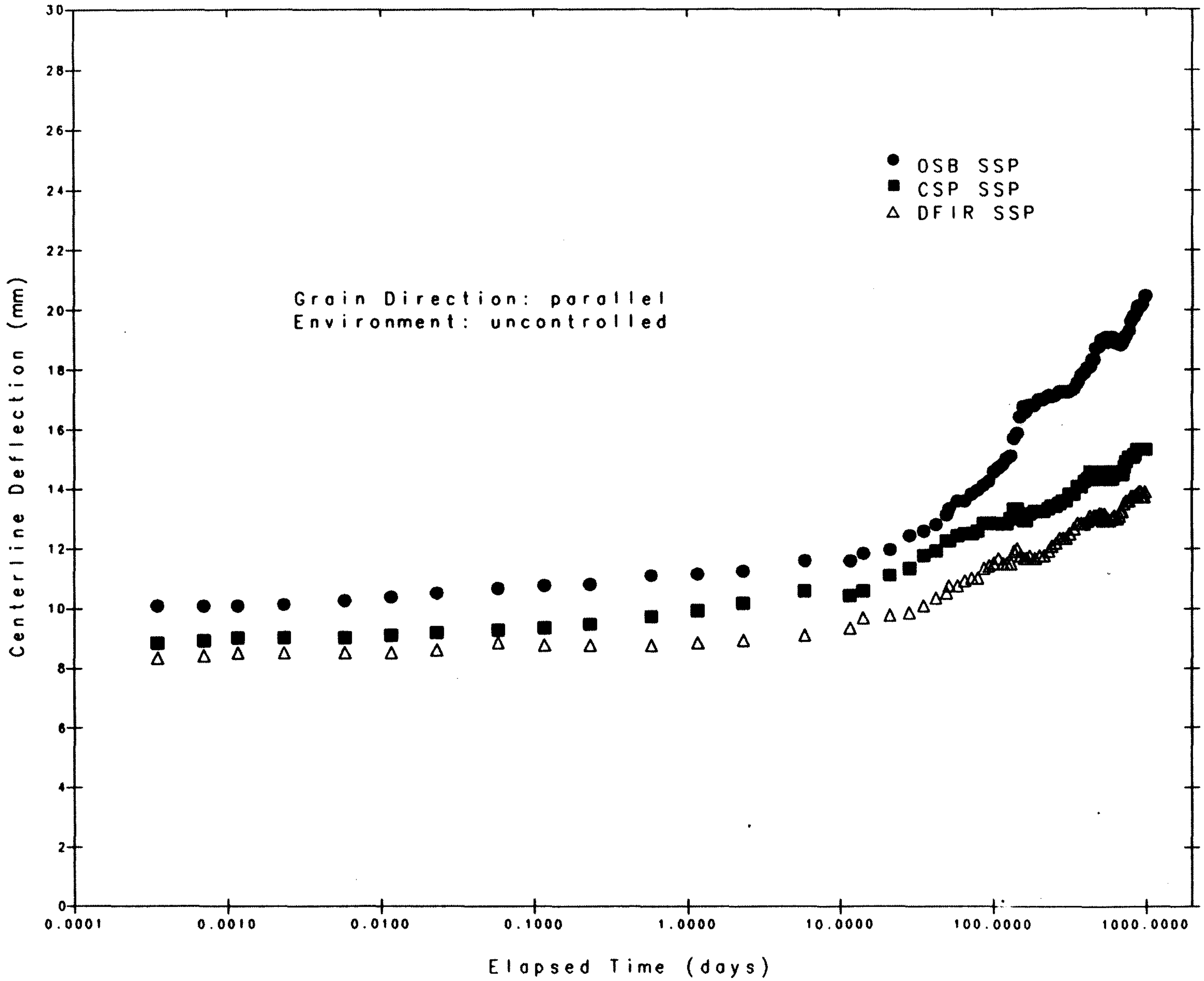


Figure A-1. Centreline deflection vs. logarithmic time for OSB, Spruce and Douglas-fir stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

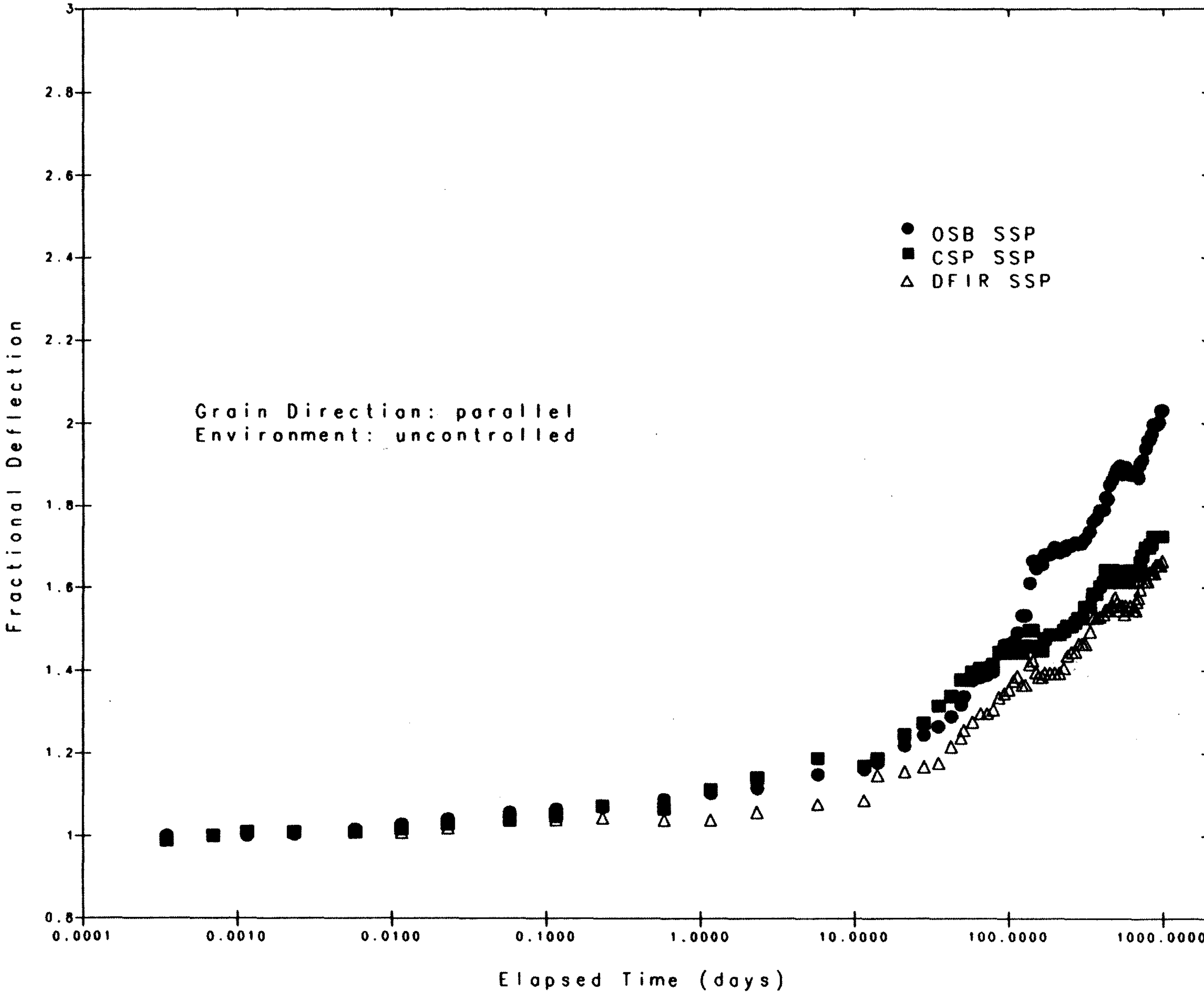


Figure A-2. Fractional deflection vs. logarithmic time for OSB, Spruce and Douglas-fir stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

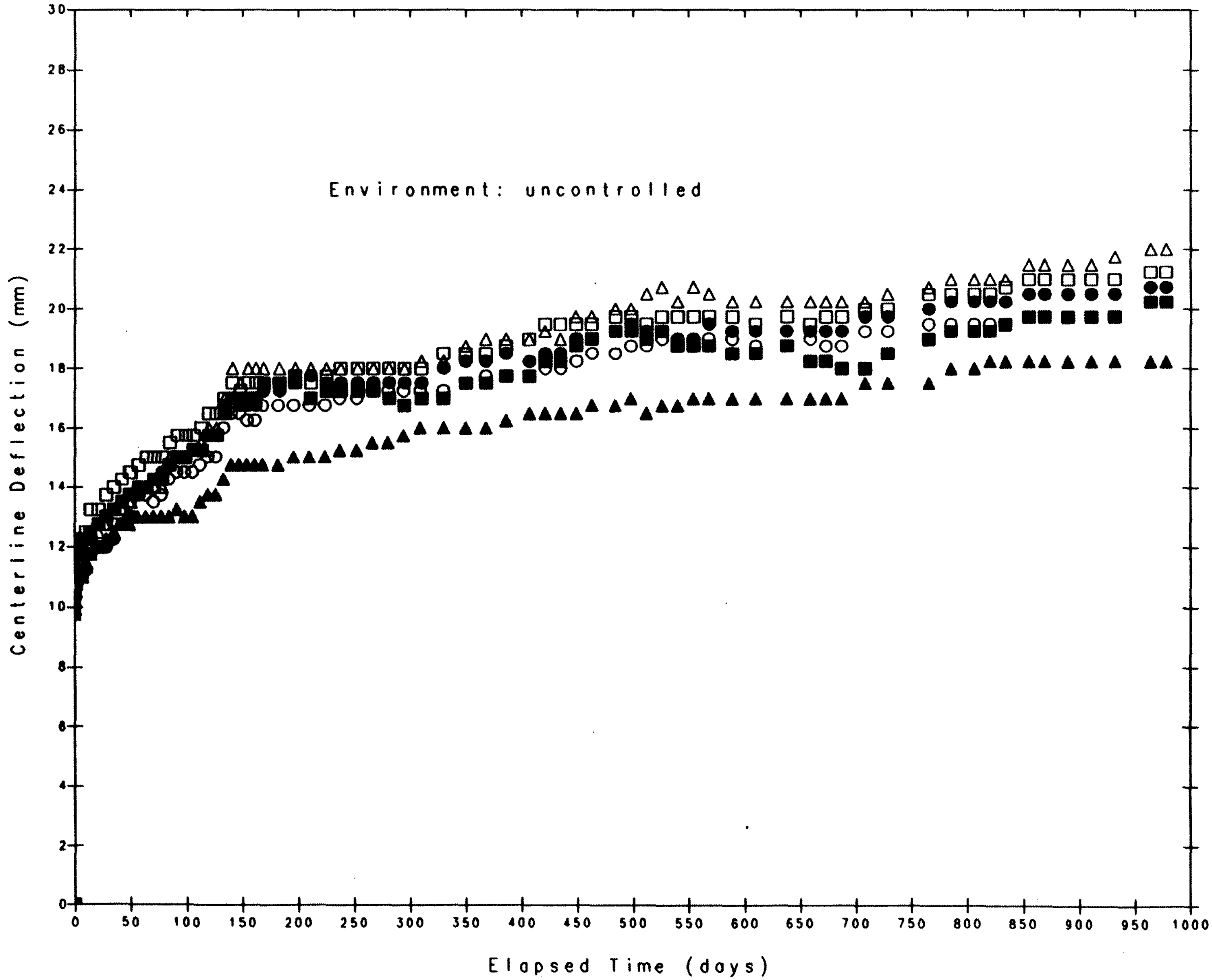


Figure A-3. Centreline deflection of 6 OSB SSP elements subjected to equal sustained moments equivalent to 2 kN/m^2 U.D.L.

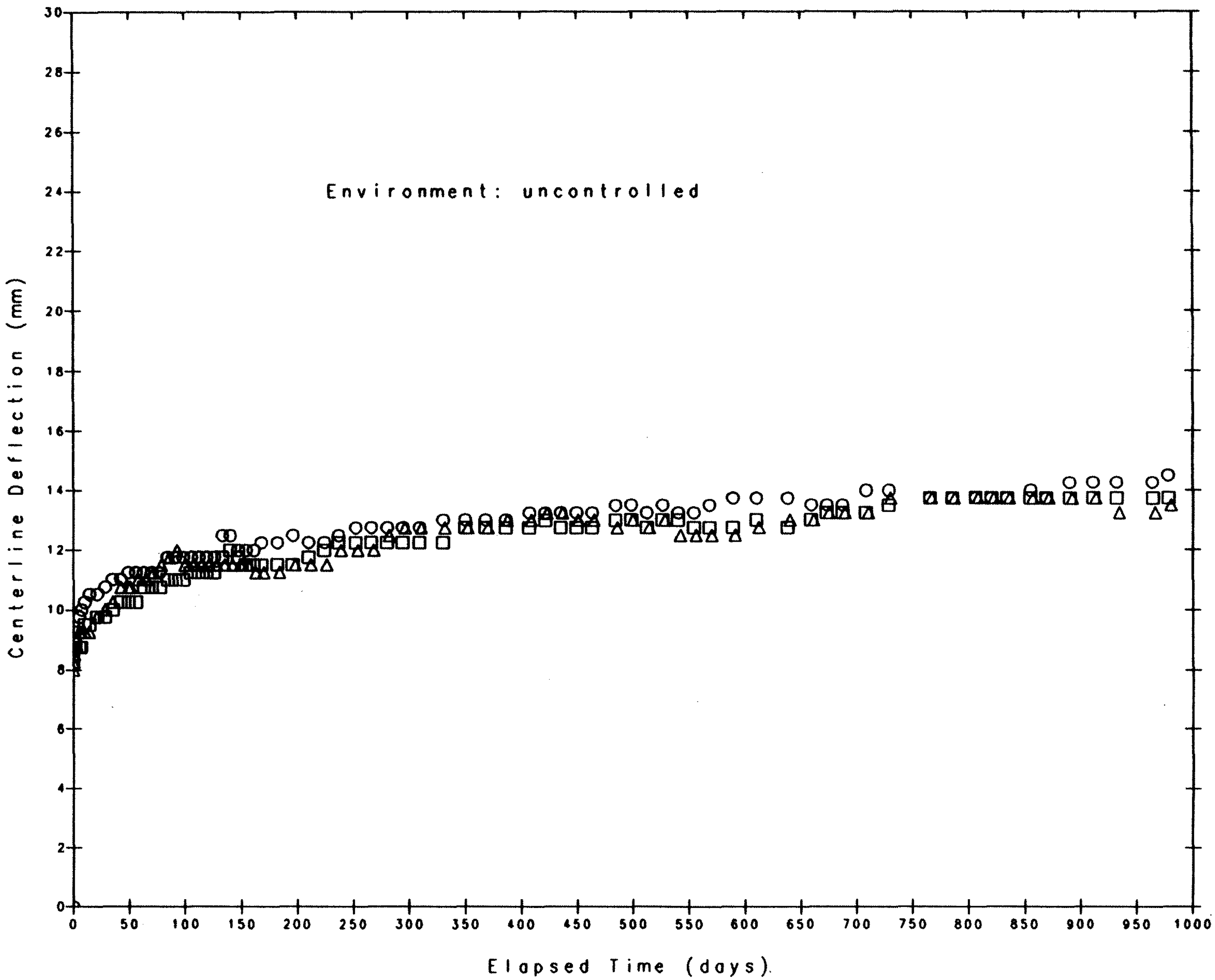


Figure A-4. Centreline deflection of 3 Douglas-fir faced SSPs subjected to equal sustained moments equivalent to 2 kN/m² U.D.L.

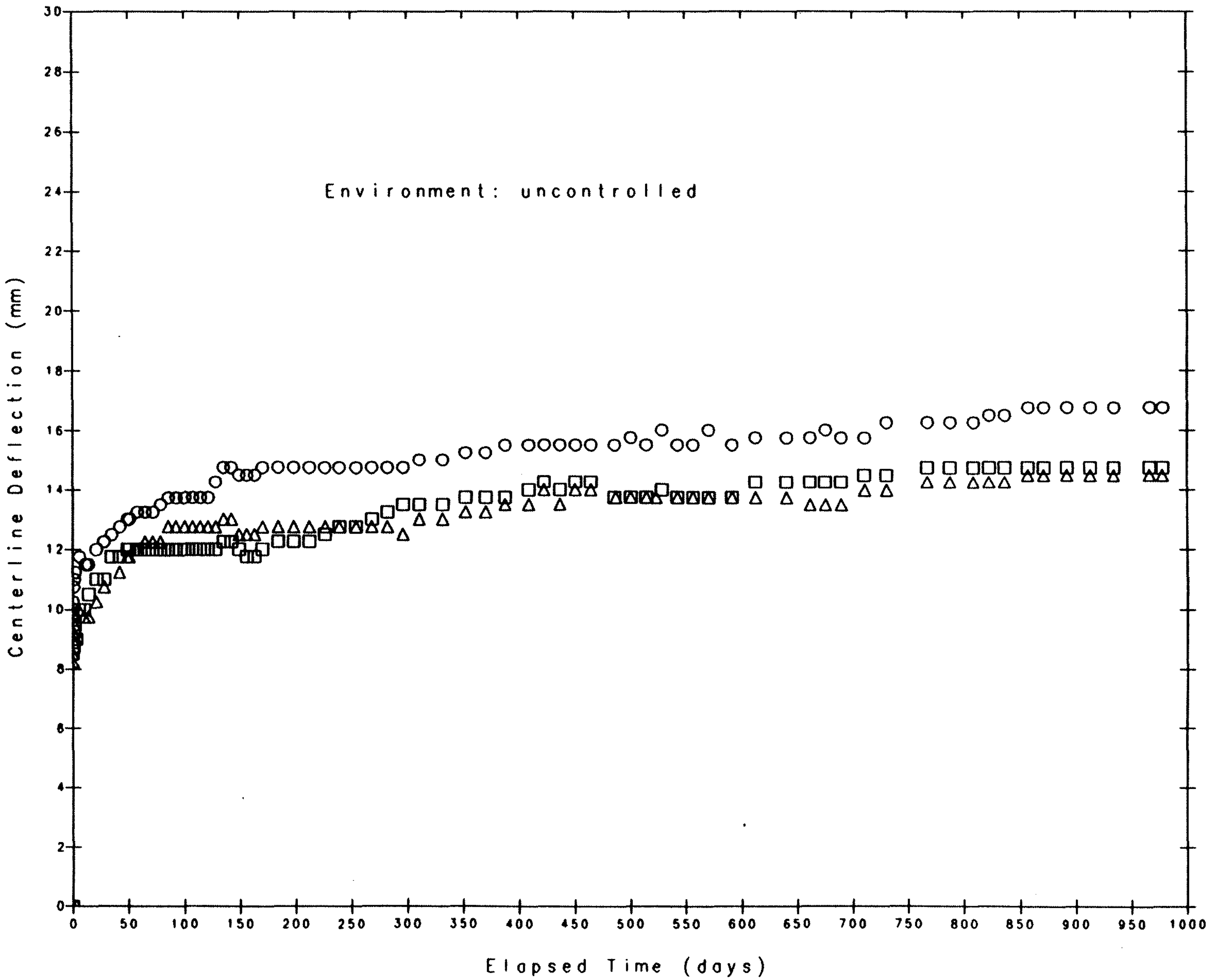


Figure A-5. Centreline deflection of 3 spruce plwood faced SSPs subjected to equal sustained moments equivalent to 2 kN/m^2 U.D.L.

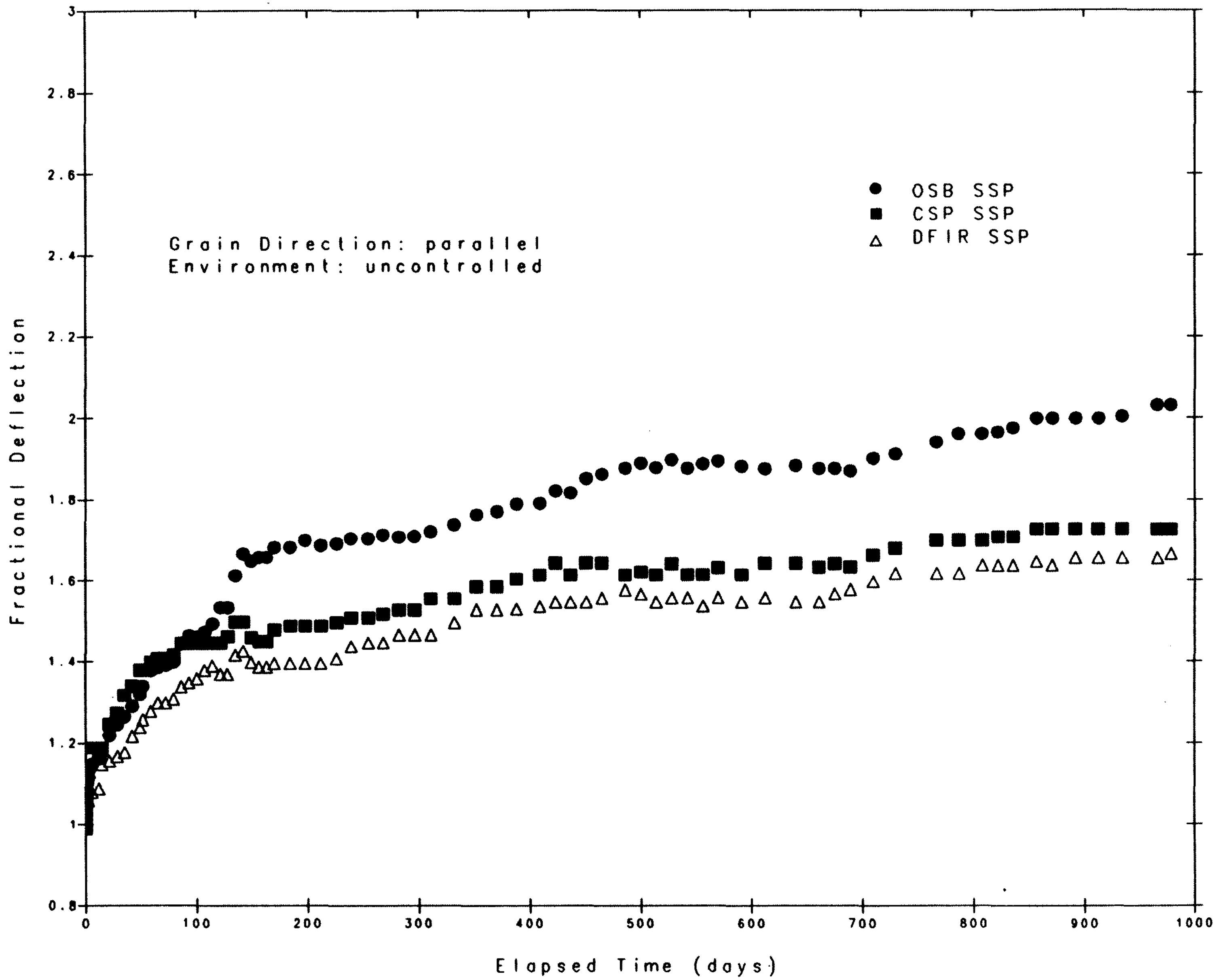


Figure A-6. Fractional Deflection of stressed skin panels made with flanges of OSB, spruce plywood and Douglas-fir plywood subjected to equal sustained moments equivalent to 2 kN/m^2 U.D.L.

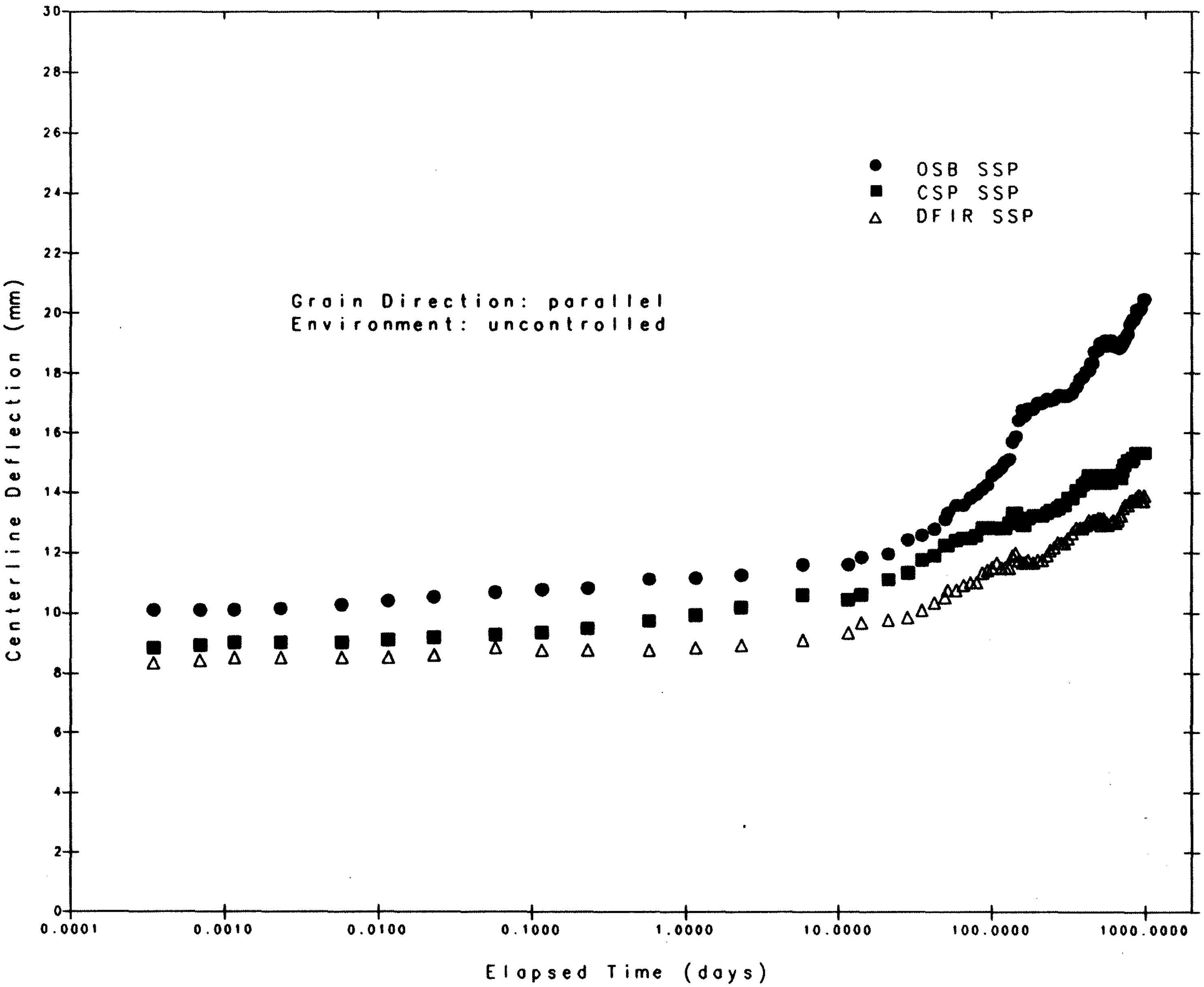


Figure A-7. Centreline deflection vs. time for OSB, spruce and Douglas-fir faced stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

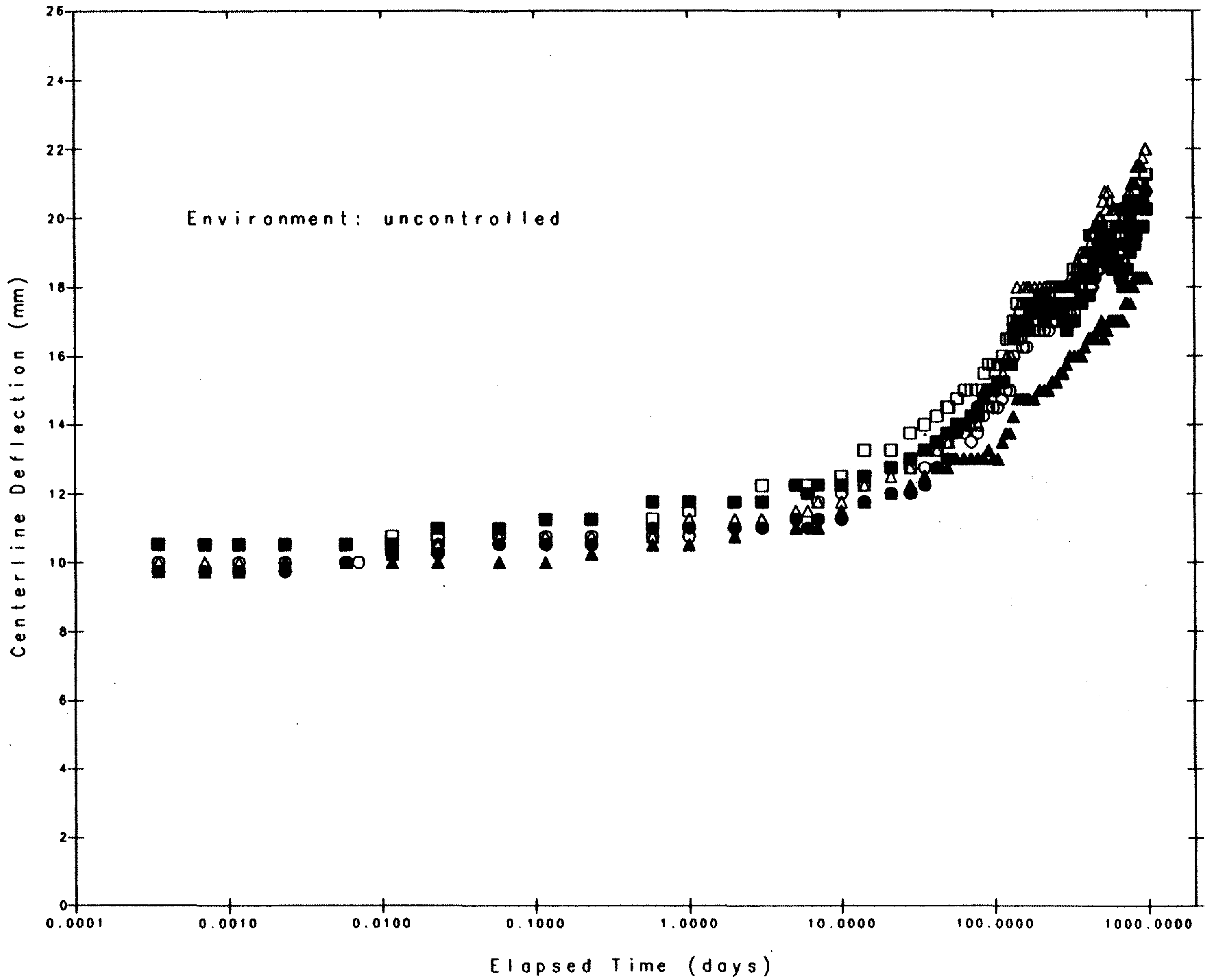


Figure A-8. Centreline deflection vs. logarithmic time for 6 OSB faced stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

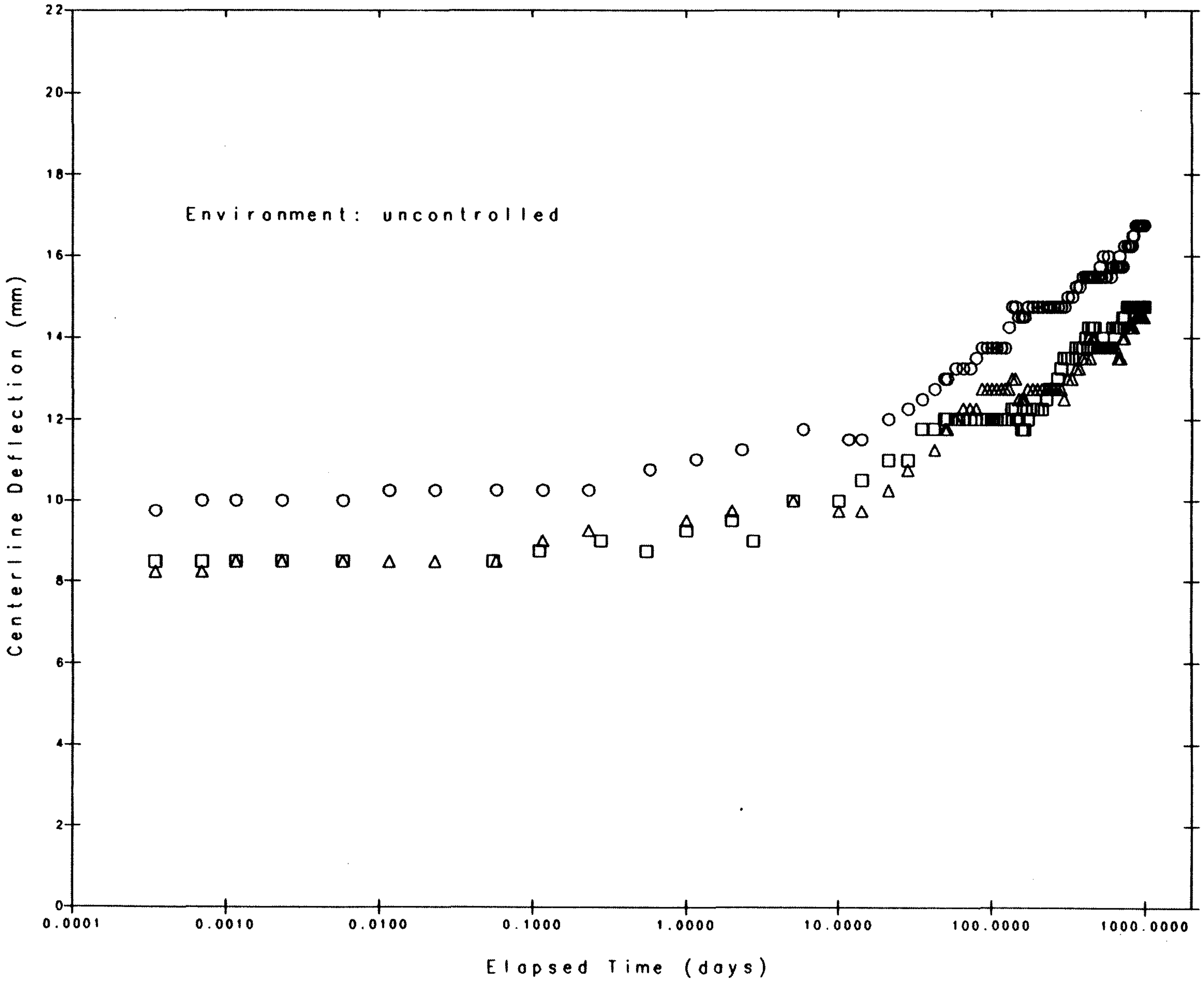


Figure A-9. Centreline deflection vs. time for 3 Spruce plywood faced stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

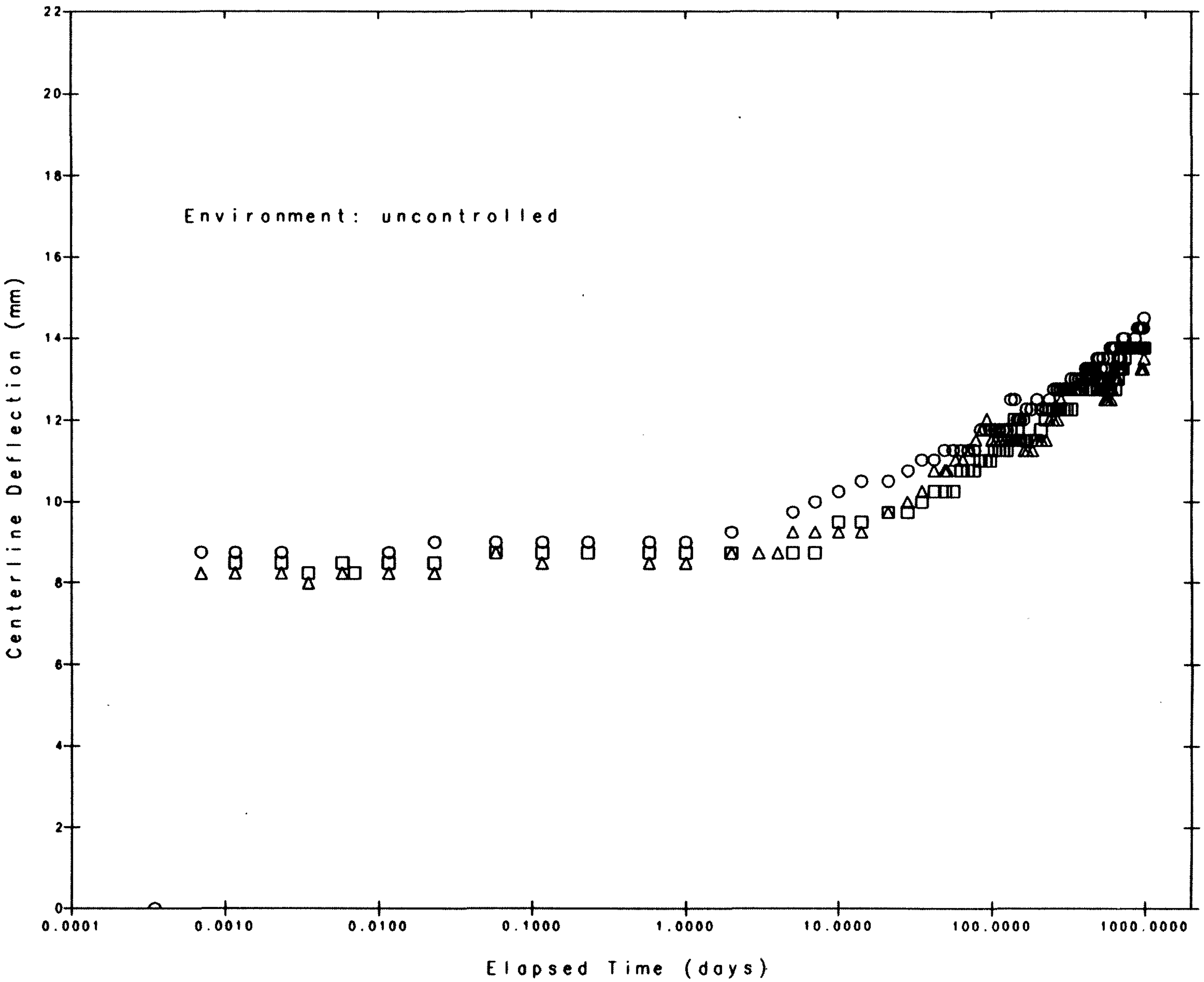


Figure A-10. Centreline deflection vs. time for 3 Douglas-fir plywood faced stressed skin panel subjected to equal sustained moments equivalent to 2 kPa U.D.L.

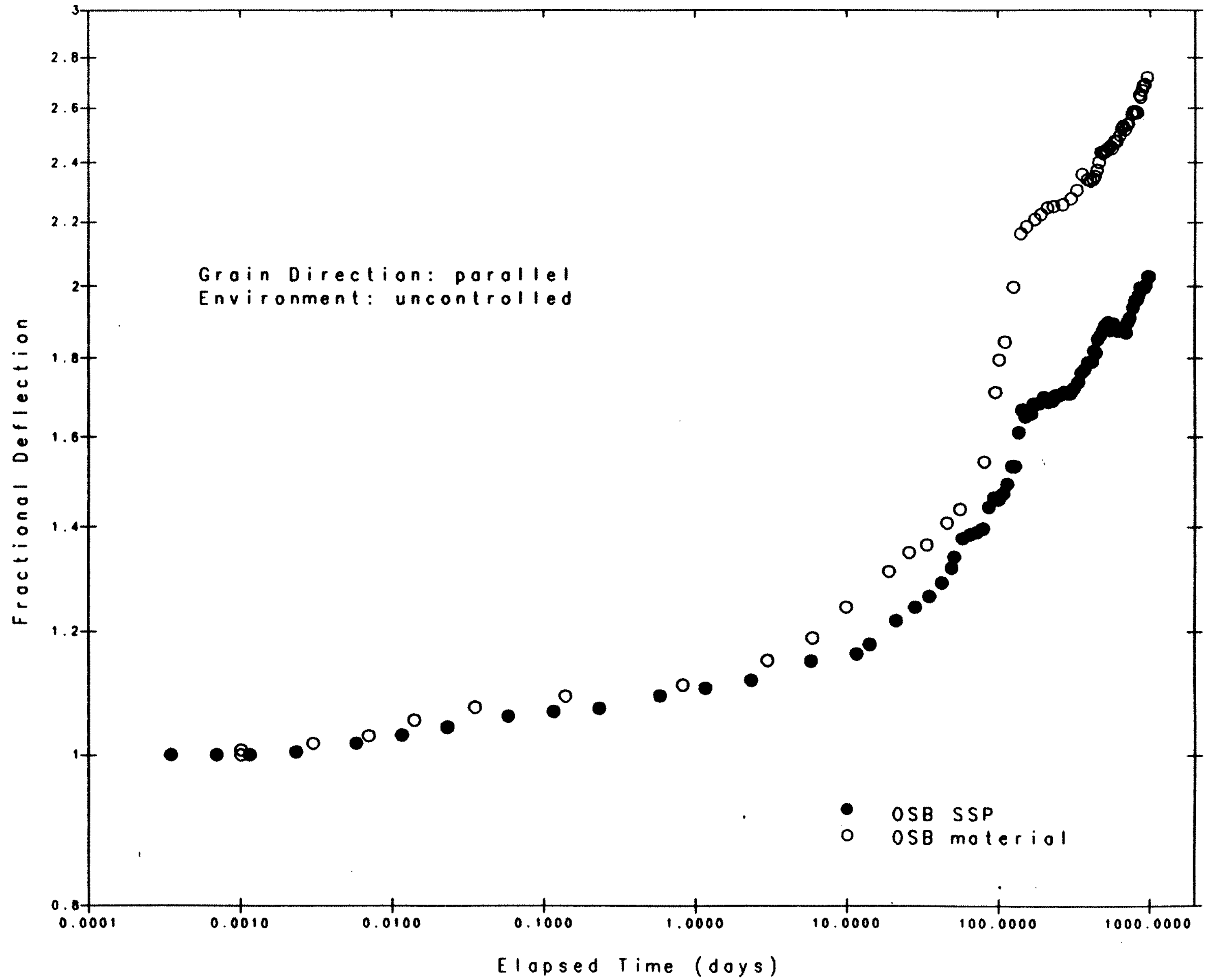


Figure A-11. Fractional flexure defelction creep for OSB faced SSPs and monolithic OSB samples.

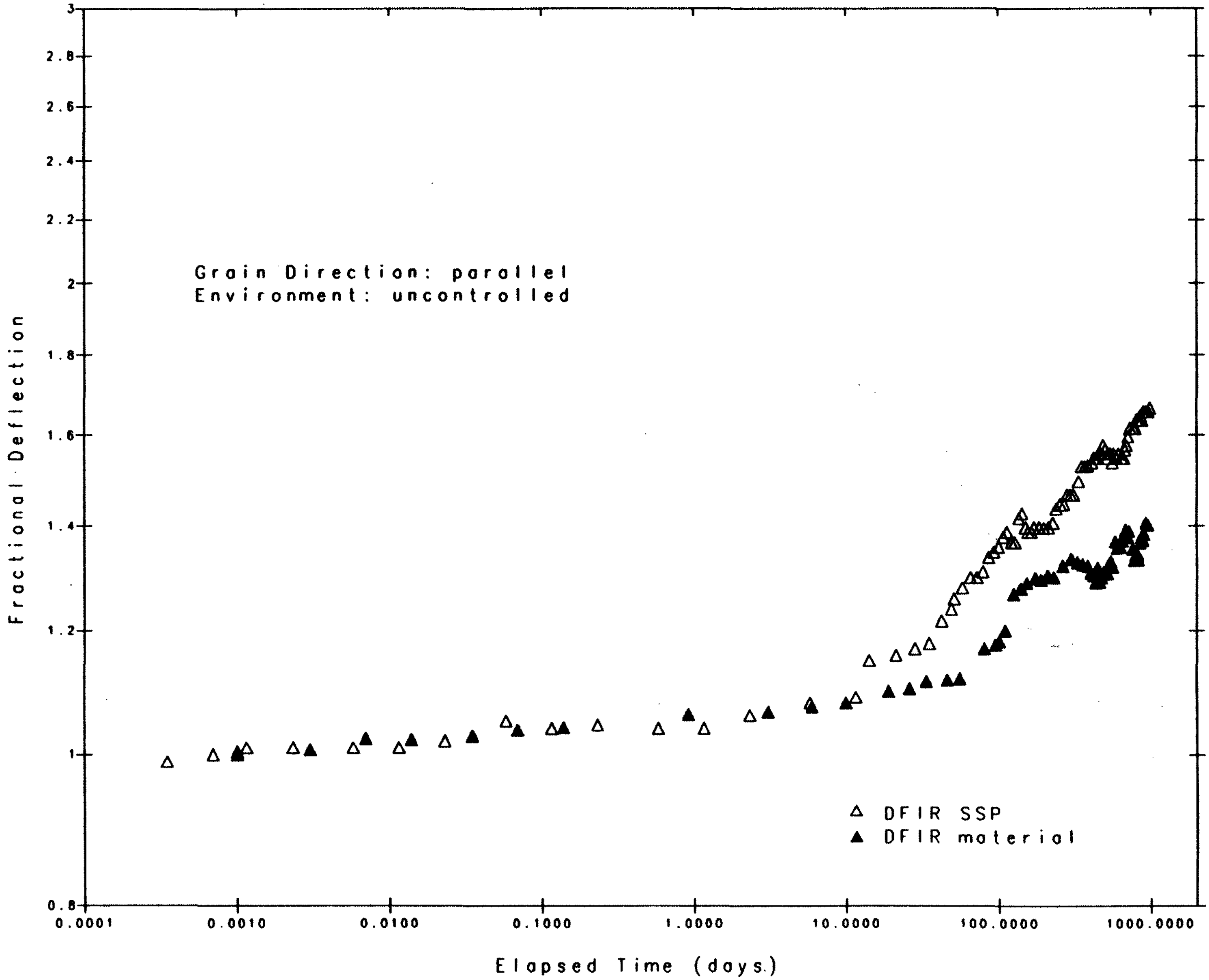


Figure A-12. Fractional flexure creep for Douglas fir faced SSPs and monothilic Douglas fir plywood samples.

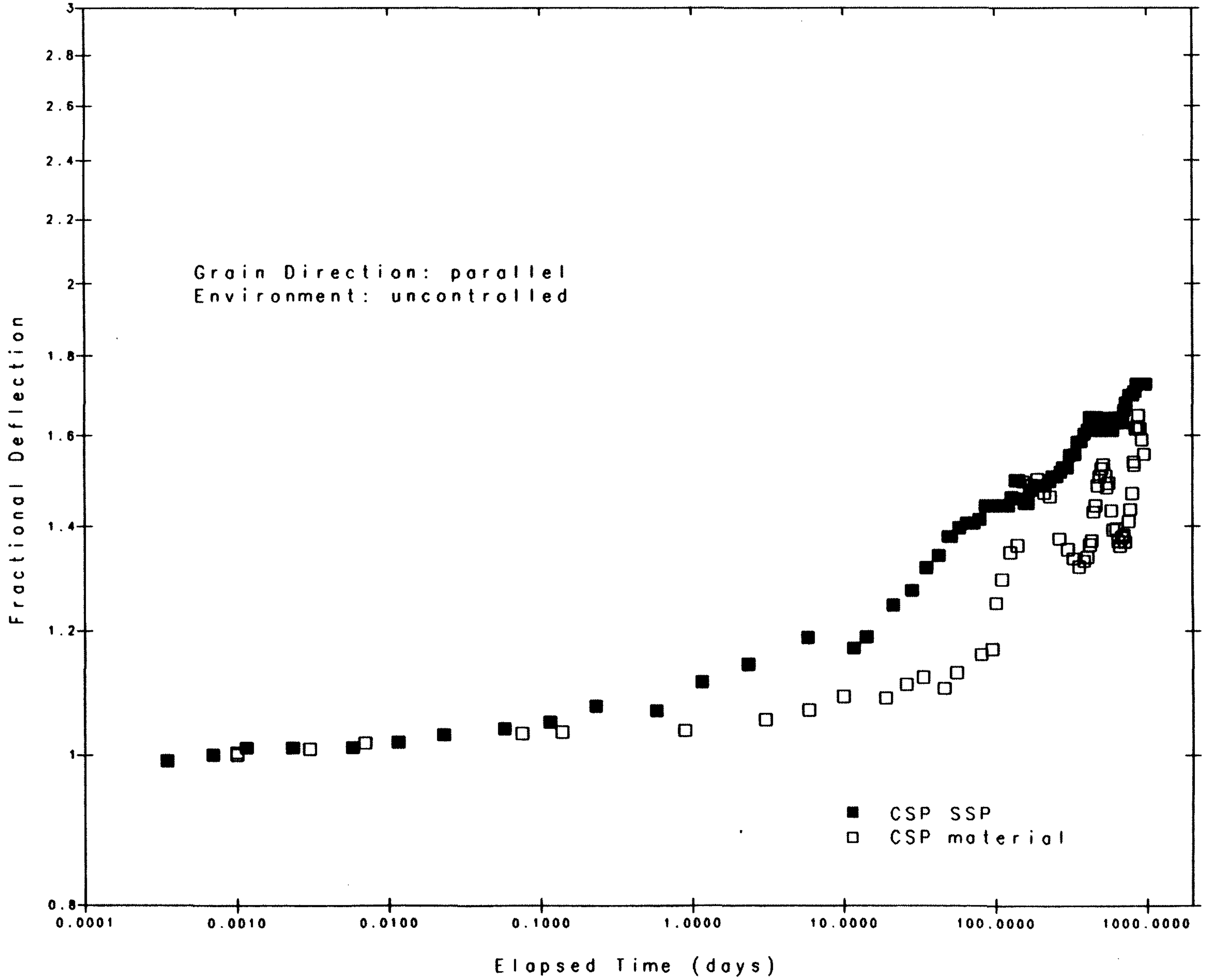


Figure A-13. Fractional flexure creep for CSP faced SSPs and monolithic CSP plywood samples.

Appendix B

Flexure Creep of Matched Samples of
the Constituent Materials Making Up the
Full Sized SSPs

Data: SSP - top skin = 15.5 mm (nominal) OSB

bottom skin = 9.5 (nominal) OSB

webs = 38 X 140 mm S-P-F Lumber

width = 1220 mm

top skin - t = 16.12 mm

E_b = 8483 MPa (based on I_{gross})

E_c = 5610 MPa (based on A_{gross})

b = 1220 mm

lumber web - t = 140 mm

E = 12138 MPa (same for uni-axial)

b = 38 mm

bottom skin - t = 9.67 mm

E_b = 8535 MPa (based on I_{gross})

E_t = 4330 MPa (based on A_{gross})

b = 1220 mm

Calculations based on E in bending

$$[1 - (1 - SR)^3] = 0.875 \quad (SR = 0.5)$$

top skin:

$$E_e = \frac{8483 \text{ MPa}}{0.875} = 9695 \text{ MPa}$$

A_e = 9833 mm2

I_e = 372633 mm^4

FD(400000) = 2.31 (flexural creep)

lumber web:

E = 12138 MPa

$$A = 38 \cdot 140 \cdot 4 = 21280 \text{ mm}^2$$

$$I = \frac{4 \cdot 38 \cdot 140^3}{12} = 347.6 \times 10^5 \text{ mm}^4$$

FD(400000) = 1.71 (flexural creep)

bottom skin:

$$E_e = \frac{8535 \text{ MPa}}{0.875} = 9754 \text{ MPa}$$

$$A_e = 5899 \text{ mm}^2$$

$$I_e = 80439 \text{ mm}^4$$

FD(400000) = 2.23 (flexural creep)

Neutral Axis Location

E	A	E · A	y	E · A · y
9695	9683	95.3 E6	157.73	150.4 E8
12138	21280	258.3 E6	79.67	205.8 E8
9754	5899	57.5 E6	4.84	2.78 E8
		Σ = 411.2 E6		Σ = 359.0 E8

N.A. = 87.3 mm

Flexural Stiffness

E	I	A	d	E (I=A d^2)
9695	372633	9833	70.42	476.36 E9
12138	347.6 E5	21280	7.64	436.99 E9
9754	80439	5899	82.47	392.08 E9

$EI_{elastic}$ = 1305.4-E9 Nmm^2

Neutral Axis Location @ 400000 minutes

Input values are identical to above except that the moduli values are reduced as follows:

$$E_{400000} = \frac{E_{elastic}}{FD(400000)}$$

∴ N.A. = 85.6 mm

Flexural Stiffness @ 400000 minutes

E_t	I	A	d	E (I=A d^2)
4197	372633	9833	72.13	216.28 E9
7098	347.6 E5	21280	5.93	252.04 E9
4374	80439	5899	80.76	168.65 E9

EI_{400000} = 637.0 E9 N-mm^2

Fractional Deflection of SSP @ 400000 minutes

$$FD\ (400000) = \frac{EIe}{EI_{400000}} = \frac{1305.4\ E9}{637.0\ E9}$$

$$= \underline{2.05}$$

compare above to the experimental result:

$$\text{difference} = \frac{2.05 - 1.71}{1.71} \cdot 100 = 19.8\ \%$$

Calculations based on uni-axial E

top skin:

E_c = 5610 MPa

A = 19666 mm^2

I = 425867 mm^4

lumber web:

E = 12138 MPa

A = 21280 mm^2

I = 347.6 E5 mm^4

bottom skin:

E_t = 4330 MPa

A = 11797 mm^2

$I = 91930\ mm^4$

Neutral Axis Location

E	A	E · A	y	E · A · y
5610	19666	110.3 E6	157.73	173.0 E8
12138	21280	258.3 E6	79.67	205.8 E8
4330	11797	51.1 E6	4.84	2.47 E8
		Σ = 419.7 E6		Σ = 382.3 E8

Flexural Stiffness

E	I	A	d	$E\ (I+A\ d^2)$
5610	425867	19666	66.64	492.34 E9
12138	347.6 E5	21280	11.42	455.60 E9
4330	91930	11797	86.26	380.48 E9

$EI_{elastic} = 1328.4\ E9\ N\text{-}mm^2$

Neutral Axis Location @ 400000 minutes

Input values are identical to above except that the moduli values are reduced as follows:

$$E_{400000} = \frac{E_{elastic}}{FD(400000)}$$

$\therefore$ N.A. = 88.8 mm

Flexural Stiffness @ 400000 minutes

E_t	I	A	d	$E\ (I+A\ d^2)$
2429	425867	19666	68.96	228.21 E9
7098	347.6 E5	21280	9.1	259.24 E9
1942	91930	11797	83.93	161.56 E9

$EI_{400000} = 649.0\ E9\ N\text{-}mm^2$

Fractional Deflection of SSP @ 400000 minutes

$$FD(400000) = \frac{1328.4\ E9}{649.0\ E9}$$

$$= \underline{2.05}$$

compare above to the experimental result:

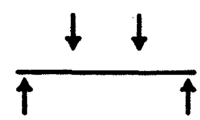
$$\text{difference} = \frac{2.05 - 1.71}{1.71} \cdot 100 = 19.8\ \%$$

Now having calculated the fractional behaviour of the SSP from the material component behaviour (or by direct experiment) the actual deflection of any SSP can be calculated.

Centerline Deflection:

$$\Delta(t) = \frac{P}{\sum_{i=1}^{n} \frac{K_i}{FD_i(t)}}$$

where P = Two equal conc. loads symetrically placed



n = number of components

$$\Delta_{mm} = \frac{Pa(3L^2-4a^2)}{24EI}$$

K_i = spring constant of the web, top or bottom skin

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

I_t = transformed moment of inertia

L = span of beam

a = moment arm

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