THE INFLUENCE OF MEMBER STIFFNESS AND MOISTURE CONTENT HISTORY ON THE DEFLECTION BEHAVIOR OF A TRUSS FASTENED WITH METAL PLATES

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ABSTRACT

THE INFLUENCE OF MEMBER STIFFNESS AND MOISTURE CONTENT HISTORY ON THE DEFLECTION BEHAVIOR OF A TRUSS FASTENED WITH METAL PLATES

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In this investigation, fifty-three full scale wood trusses were tested to determine the effects of individual member stiffness or EI and moisture content history on truss deflection behavior. The trusses were fabricated from two lumber species and three kinds of metal plate fasteners.

Statistical significance among variables was not found because of individual small sample size, small degrees of freedom and scatter. However, the following averages and consistent trends were observed.

Average midspan truss deflections, without regard for EI and moisture content history, were found for the two lumber species groups and for the three plate type subgroups.

EI designation of a truss refers to the average of the individual member EI values which were determined by nondestructive testing. The midspan deflections of trusses with various EI averages were compared. It was found that average EI inversely affected truss deflection; as EI increased, deflection decreased.

The influence of moisture content involved two series. In Series I there was no change in truss moisture content from fabrication to test, while in Series II the assembled truss dried from a higher moisture content at fabrication prior to testing. It was found that moisture content in either Series I or Series II had only a minor effect on deflection and no determinable effect on creep behavior characteristics.

It was found in this investigation that a lower chord load exhibited a more substantial influence on truss deflection than a comparable upper chord load.

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INTRODUCTION

The utilization of wood trussed rafters in light construction has vastly increased in the last decade. Initially, wood trusses were fastened with nail-glued plywood gussets but their acceptance by industry was slow due to the awkward and time consuming gluing process. However, with the introduction of stamped metal plate fasteners, efficient production line assembly was made possible. The metal plate truss became highly competitive and rapidly replaced the conventional rafter and joist system in roof framing.

Thus the advantages of wood trusses were finally realized. Some of the important advantages are: (1) elimination of interior load bearing partitions (2) rapid enclosure of the building and (3) extension of spacing made possible by the increased stiffness of a wood truss.

However, the metal plate fastened truss also created problems of structural design to the engineer and architect. The problem was complex, requiring a comprehensive knowledge of mechanically fastened wood joints. Initially, designers employed elementary engineering design principles requiring several simplifying assumptions such as; pin connected joints, no moisture content influence, minor duration of load factors and direct relation of member stiffness to truss stiffness.

Research has shown that some of these assumptions are invalid. However, little is known about the influence of moisture content, lower chord loading and member stiffness on truss deflection.

CHAPTER I

REVIEW OF LITERATURE

In the last twenty years, a great deal of research has been done on the behavior of light wood trusses. Much of this work has been in testing full scale trusses of many designs under simulated design loads to ascertain the performance of these structures as related to acceptance criteria of codes and performance specifications. A large segment of such research has been done by truss manufacturing companies in order to qualify their designs for acceptance or as part of their development effort. These technical results have not been published.

Universities, the U. S. Forest Products Laboratory, and other research institutions have conducted research of full scale trusses to determine load-deflection and ultimate strength of trusses of many designs (10, 14, 17, 19).* In these cases little rigid control was made in regard to moisture content history and individual member EI. Very often this research involved comparing the performance of different fastening systems in full scale truss tests (14, 17, 19, 20).

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*Underlined numbers in parenthesis refer to literature cited at the end of this thesis.

Some effort was directed toward the behavior of the trusses when subjected to various atmospheric conditions particularly the influences of low and high humidity and moisture content history on overall truss stiffness (10, 14, 20). Glued plywood gusset trusses in Luxford's study (10) showed some loss in stiffness and considerable loss in maximum strength when subjected to cycles of high and low humidity. Luxford found that nailed plywood gusset trusses were less affected. Mechanically fastened trusses in research conducted by Stein and Stoneburner (20), exhibited a decrease in stiffness when fabricated wet and tested after drying. Radcliffe and Sliker (14) found similar results with nail-on metal plate and stamped plate fasteners, however their nailed-glued plywood gusset trusses were not affected by a moisture content change prior to test.

The individual investigations described above cannot be compared because the fastening systems, gussets and geometries were not the same. The results were generally inconclusive because the number of trusses in each case was small, or the research was restricted to one moisture content change.

Research on the effects of cyclic loading and the nature of creep was also conducted by Sliker and Radcliffe (14, 15) in full scale tests. Creep, or the increase in deflection under a constant load, was discovered in this

study to be pronounced for trusses fastened by nail-on metal plates and stamped metal plates. In this investigation, creep behavior was found to follow definite mathematical expressions relating deflection, load and time.

Besides the full scale tests mentioned above, numerous tests were made on the load-deflection performances of individual joints. Many fastening systems were compared and evaluated for design purposes (5, 6, 18, 20). However, little research was conducted on the many possible variables affecting joint behavior. Longworth and McMullin (9) researched the effect of moisture content on the strength of bolted timber connectors on heavy joints. In this investigation it was found that the proportional limit load of the bolted joint decreased with increased moisture content and a seasoned joint also showed a decrease. Creep in nailed joints was investigated by Mack (11). Mack's results indicated that total relative displacement after prolonged loading may be considerably larger than the displacement immediately after loading. The results also demonstrated that the rate of drying may have some effect on the creep rate.

Effort was made to structurally analyze and design wood trusses fastened with a number of different connectors. Empirical, theoretical and a combination of empirical-theoretical approaches were attempted. Originally, the structure analysis of a truss consisted of determining the primary stresses in the members where the joints were assumed to be smooth pins. This was found to be inadequate because the joints were often far from a pinned condition. Assuming the joints rigid or semi-rigid made the truss statically indeterminate to a high degree. Early research on the highly indeterminate structure utilized electrical resistance strain gages to empirically measure the forces and moments in each member (12, 13). The forces and moments were subsequently used to analyze the connectors. Structural analysis of the indeterminate truss later involved strictly theoretical methods such as slope-deflection and energy methods (21, 22).

Thorough research has been conducted on the creep characteristics, influence of duration of load, and the effect of moisture content on wood (1, 4, 7, 24). Specifications have been written for light metal plate trusses (3) and for the lumber (1).

CHAPTER II

PURPOSE

The purpose of this investigation was to determine the influences of individual member stiffness and moisture content upon truss deflection behavior. The wood trusses were fabricated with three different metal plate types and two lumber species.

The influence of moisture content was classified into: (1) the influence of a base moisture content (trusses fabricated and tested at the same moisture content) and (2) the influence of a change in moisture content where the trusses were tested after they had dried from a higher base moisture content.

CHAPTER III

DESCRIPTION OF MATERIALS, TEST APPARATUS AND TEST METHOD

General

A total of fifty-three full size twenty-six foot span wood roof trusses were fabricated and tested in this research. The trusses were stratified into eight categories based on the variables involved. The variables included lumber species, type of metal plate fastener, moisture content of lumber at manufacture, moisture content at time of test loading, and the stiffness factor EI (modulus of elasticity x moment of inertia) of 2 x 4 members. The trusses were fabricated with two lumber species and three types of metal plate fasteners. Trusses in Group I had West Coast hemlock nominal 2 x 4 lumber members and nail-on-plate fasteners. The members of Group II were Douglas fir. Three types of metal plate fasteners were used in Group II; (A) nail-on plates as in Group I, (B) plates with punched triangular teeth and (C) plates with punched rectangular prongs.

The lumber was carefully conditioned before and after fabrication of trusses to predetermined levels of moisture content. Two series for each group and plate type describe the moisture content histories. Series I trusses were fabricated and tested at the same moisture content. The trusses of Series II were manufactured with lumber at several levels of moisture content and tested after the trusses were dried to a lower base moisture content.

Specimen Coding

In order to simplify the identification as to lumber species, plate type, stiffness factor and moisture content history of each truss, a coding system was necessary. The following is an example of the six element code used: DF-C-11.6-F13.9-T9.0-11. In this specific example, each element (separated by dashes) would have the following meaning:

- DF - species, Douglas fir
- C - plate type, punched rectangular teeth
- 11.6 - average value of stiffness of lumber, EI in pound inches^2 units x 10^6
- F 13.9 - moisture content of 13.9% at fabrication (denoted by F)
- T 9.0 - moisture content at test (T) of 9.0%
- 11 - truss number for Group, plate type and Series specified

This code designation will be used throughout this paper. The species in this study were either WCH (WC Hemlock) or DF (Douglas fir). Three plate types, A, B, and C were used. These are described in detail in Joint Fasteners.

Geometry of Trusses

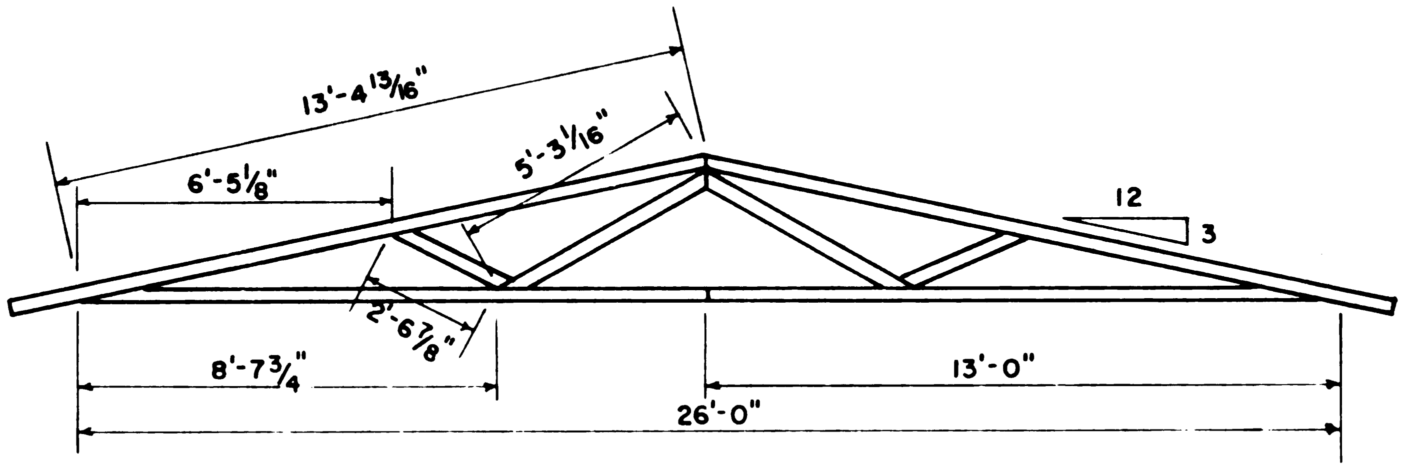
All trusses were W-type with a span of 26 feet and a slope of 3 in 12. The geometry details for trusses of Group I (West Coast hemlock) is shown in Figure 1. This was the original geometry suggested in the UNICOM system of NLMA (2). All chord and web members of Group I were of West Coast hemlock. Only the nail-on (type A described below) metal plate was used for the connections of trusses in this group.

Group II trusses had members of Douglas fir and was comprised of subgroups with all three types of metal plate fasteners. As shown in Figure 1, slight changes were made for the Douglas fir trusses of Group II. The tension diagonal had a double cut at the peak and the tension splice in the lower chord was off-set one foot. These minor changes were made to conform to specifications suggested by the cooperating plate manufacturers. All end cuts of members for both groups were made at proper angles to insure tight fitting joints.

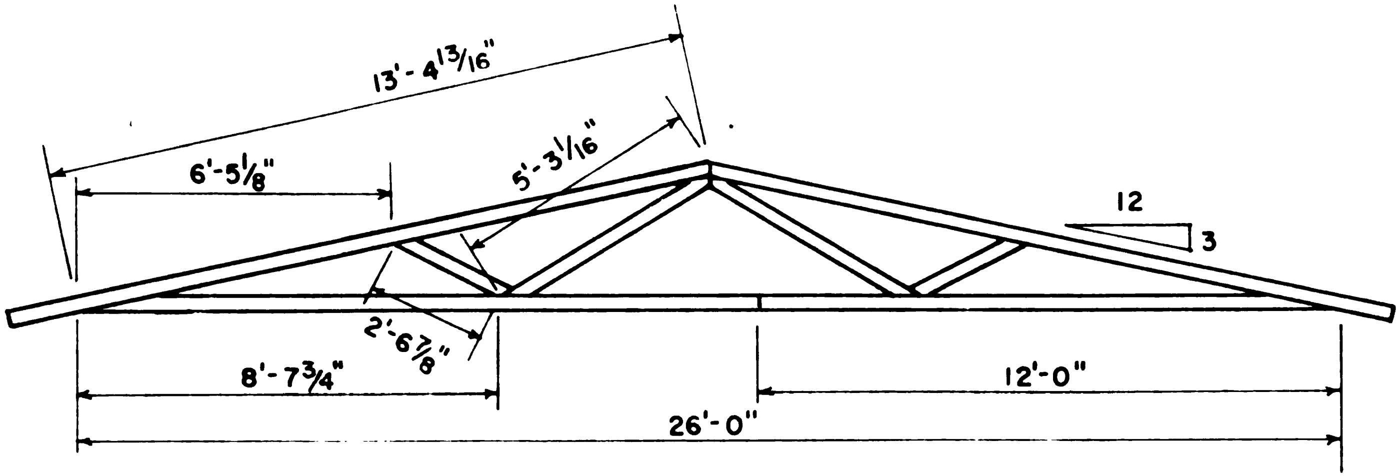
Selection of Lumber

All chord and diagonal members of trusses in Group I were of clear West Coast hemlock [<u>Tsuga heterophylla</u> (Raf) Sarg.]. This nominal 2 x 4 lumber was free of defects other than compression wood.

The Douglas fir [<u>Pseudotsugo menziesii</u> (Mirb.) Franco] nominal 2 x 4 lumber of Group II trusses was 1500f



W.C. HEMLOCK GROUP



DOUGLAS FIR GROUP

FIGURE 1

GEOMETRIES OF TRUSS GROUPS

Industrial Light Framing grade. Knots, wane and other defects typical of this grade were present.

All of the lumber was non-destrictively tested to determine stiffness factor in bending, EI (the modulus of elasticity times the moment of inertia). The test method used is shown in Figure 2. Each 2 x 4 was simply supported on reactions spaced 8 feet o.c. The nominal four inch dimension was the bean depth. Load was applied at midspan by means of a hydraulic cylinder. Deflections at midspan were measured by an Ames dial gage with a .001 inch sensitivity. The stiffness factor EI was computed as (23):

$$EI = \frac{PL^3}{48\Delta} \text{ lb. in}^2 \qquad (1)$$

In equation (1), P represented a load difference of 200 lbs. An initial load of 100 lbs. was placed on the beam to insure that any slack was taken up in the system. The deflection at this load was assumed as zero. The hydraulic piston load was then increased to 300 lbs. and the midspan deflection was read from the dial gage to the nearest 0.001 inch. Thus Δ in equation (1) referred to the deflection difference corresponding to the 200 lb. load increment.

From a number of preliminary tests, it was determined that load-deflection behavior was linear and that the proportional limit stress was not exceeded for the 100 to 300 lb. range of load used for both species.

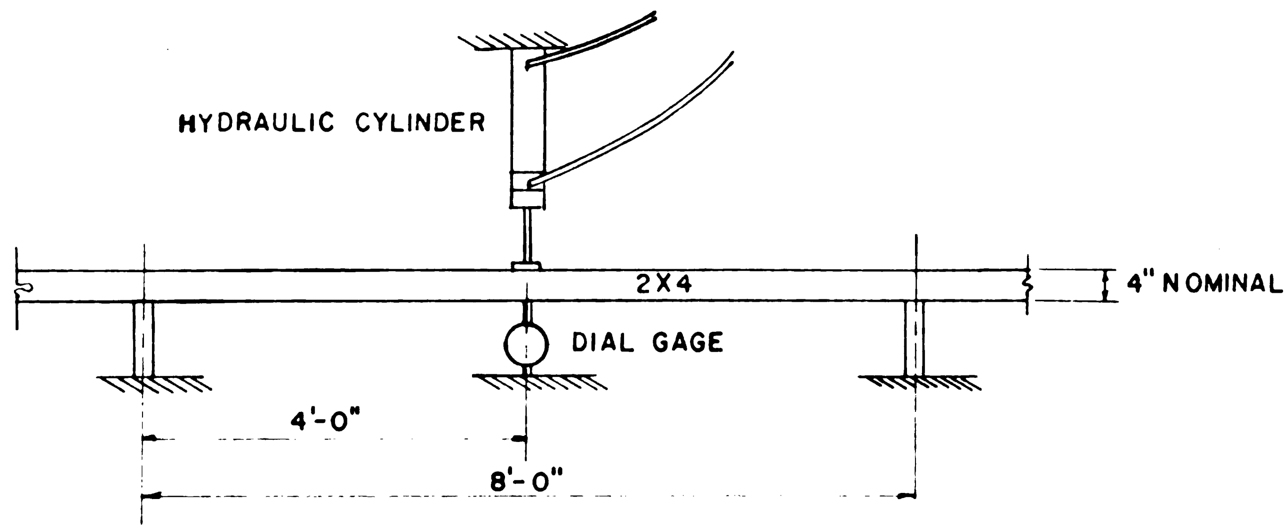


FIGURE 2

NONDESTRUCTIVE TEST APPARATUS

The effect of shear on deflection was neglected since it would be negligible for the span-depth ratio of this case.

The lumber was accepted within a total EI range of 10×10^6 to 18×10^6 lbs-in^2. The EI range of pieces in any particular truss was limited to a 3×10^6 lbs-in^2 EI category. The EI for each truss given in Table 1 was the average of the EI values for all chord and diagonal members in each truss.

Moisture Conditioning

The moisture content of the precut lumber at the time of truss fabrication and the moisture content of the assembled trusses at the time of test were carefully controlled to predesignated levels. The detail of moisture content will be further discussed under Test Procedure.

Within each species group and for each plate type series, trusses were manufactured and tested at four levels of moisture content. For each level, a number of trusses were manufactured, some to be tested immediately at that moisture content and others to be conditioned to a lower base moisture content of ten per cent prior to testing.

The general procedure of conditioning was as follows. After the lumber was non-destructively tested to establish EI and precut, it was placed in a standard kiln where it was conditioned to various moisture content levels. For each moisture content level, the lumber remained in the

TABLE 1.--Truss variables.

Douglas Fir Group				
Plate Type	Average E.I.	Fabrication Moisture Content	Test Moisture Content	Number
A	12.3	24.0	9.5	1
A	10.8	24.0	9.8	2
A	11.4	20.4	9.9	3
A	15.9	20.4	10.4	4
A	13.1	13.3	9.6	5
A	12.8	24.0	24.0	6
A	13.1	20.4	20.4	7
A	14.6	20.4	20.4	8
A	13.4	13.5	13.5	9
A	11.6	13.0	13.0	10
A	14.9	9.9	9.9	11
A	12.8	10.5	10.5	12
B	11.1	24.0	10.4	1
B	11.5	24.0	10.4	2
B	13.8	18.0	9.9	3
B	12.8	18.0	8.9	4
B	11.0	13.7	9.9	5
B	15.5	12.6	10.8	6
B	16.3	13.6	9.2	7
B	11.6	24.0	24.0	8
B	14.6	24.0	24.0	9
B	15.4	13.7	13.7	10
B	12.9	13.3	13.3	11
B	13.4	13.7	13.7	12
B	12.9	10.1	10.1	13
C	16.0	24.0	9.5	1
C	13.0	24.0	10.4	2
C	12.5	18.4	9.8	3
C	15.3	18.4	9.8	4
C	12.1	13.9	10.9	5
C	11.6	13.9	9.0	6
C	13.0	24.0	24.0	7
C	12.1	24.0	24.0	8
C	12.0	18.4	18.4	9
C	12.3	13.9	13.9	10
C	16.4	10.3	10.3	11
C	10.9	10.9	10.9	12
C	10.8	10.3	10.3	14
C	10.8	10.3	10.3	14

TABLE 1.--Continued

West Coast Hemlock Group				
Plate Type	Average E.I.	Fabrication Moisture Content	Test Moisture Content	Number
A	16.5	20.0	9.5	1
A	15.4	20.0	9.5	2
A	15.5	18.5	9.9	3
A	14.9	18.5	9.8	4
A	13.9	13.1	10.1	5
A	13.3	13.1	8.7	6
A	13.0	7.5	7.5	7
A	16.9	20.0	20.0	8
A	14.8	18.5	18.5	9
A	14.0	13.1	13.1	10
A	14.4	10.6	10.6	11
A	14.3	10.4	10.4	12

kiln until moisture gradient disappeared and the desired equilibrium moisture content level was attained. A continuous record of the moisture content of the lumber was made during the conditioning period by means of electric probes connected to a moisture detector-recorder device. Moisture content readings were made twice daily during the conditioning periods.

When a predetermined level was reached, the moisture gradient was checked. The check consisted of taking two 0.5 inch deep slices from control pieces of 2.4 for each of the two species. See Figure 3. The two slices were cut at least 12 inches from the end of the control piece. The moisture content of each of the slices was determined by the oven dry method. When the moisture content of the two 0.5 inch slices were the same and at the equilibrium level, the appropriately matched wood members for a particular truss were removed from the kiln for immediate fabrication.

Joint Fasteners

A detailed description of the three metal plate types used is given in Table 2. Photographs of the plates are shown in Figures 4, 5, and 6. All plates were galvanized steel with the thicknesses given in Table 2.

The dimensions and placement of type A plates are shown in Figure 7. In this case, the plates fastened a

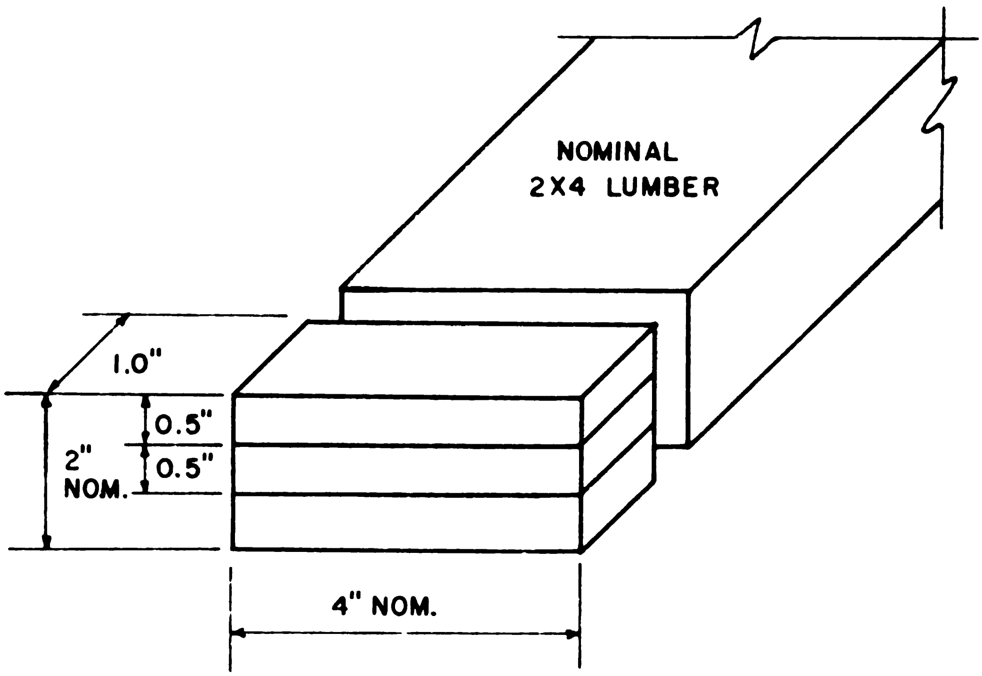


FIGURE 3

MOISTURE GRADIENT SAMPLE

TABLE 2.--Description of plast fasteners.

Truss Type	Plate Material and Thickness	Fastening Device	Description
A	Steel sheet .040 inches	Square, barbed nails diam. = 0.125 inches length = 1.5 inches	1" by 5/8" spacing through punched holes
B	Corrugated steel sheet .040 inches	Triangular, hooked prongs	3/8" teeth length spaced 1" by 1" o.c.
C	Steel sheet .040 inches	Rectangular teeth	3/8" teeth length spaced 3/4" by 3/8" o.c.

Figure 4. Plate Type A.

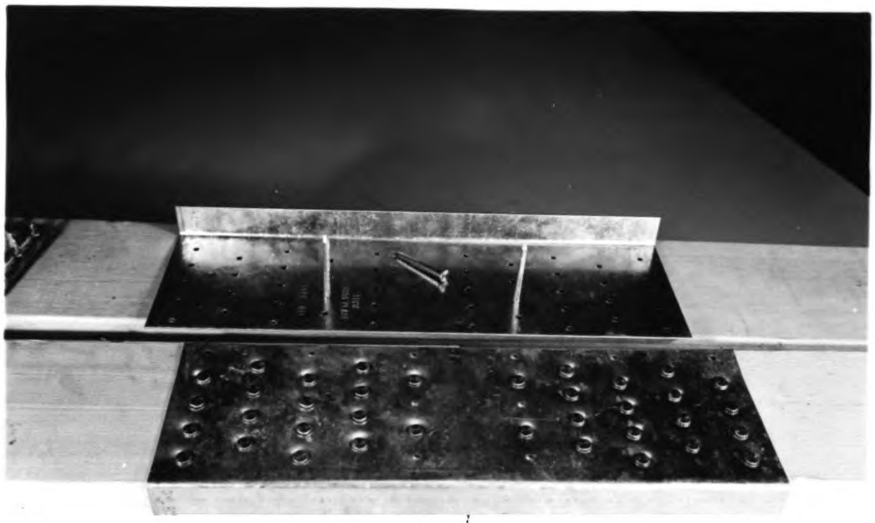


Figure 5. Plate Type B

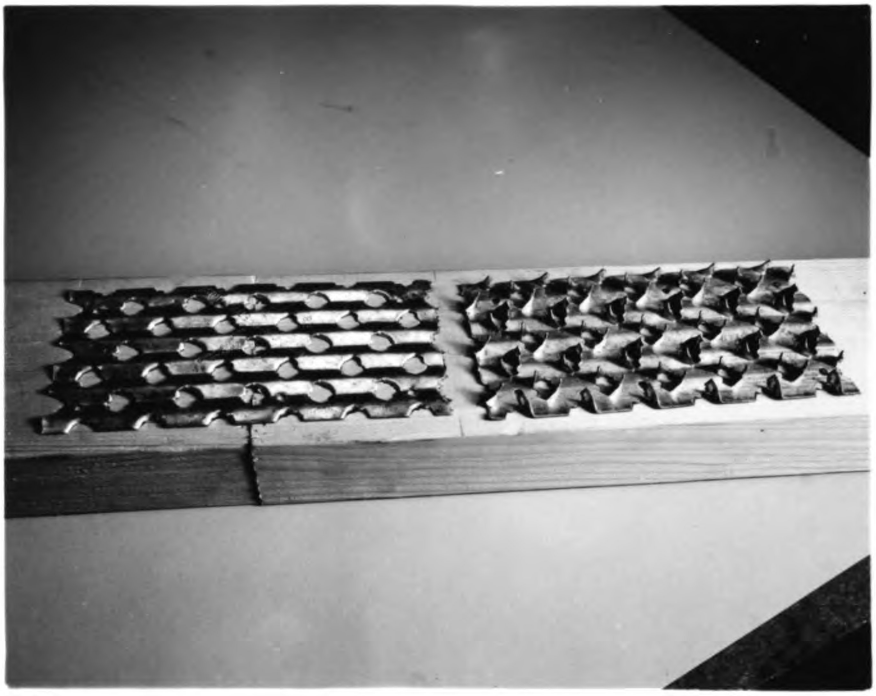
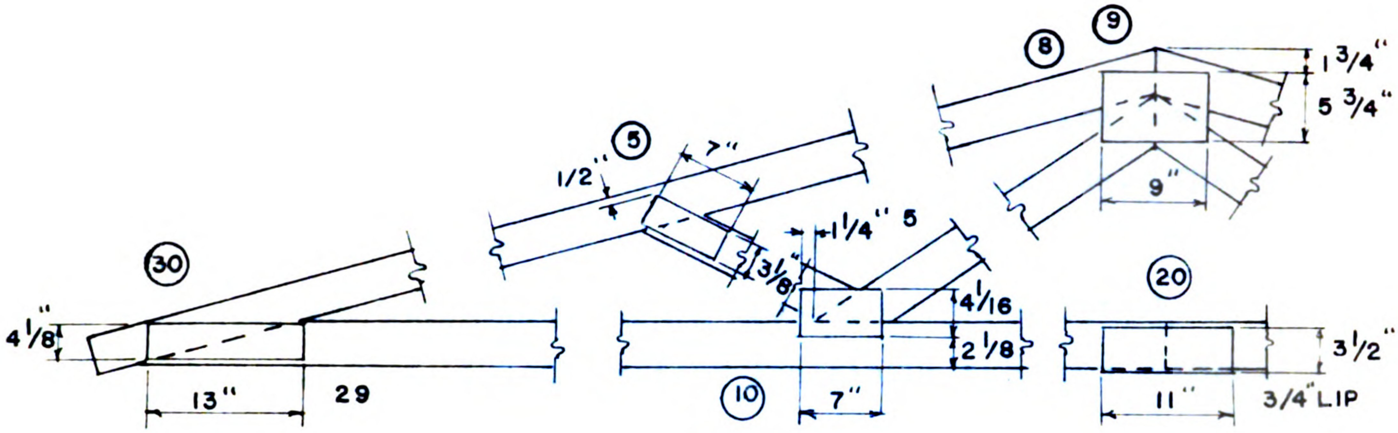
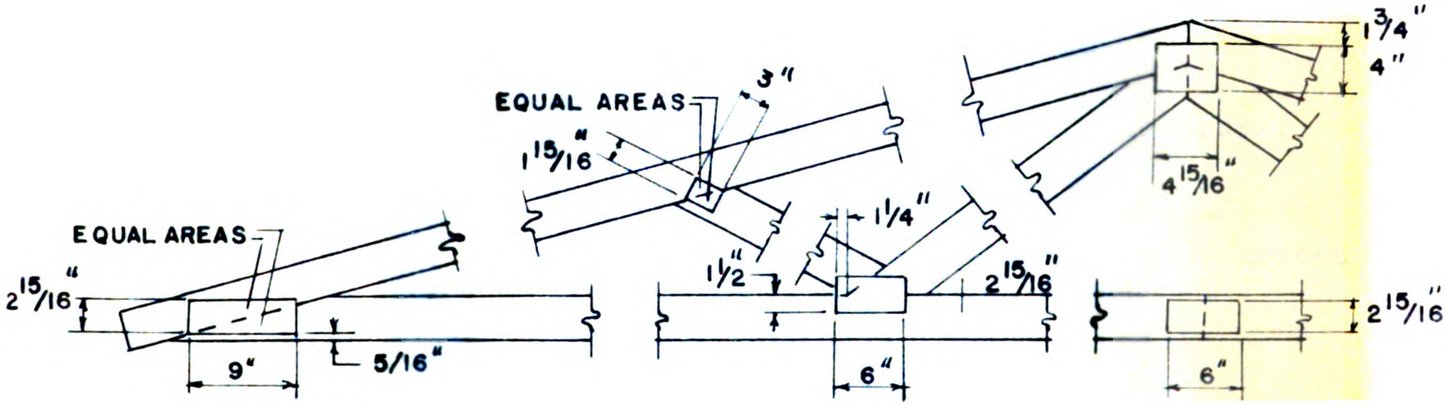


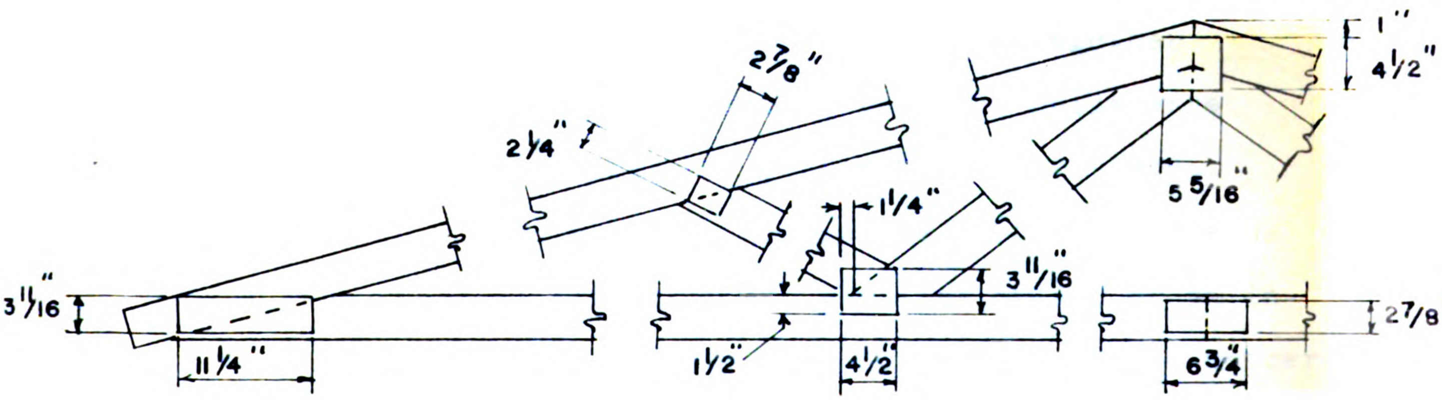
Figure 6. Plate Type C.



TYPE A – W.C. HEMLOCK GROUP



TYPE B – DOUGLAS FIR GROUP



TYPE C – DOUGLAS FIR GROUP

FIGURE 7

SIZE AND POSITION OF PLATES ON TRUSSES

West Coast hemlock truss (Group I). The same plates were utilized on Douglas fir trusses (Group II). Notice that the tension splice plate has a lip on the underside. The circled number refers to the quentity of nails in the member. Square-barbed nails, 1.5 inch long and .125 inch in thickness, fastened the type A plate to the wood member. The type of special nails used may be seen in Figure 4.

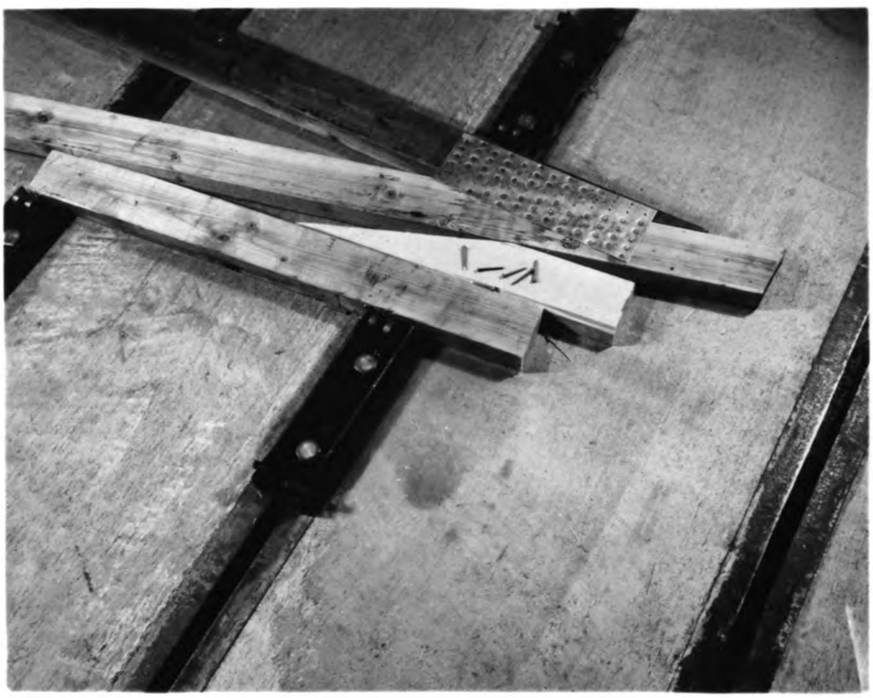
Figure 7 also shows the location and size of type B and C plates, respectively, on a Group II truss. The type B peak plate had eight .75 inch long presetting teeth besides the triangular prongs given in Table 2. In all cases, the plates were applied to both sides of the truss.

The complete calssification of all trusses, as to species, plate type and moisture content history is presented in Table 1.

Fabrication

All the nail-on plates (type A) were fabricated in a jig to insure consistent geometry. The jig was arranged so that the heel joint member could be held together tightly during the nailing (Figure 8). The nails were hand driven so as to draw the plate tight to the wood. Type B and C plates were applied by the cooperating manufacturers who used a flat press, a roller press, or an individual joint press to fasten the plate to the wood members. In some cases, the plates were secured with a flat press followed by a roller press operation on the assembled truss.

Figure 8. Heel joint in fabrication jig with Type A plates.



In all the fabrication methods, the plates were carefully positioned according to the manufacturer's recommendations. A number of the stamped plate trusses were manufactured in Detroit, Michigan. In those cases, the kiln-conditioned, precut lumber was wrapped in polyethylene for shipment. The manufactured trusses were also wrapped for their return shipment to Michigan State University. The wrapping was to prevent change in moisture content during the shipments.

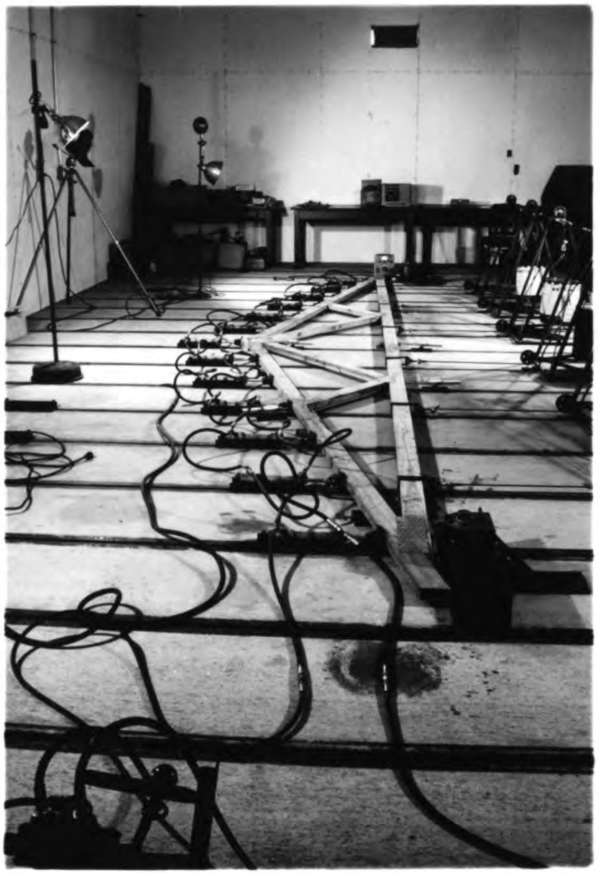
Test Apparatus

The full scale trusses were tested horizontally on a steel reinforced concrete slab (Figure 9). The test floor had steel channels spaced two feet on center which provided the means for attaching reactions and load apparatus to the floor. The two reactions permitted free rotation but restricted translation of the truss. The truss was supported from the floor by plate and roller bearings which prevented frictional resistance from the floor, thereby allowing free deflection in the plane of loading.

Dead load was applied to the lower chord through a system of pulleys and weights. The six weights were attached to the lower chord with U-brackets.

A hydraulic system provided the variable live load on the upper chords. Hydraulic cylinders were fastened to the floor on two feet centers. As the pistons extended, they applied a load perpendicular to a line drawn through the reaction points. A hydraulic constant speed gear pump

Figure 9. Full scale truss on test floor.



provided the pressure while a two-way bypass valve was used to control pressure. The system allowed the pistons to follow creep deflection with a given valve setting. The cylinders had been previously calibrated individually in a universal testing machine. Load versus pressure calibration curves were plotted.

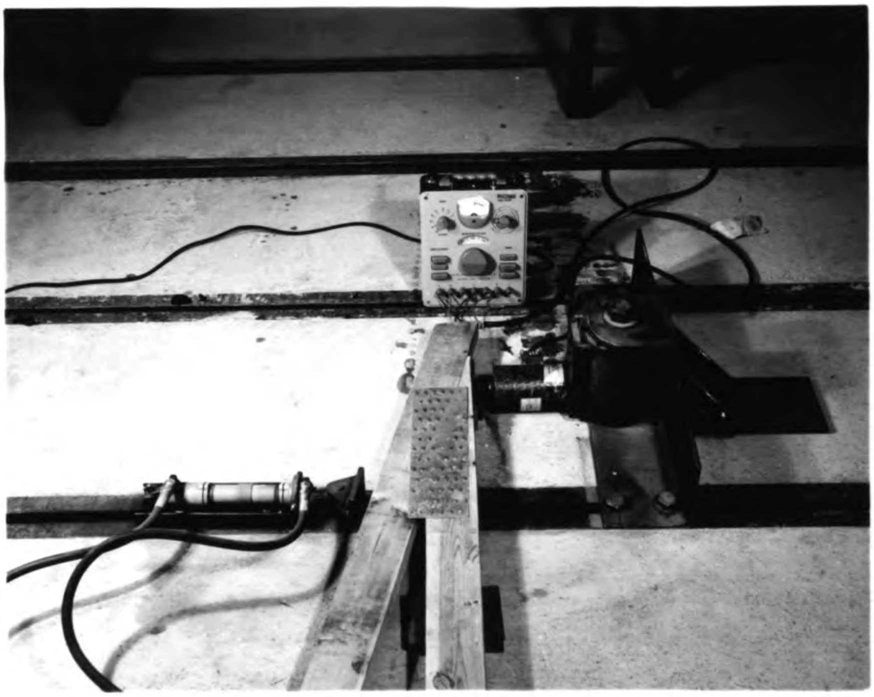
Pressure in the system was read from a pressure gage interposed in the line. The live load, in plf on the upper chord, was determined by the gage pressure and the calibration curves. The accuracy and stability of the load system was checked by means of an electronic load cell and strain indicator (Figure 10).

Figure 11 shows the four locations of the dial gages which measured the displacement at these positions for each truss.

Time during test loading was measured by means of stopwatches to the nearest 0.01 minutes.

The temperature and humidity of the test room were maintained at approximately 80° F and 40% r.h. Since each test duration was less than one hour, no moisture content change of any consequence took place in the truss lumber regardless of moisture content level. This was verified by a moisture content test specimen cut from each truss after testing.

Figure 10. Load cell and strain indicator at end reaction.



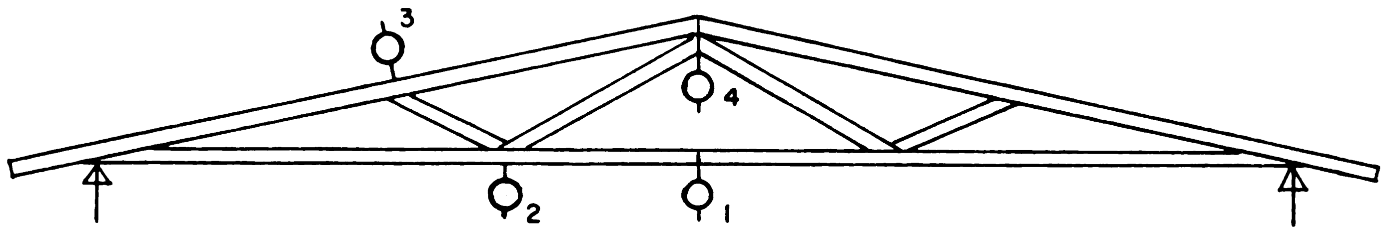


FIGURE II

LOCATION OF DIAL GAGES

Test Procedure

After each truss was carefully positioned on the test floor, as described before, and the dial gages were properly positioned, a load of 20 plf (subject to calibration curve correction) was applied to the upper chords. When dial gages indicated all movement due to the removal of slack and any creep had stopped, a deflection recording was made at each dial gage location. Then the constant 20 plf. lower chord load was applied by the pulley system described. As in the case above, the deflections at the four points were recorded after all creep had stopped. These measurements were the datum "zero" for each respective gage.

The 20 plf. incremental increases in load were accomplished as follows. The load on the upper chords was increased to 40 plf. As soon as this load was reached, the deflection at midspan was recorded. One-tenth of a minute later, another reading was taken at midspan. Deflection readings were subsequently taken at .02 minute intervals until no change in the deflection reading occurred for three successive readings. This deflection-time point was arbitrarily defined as the "creep limit." After the "creep limit" was attained, the deflections at the three other points were recorded. During the entire period the 40 plf. load was maintained constant.

The upper chord load was then increased by increments of 20 plf. For each measured load level the procedure described above was followed.

The dial gages were removed after the 200 plf. readings were taken. The first few trusses were then loaded to ultimate failure and the nature of the failure was carefully noted, as well as the load that caused it. However, the loading to ultimate failure was discontinued as the hydraulic cylinders were occasionally damaged at the higher loads. In some cases, truss failure appeared evident before a 200 plf. load was reached.

Deflections for each of the four dial gages were recorded in the manner described above. However, this investigation utilized only the midspan deflection (dial gage 1).

A detailed procedure was followed in sequencing each full scale truss test because of the control exercised on a truss's moisture content history. At each moisture content level, three trusses of the West Coast hemlock series were fabricated. One truss was tested immediately, while the other two were dried upright in a large polyethylene enclosure to an approximate ten per cent moisture content. While in the enclosure, the trusses were dried by forced warm air and dehumidification. The approximate moisture content was periodically checked by an electrical resistance moisture meter. In the Douglas fir series, four trusses were fabricated at each level. Two were promptly tested, while the remaining two were dried as in the Hemlock series. The quantity of trusses actually used varied from this description because a number of the trusses failed to meet the specifications, regarding the quality of manufacture.

Immediately after a full scale test, a clear moisture content sample was cut from a top chord and from a bottom chord of each truss. The moisture content of each sample was determined by the oven-dry method. The moisture content given for each truss was the average of these two values.

CHAPTER IV

TEST RESULTS

Test Data

All trusses of Groups I and II were tested in the same manner as described in Test Procedure. The physical measurements made were load, deflection, and time. This may be summarized as follows (chronologically for a typical truss):

1. An initial load of 20 plf was applied to the upper chord. Deflections at the four dial gage locations were noted after movement had stopped.

2. A static load of 20 plf was then placed on the lower chord. This load remained constant throughout the subsequent upper chord loading. The pulley and weight system permitted this load to remain constant as deflections occurred in the lower chord.

The deflections at all dial gage positions were recorded for this lower chord load after the creep had stopped. The deflection with the 20 plf upper chord load applied was the "zero" reference for deflection readings which followed. All slack in the system was assumed to have been removed.

3. Deflection readings at dial gage positions for subsequent load increments of 20 plf resulted in the following data:

a. Midspan deflection of lower chord (dial 1)

(1) An immediate deflection reading upon reaching predesignated load level on upper chord.

(2) Creep deflection readings at the steady load condition for each load level; a reading at 0.1 minutes and readings at subsequent 0.2 intervals (until the "creep limit" was indicated by three successive unchanged deflection readings).

b. Creep limit deflections at each 20 plf level for the other three dial positions.

Midspan Deflection vs. Time at Increments of Upper Chord Load

A typical time-deflection plot for a truss is shown in Figure 12. Such a graph was made for each truss tested. The ordinate was midspan deflection measured in 0.001 inches, with the origin representing the "zero" deflection datum of 20 plf on both upper and lower chord as described above. The abscissa was time, measured in 0.10 minutes. The origin represents "zero" time for each load level curve, with stopwatch readings started at the instant the predesignated load on the upper chord was reached.

The family of solid lines represent the creep curves for the load level. Each plot is identified with the appropriate value of intensity of total upper chord load in plf. The individual data points are shown.

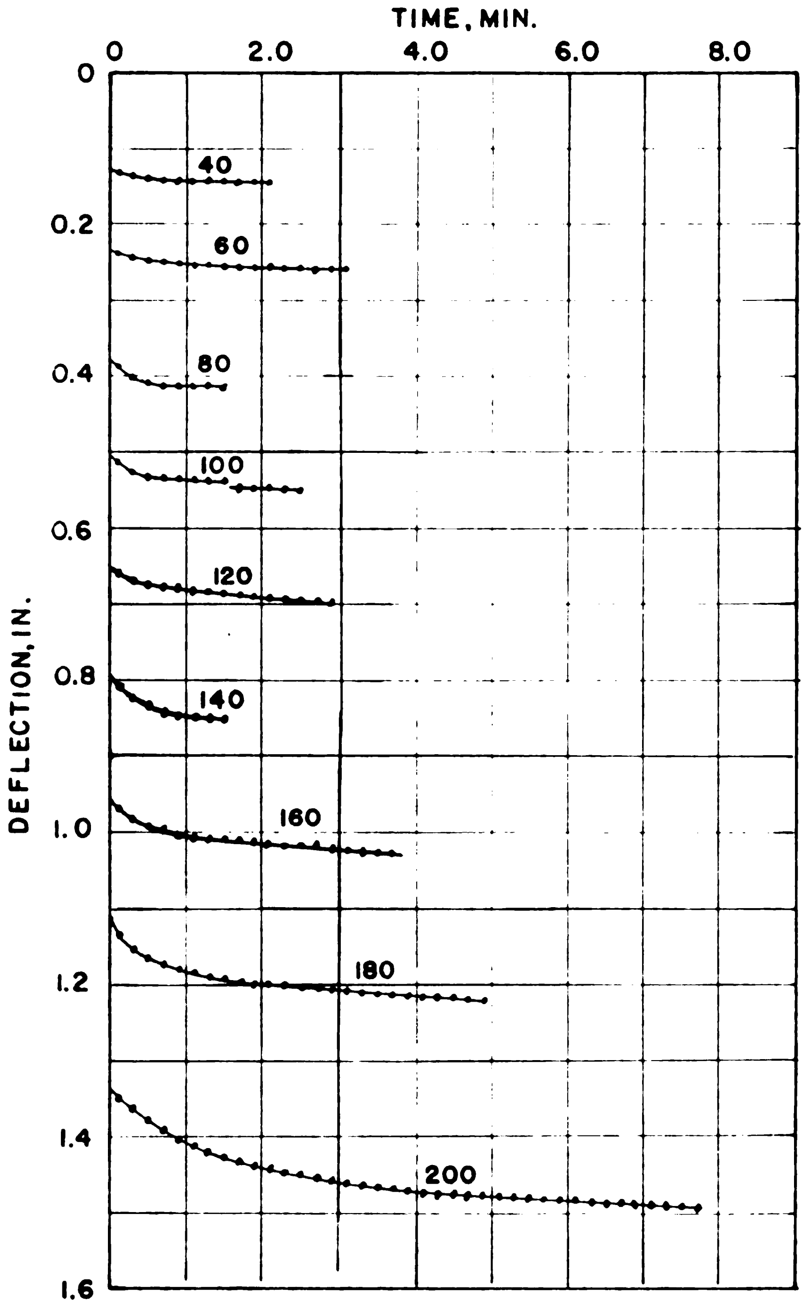


FIGURE 12

TIME VS. DEFLECTION

TRUSS DF-C-12.0-F18.4-T18.4-9

The time-deflection plots for all trusses were similar; differing only in magnitude of deflection, rate of change of slope, and total time to reach the creep limit.

Referring to Figure 12, it may be seen that as load level increased, the total time to reach the creep limit increased, the initial slope of the time-deflection curve increased, and the rate of change of slope decreased.

However, prior to loads for which a "creep limit" may be reached without ultimate failure, the mathematical nature of the creep curves was found to be the same as by Radcliffe and Sliker (14). They established a general equation which proved reliable regardless of species, plate type, moisture content, or intensity of load (below "creep limit" failure).

The "creep limit" deflection at midspan was determined from the time deflection plot of each truss tested. The time required to reach this steady state condition for each load level was also found.

Load vs. Deflection at "Creep Limit

A typical load-deflection plot is shown in Figure 13. This example corresponds to truss data used in Figure 12. Such a graph was made for each truss tested. As before, all plots were similar in nature.

The points plotted were based on "creep limit" deflection for each upper chord load increment. These values were taken directly from the time vs. deflection curves. A smooth curve was drawn to best fit the plotted data points.

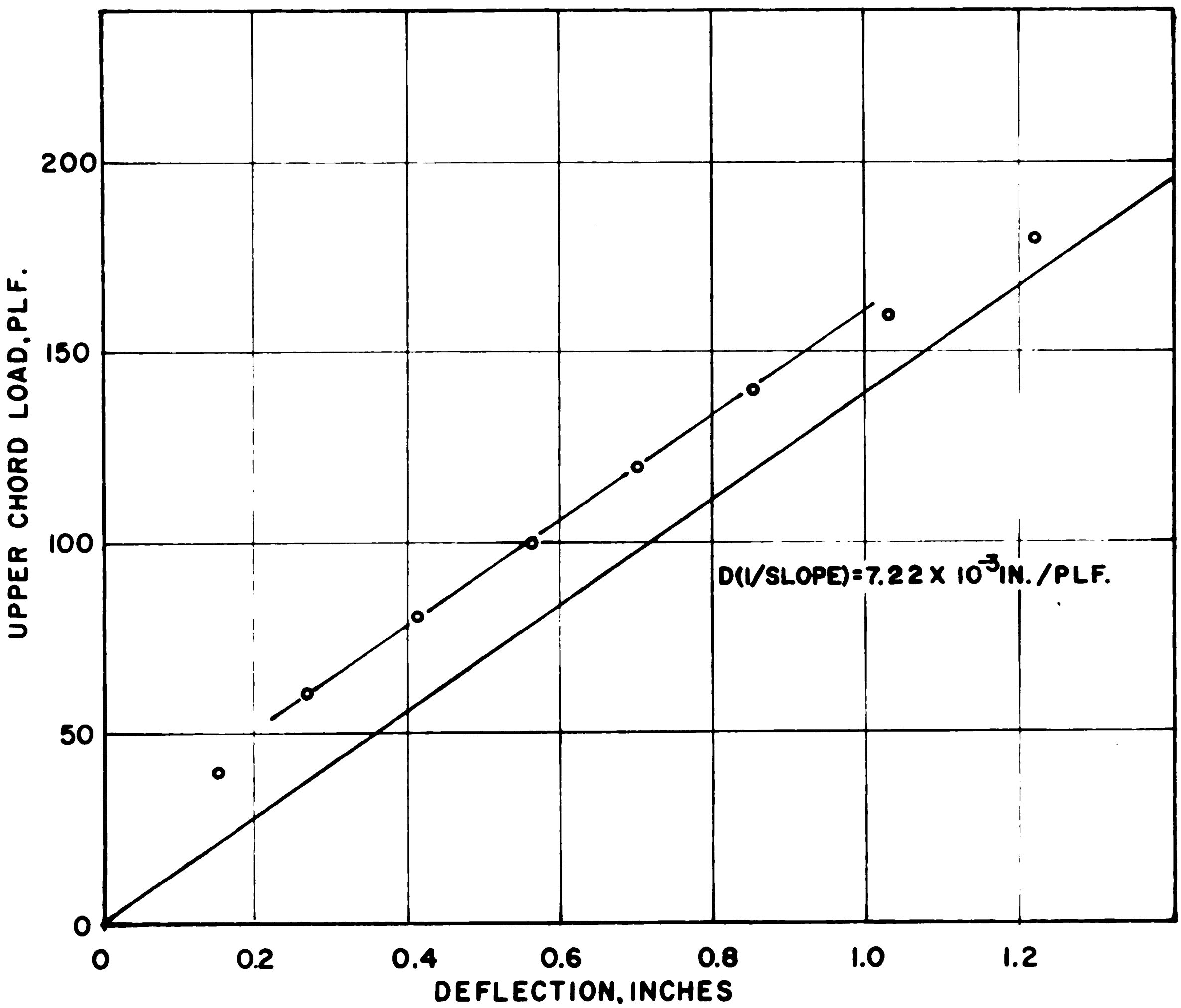


FIGURE 13

UPPER CHORD LOAD VS. DEFLECTION

TRUSS DF-C-12.0-F18.4-T18.4-9

All such curves exhibited a linear trend at lower load level and become curvilinear after a "proportional limit" was passed.

An adjusted straight line, parallel to the linear portion of the load deflection curve, was drawn through the origin. The slope of this line was determined as a measure of the overall stiffness of the truss. For convenience of comparison between trusses, the reciprocal of the slope (symbol used, D) was calculated in units of inches x 10^{-3} per plf of upper chords load. A larger D represents more deflection and hence a more limber truss.

Summary of Results

The results obtained as described are given in Table 3. Code identification of trusses listed in this table were explained in Description of Trusses and Test Apparatus. Column 2 lists the deflection constant D, while column 3 shows the increase in deflection from an elapsed time of 0.10 minutes to the "creep limit" under a constant upper chord load of 100 plf and the static lower chord load of 20 plf. The elapsed time from 0.1 minute to the "creep limit" is shown in column 4.

TABLE 3.--Deflection and creep.

Code	D[1]	Creep[2]	Elapsed Time[3]
WCH-A-16.5-F20.0-T9.5-1	5.74	0.016	1.80
WCH-A-15.4-F20.0-T9,5-2	5.77	0.014	1.00
WCH-A-15.5-F18.5-T9,9-3	6.21	0.020	2.60
WCH-A-14.9-F18.5-T9.8-4	6.44	0.020	1.60
WCH-A-13.9-F13,1-T10.1-5	6.10	0.011	0.80
WCH-A-13.3-F13.1-T8.7-6	5.93	0.015	1.40
WCH-A-13.0-F7.5-T7.5-7	6.41	0.019	2.00
WCH-A-16.9-F20.0-T20.0-8	5.85	0.020	2.40
WCH-A-14.8-F18.5-T18.5-9	5.28	0.023	2.80
WCH-A-14.0-F13.1-T13.1-10	5.96	...*	...*
WCH-A-14.4-F10.6-T10.6-11	4.90	0.012	1.40
WCH-A-14.3-T10.4-T10.4-12	5.23	0.012	1.40
DF-A-12.3-F24.0-T9.5-1	6.50	0.012	0.80
DF-A-10.8-F24.0-T9.8-2	5.92	0.015	1.20
DF-A-11.4-F20.4-T9.9-3	6.22	0.015	1.20
DF-A-15,9-F20.4-T10.4-4	4.98	0.017	1.60
DF-A-13.1-F13.3-T9.6-5	5.58	0.001	0.60
DF-A-12.8-F24.0-T24.0-6	6.75	0.017	2.00
DF-A-13.1-F20.4-T20.4-7	5.20	0.013	1.60
DF-A-14.6-F20.4-T20.4-8	4.85	0.011	1.40
DF-A-13.4-F13.5-T13.5-9	4.85	0.006	0.60
DF-A-11.6-F13.0-T13.0-10	5.50	0.005	0.60
DF-A-14.9-F9.9-T9.9-11	4.90	0.010	1.20
DF-A-12.8-F10.5-T10.5-12	6.08	0.003	0.60
DF-B-11.1-F24.0=T10.4-1	6.40	0.030	2.00
DF-B-11.5-F24.0-T10.4-2	5.70	0.021	2.40
DF-B-13.8-F18.0=T8.9-3	7.58	0.042	2.40
DF-B-12.8-F18.0-T8.9-4	6.71	0.012	1.20
DF-B-11.0-F13.7-T9.9-5	7.84	0.026	1.60
DF-B-15.5-F13.6-T10.8-6	5.60	0.021	2.40
DF-B-16.3-F13.6-T9.2-7	5.55	0.025	1.80
DF-B11.6-F24.0-T24.0-8	7.59	0.043	3.00
DF-B-14.6-F24.0-T24.0-9	9.29	0.060	5.40
DF-B-15.4-F13.7-T13.7-10	6.52	0.012	2.00
DF-B-12.9-F13.3-T13.3-11	7.30	0.035	2.20
DF-B-13.4-F13.7-T13.7-12	5.22	0.015	0.80
DF-B-12.9-F10.1-T10.1-13	8.42	0.014	1.40

TABLE 3.--Continued.

Code	D[1]	Creep[2]	Elapsed Time[3]
DF-C-16.0F24.0-T9.5-1	5.01	0.008	1.00
DF-C-13.0F24.0-T10.4-2	6.16	0.016	2.20
DF-C-12.5-F18.4-T9.8-3	6.87	0.030	1.60
DF-C-15.3-F18.4-T9.9-4	5.78	0.024	1.40
DF-C-12.1-F13.9-T10.9-5	6.01	0.011	2.00
DF-C-11.6-F13.9-T9.0-6	6.09	0.029	2.20
DF-C-13.0-F24.0-T24.0-7	8.09	0.027	4.60
DF-C-12.1-F24.0-T24.0-8	7.31	0.040	4.00
DF-C-12.0-F18.4-T18.4-9	7.22	0.036	2.40
DF-C-12.3-F13.9-T13.9-10	6.98	0.030	2.20
DF-C-16.4-F10.3-T10.3-11	6.42	0.024	1.20
DF-C-10.9-F10.9-T10.9-12	6.88	0.036	1.40
DF-C-12.2-F10.9-T10.9-13	8.39	0.049	2.80
DF-C-10.8-F10.3-T10.3-14	9.21	0.067	3.20

[1]Deflection constant in 10^{-3} in/plf units.

[2]Deflection, in inches, from an elapsed time of 0.10 minutes to the "creep limit."

[3]Elapsed time, in minutes, from 0.10 minutes to the "creep limit."

*Missing data.

CHAPTER V

ANALYSIS OF DATA

General

Analyses were made to determine the effects of physical variables of the wood (EI, MC and ΔMC) upon the midspan deflection behavior of trusses within and between specie Groups and plate type subgroups. Total deflection was composed of the elastic deflection due to the incremental load and the inelastic creep deflection.

The analyses are confined to the range of essentially linear behavior of load vs. "creep limit" deflection. Investigation may be categorized as follows: (1) truss deflection as a function of lumber EI, (2) deflection vs. moisture content of truss lumber, (3) truss deflection as influenced by the combined interrelated effects of EI and moisture content, (4) influence of moisture content history on creep, and (5) effect of lower chord load on truss deflection.

Where two variables (therefore two dimensional) comparisons were made, scatter diagrams were plotted. A simple regression line was plotted on each scatter diagram. Also the regression equation was given. In the case of three variables, multiple regression equations were tabulated. A discussion of the statistical techniques utilized is found in Appendix II. The analyses of the five categories of behavior follow.

Average Deflection for Each Plate Type

The ratio of lower chord deflection at midspan to upper chord load below the proportional limit, has been averaged for the trusses of each of the eight categories. These eight averages, or means of deflection-load ratios are presented in Table 4. The trusses were classified into two species groups and three plate subgroups. Each subgroup was further divided into two moisture content history series; Series I (MC) and Series II (ΔMC). The standard deviation corresponding to each average deflection value is given in the table. The means and standard deviations for the EI, MC and ΔMC variables are listed by category in Table 4. As seen in Table 4, the nail-on plate (Type A) categories generally exhibited less mean deflection than the other plate types.

The averages of midspan deflections (expressed in inches x 10^{-3}/plf of upper chord load for convenience) can be summarized for major groups without regard for moisture content history or EI classification. Ranges are also given.

TABLE 4.--Means and standard deviations.

	EI		M.C.[1]		ΔM.C.[2]		D[3]	
Category	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
WCH-A-MC	14.567	1.294	13.350	4.925	--	--	5.605	0.562
WCH-A-ΔMC	14.917	1.160	--	--	7.950	3.558	6.032	0.271
DF-A-MC	13.314	1.132	15.957	5.559	--	--	5.447	0.727
DF-A-ΔMC	12.700	1.991	--	--	10.580	4.363	5.840	0.500
DF-B-MC	13.467	1.353	16.467	5.990	--	--	7.390	1.427
DF-B-ΔMC	13.143	2.142	--	--	8.057	4.523	6.483	0.946
DF-C-MC	12.462	1.750	15.338	5.996	--	--	7.562	0.932
DF-C-ΔMC	13.417	1.804	--	--	8.850	4.572	5.987	0.603

[1]Base moisture content in % units.

[2]Change in moisture content in % units.

[3]Deflection constant in 10^{-3} in/plf units.

Species	Plate Type*	Average Deflection (inches x 10^{-3}/plf)	Range (inches x 10^{-3}/plf)	No. of Trusses
W.C.Hemlock	A	5.82	4.90-6.44	12
Douglas Fir	A	5.61	4.85-6.75	12
Douglas Fir	B	6.90	5.22-9.29	13
Douglas Fir	C	6.89	5.01-9.21	14

*The plate type refers to sheet metal fasteners: type A, nail-on plates; type B, corrugated with triangular, hooked prongs; and type C, flat with rectangular teeth.

Comparisons of the mean deflections between categories are not justified due to the following: the trusses in a given category were not always fabricated by the same manufacturing process. Secondly, the large standard deviation of the mean deflection of each category precludes any statistical inference. For example, a 99.7% confidence interval on the mean deflection for the WCH-A-ΔMC category yielded a three standard deviation interval of 6.032 ± 0.813 units. It is evident the interval was too wide to warrant significant statistical inference. Lastly, the means and standard deviations of the independent variables; EI, MC and ΔMC vary appreciably between categories, thereby eliminating a comparison of like categories.

Since comparisons without reservations between categories are not justified, comparisons between plate types and between species are not justified.

Truss Deflection as a Function of Lumber EI

Deflection data from all the truss tests results was used to evaluate the effect of EI. The deflection constant, D, was taken from the load-deflection diagram of each truss and plotted against the average EI in scatter diagrams. Eight scatter diagrams were constructed, one for each of the categories listed in Table 4. The scatter diagrams are shown in Figures 14-21. The calculated simple regression equation accompanies each diagram. Table 4 lists the means and standard deviations of the variables by categories.

Deflection vs. Moisture Content of Truss Lumber

The influence of moisture content was divided into two series. Series I was the effect of a base moisture content (MC) on deflection, while Series II was the effect of a change in moisture content (ΔMC) from fabrication to testing on deflection. Each series included four categories (Table 4).

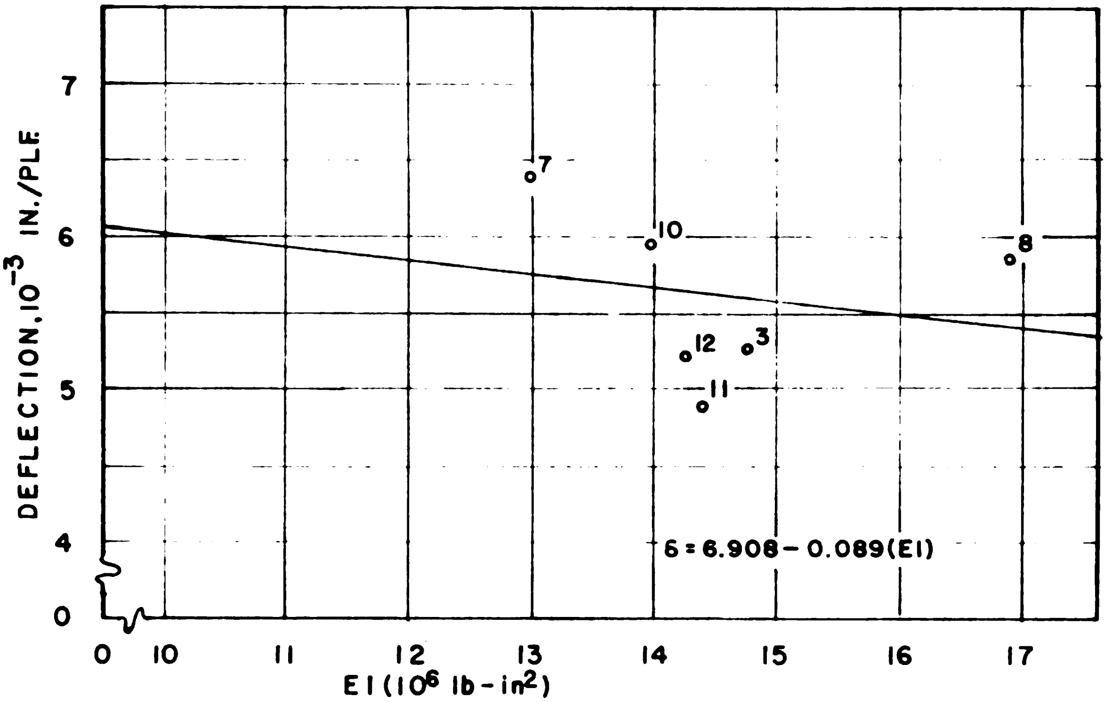


FIGURE 14

INFLUENCE OF MEMBER STIFFNESS - WCH-A

SERIES I

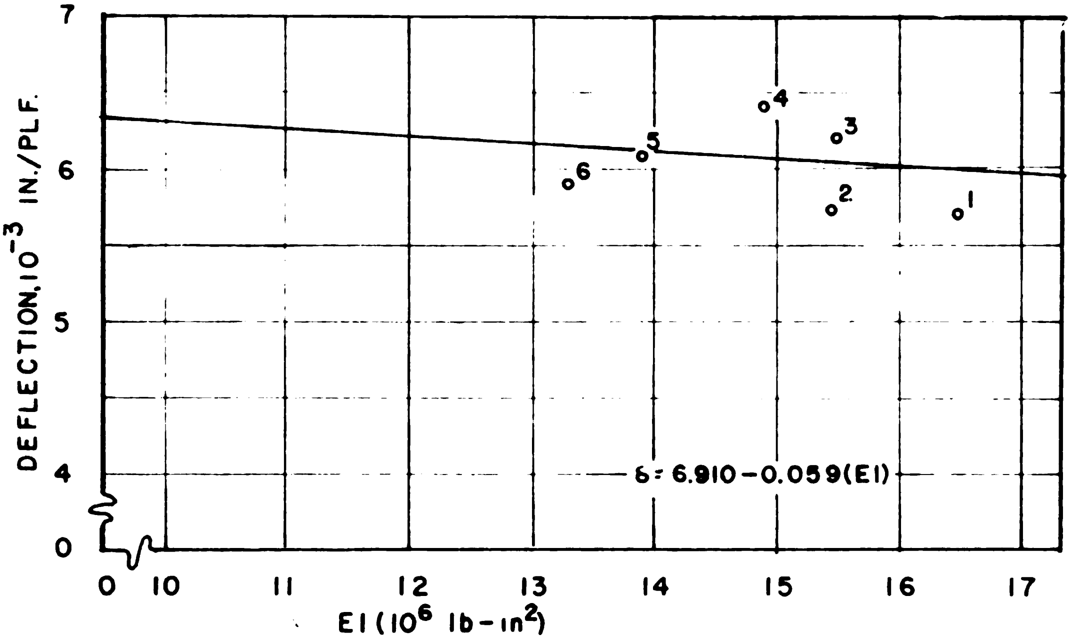


FIGURE 15

INFLUENCE OF MEMBER STIFFNESS - WCH-A

SERIES II

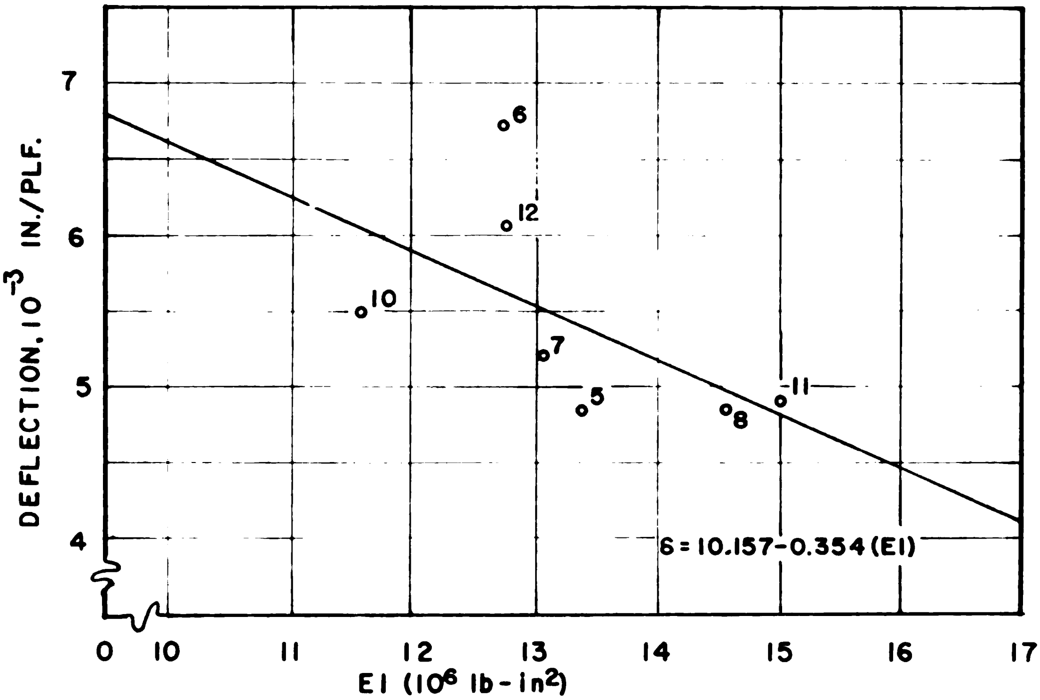


FIGURE 16

INFLUENCE OF MEMBER STIFFNESS – DF-A

SERIES I

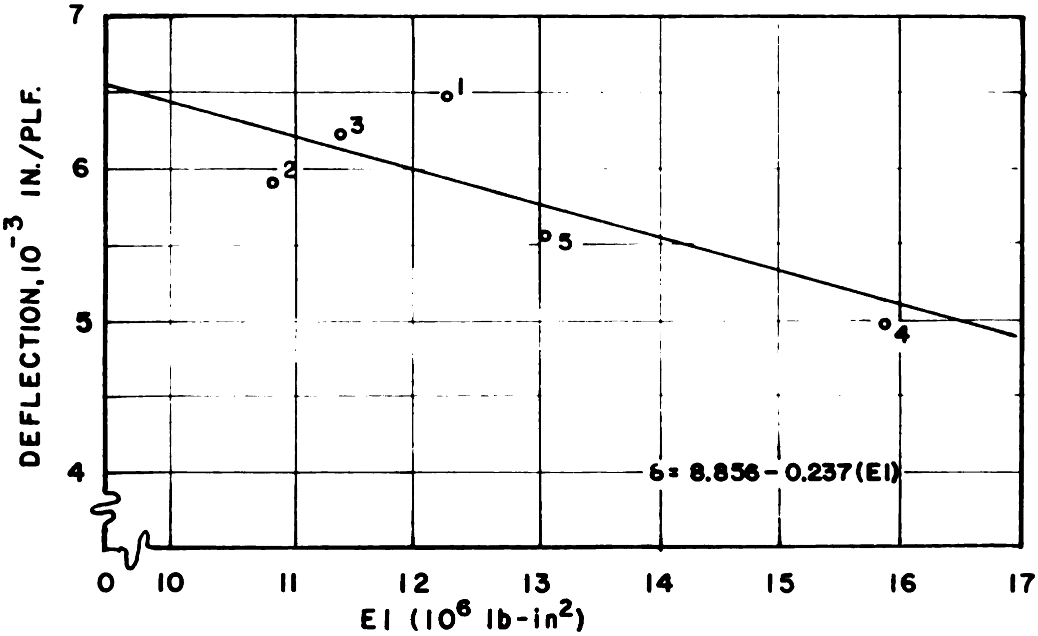


FIGURE 17

INFLUENCE OF MEMBER STIFFNESS – DF-A

SERIES II

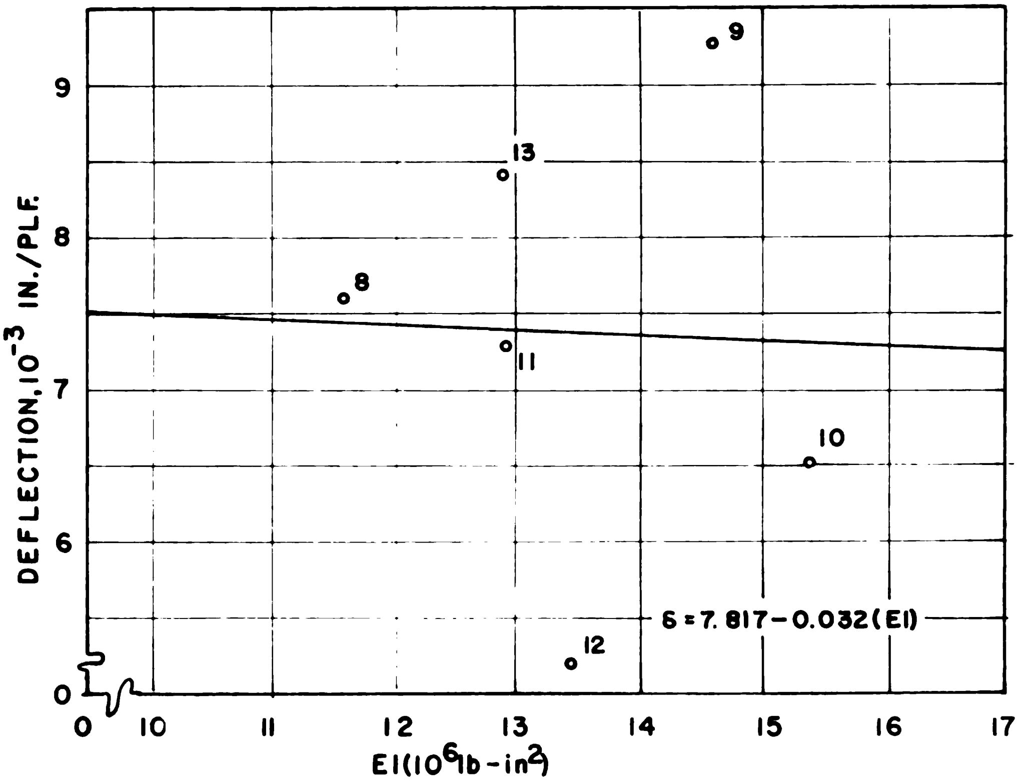


FIGURE 18

INFLUENCE OF MEMBER STIFFNESS-DF-B

SERIES I

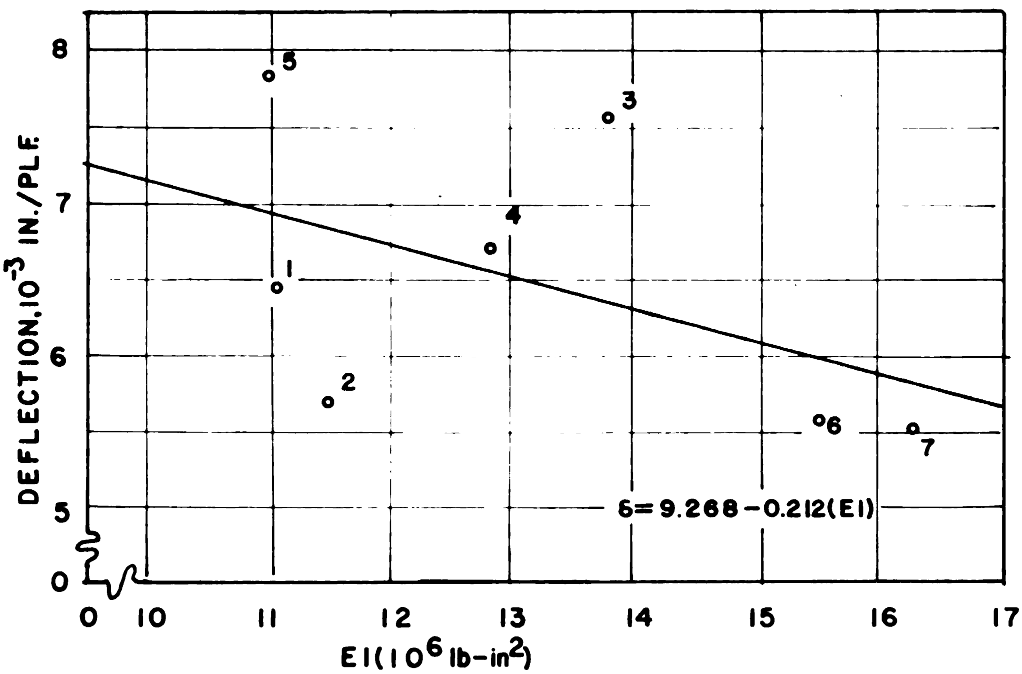


FIGURE 19

INFLUENCE OF MEMBER STIFFNESS-DF-B

SERIES II

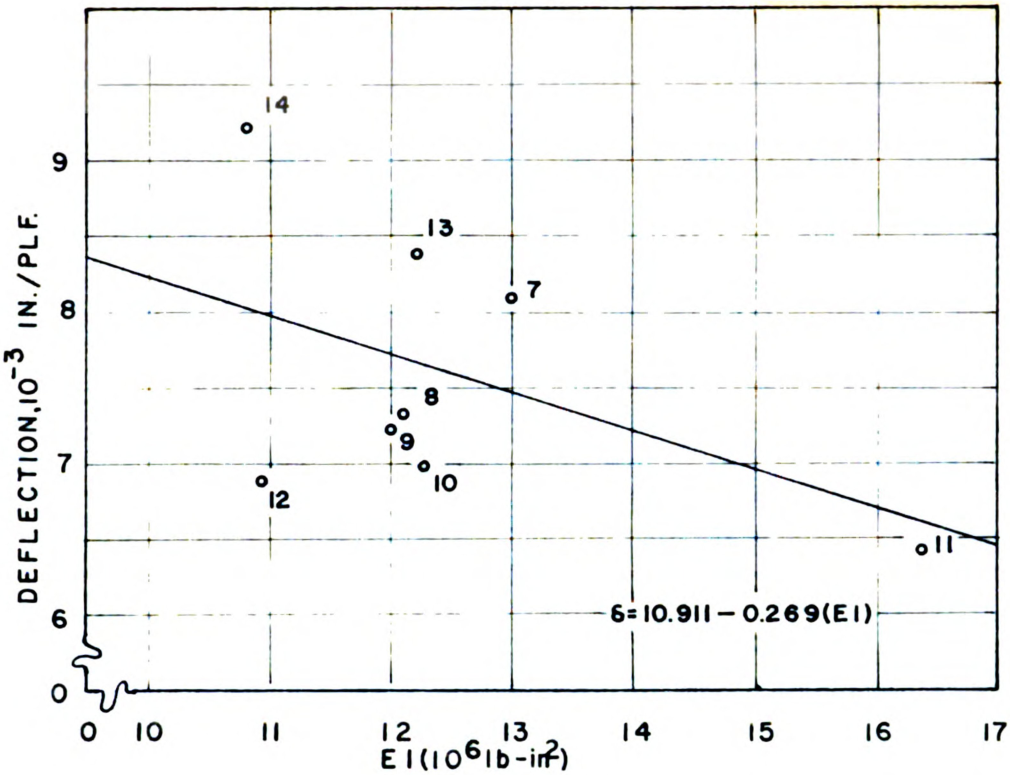


FIGURE 20

INFLUENCE OF MEMBER STIFFNESS-DF-C

SERIES I

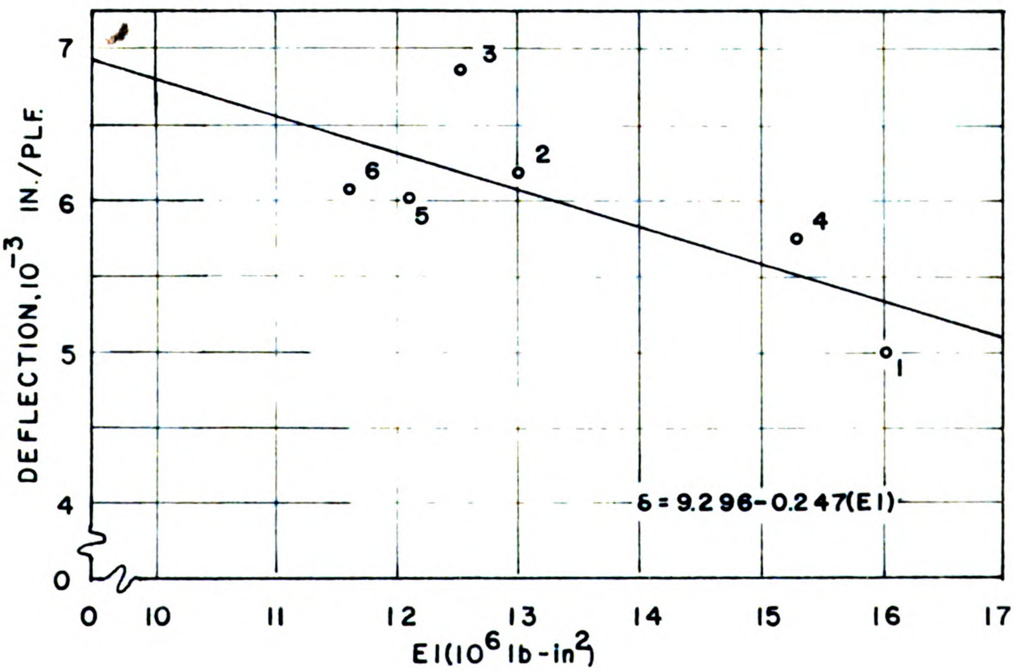


FIGURE 21

INFLUENCE OF MEMBER STIFFNESS-DF-C

SERIES II

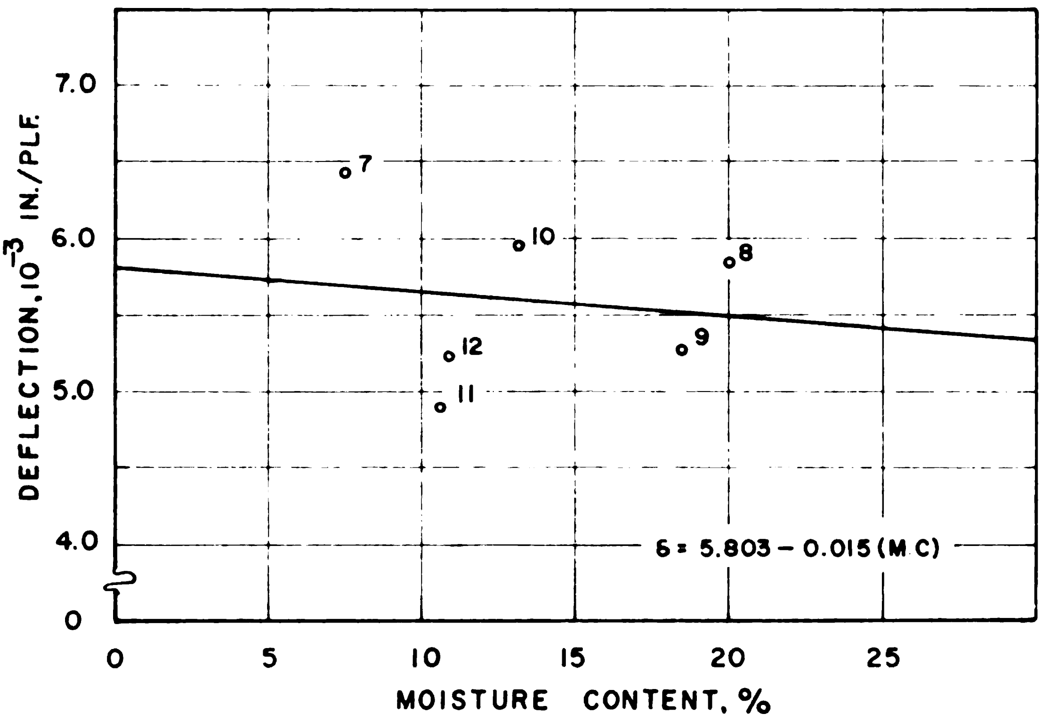


FIGURE 22

INFLUENCE OF MOISTURE CONTENT − WCH-A

SERIES I

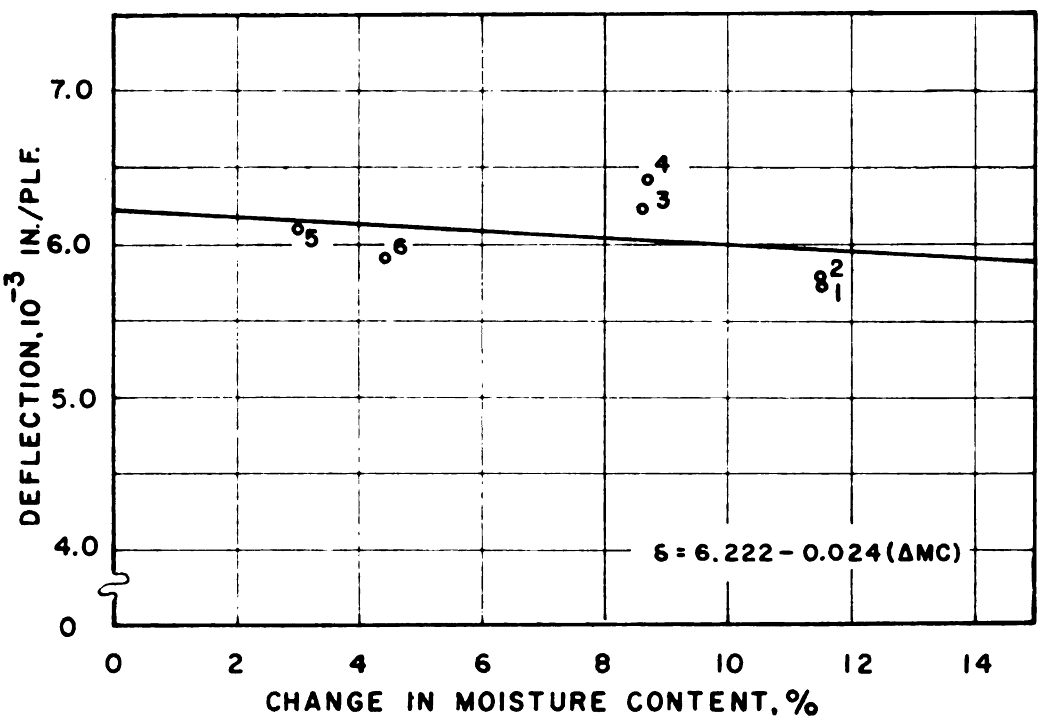


FIGURE 23

INFLUENCE OF MOISTURE CONTENT − WCH-A

SERIES II

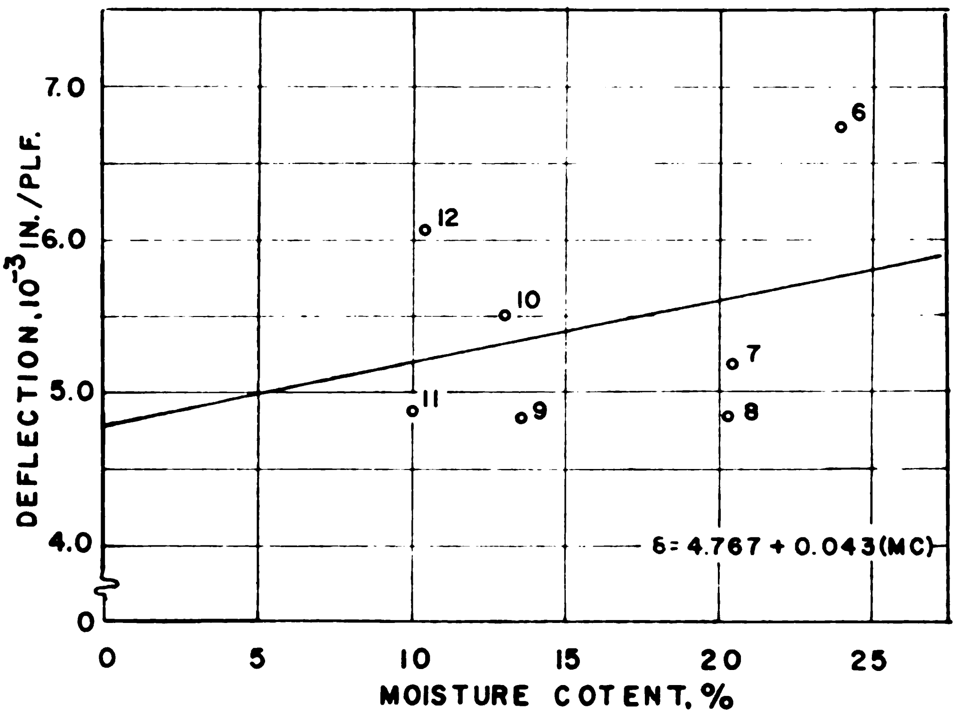


FIGURE 24

INFLUENCE OF MOISTURE CONTENT-DF-A

SERIES I

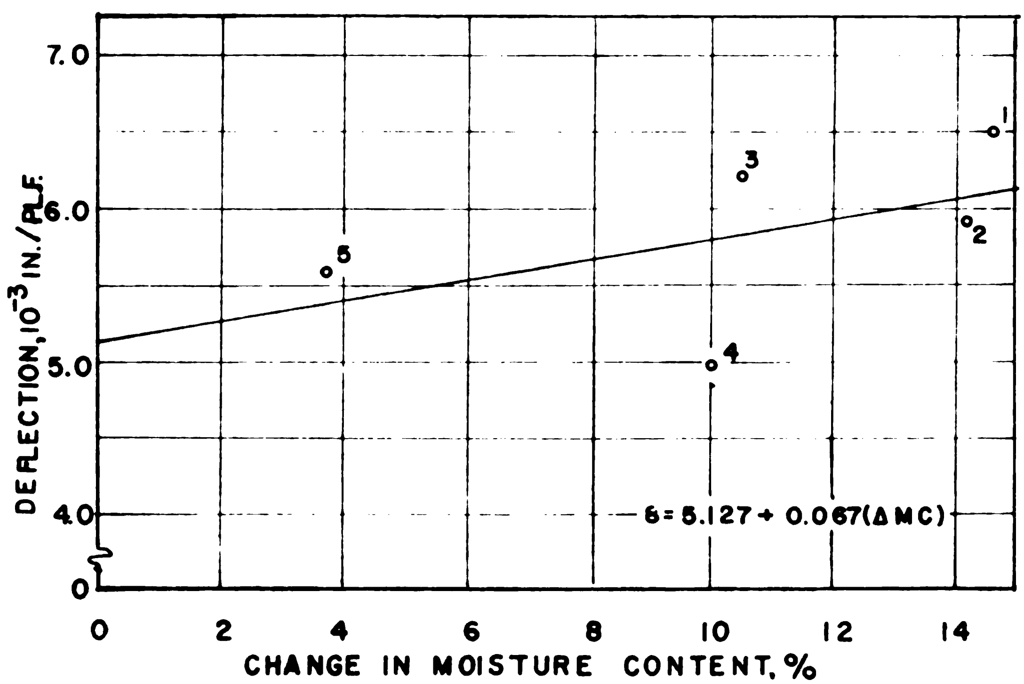


FIGURE 25

INFLUENCE OF MOISTURE CONTENT-DF-A

SERIES II

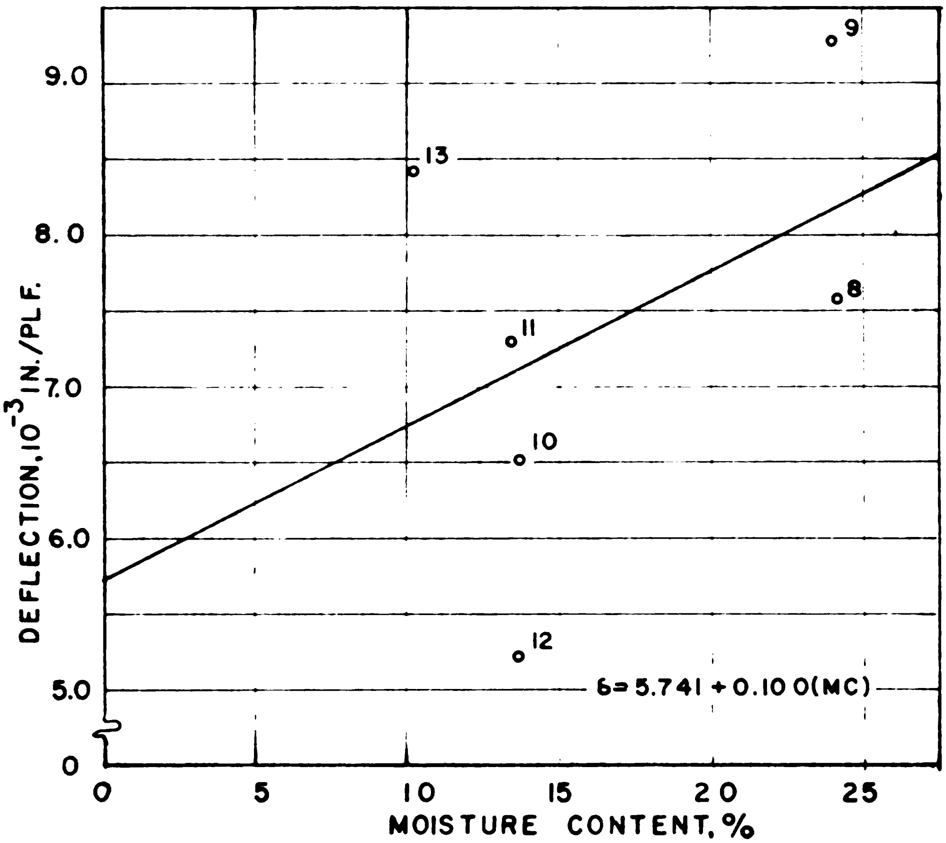
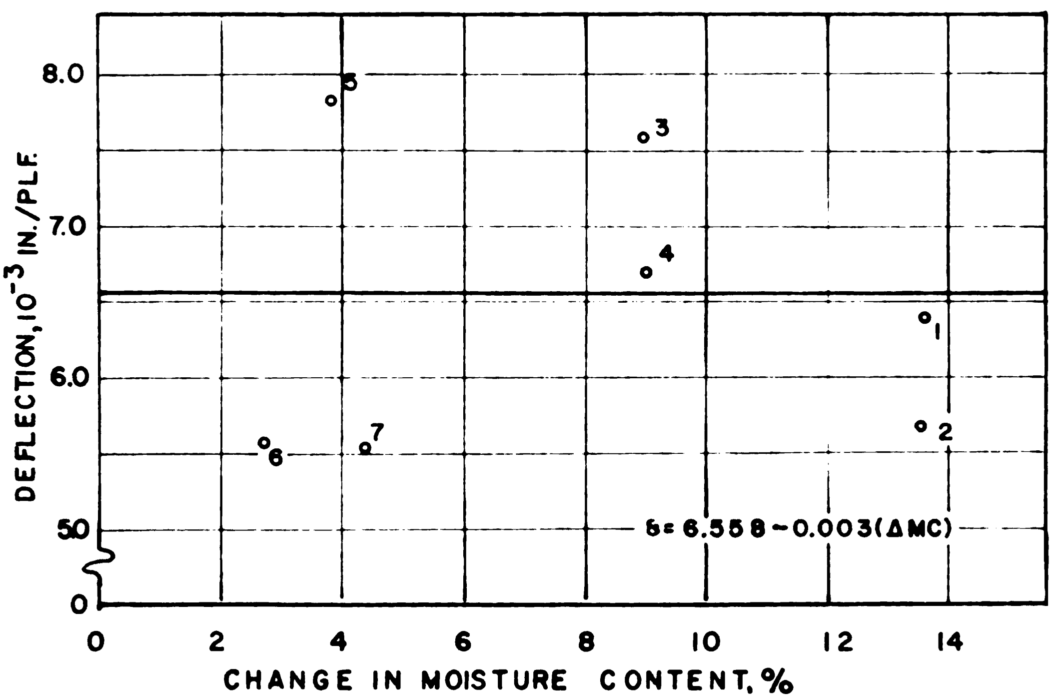


FIGURE 26

INFLUENCE OF MOISTURE CONTENT–DF-B

SERIES I



INFLUENCE OF MOISTURE CONTENT–DF-B

SERIES II

FIGURE 27

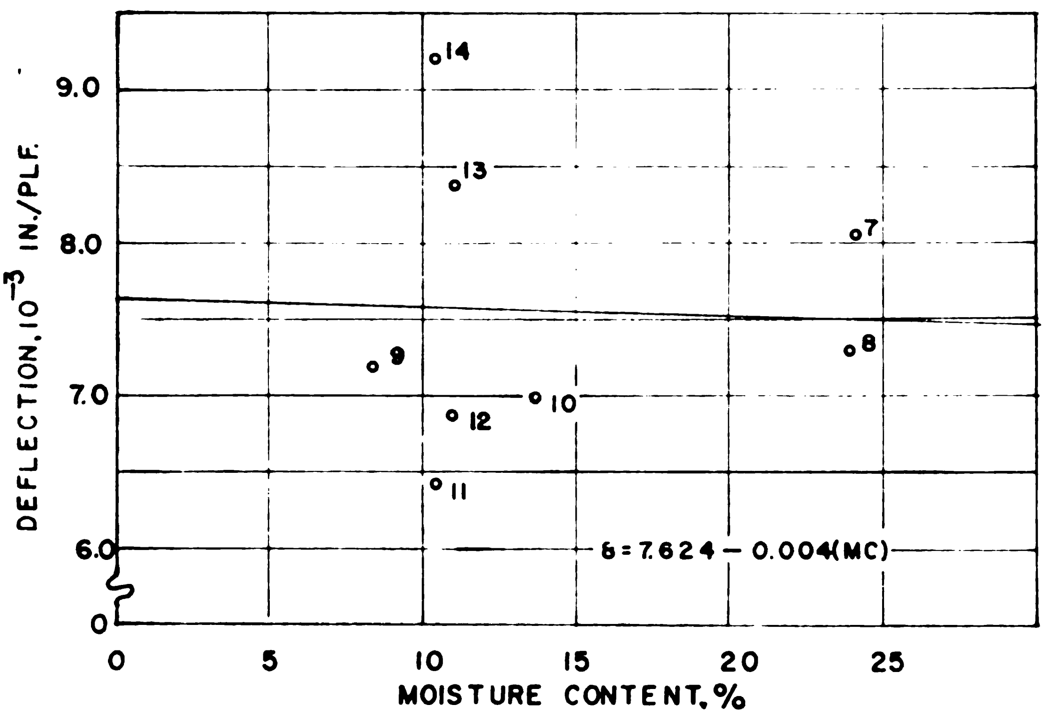


FIGURE 28

INFLUENCE OF MOISTURE CONTENT-DF-C

SERIES I

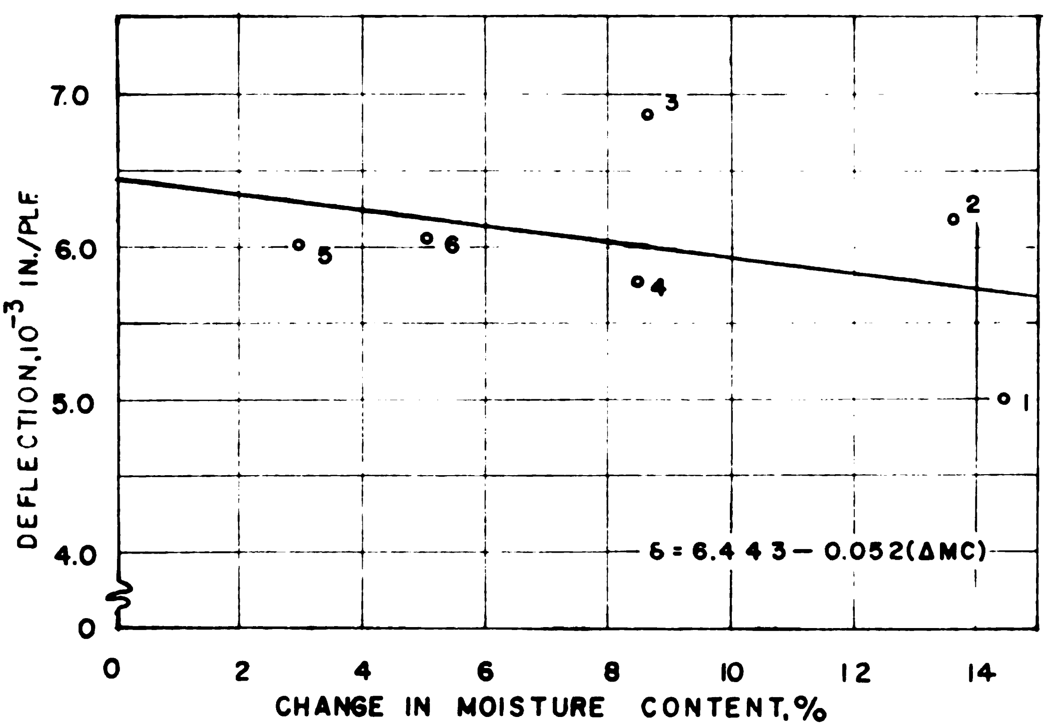


FIGURE 29

INFLUENCE OF MOISTURE CONTENT-DF-C

SERIES II

Scatter diagrams with D plotted against MC (Series I) were drawn for each of four categories (Figures 22, 24, 26, 28). The simple regression line was plotted. The regression equation was also given.

Series II scatter diagrams had D plotted against ΔMC for four categories (Figures 23, 25, 27, 29). Each diagram includes a plot of the simple regression line and the regression equation.

The means and standard deviations for the variables in the two series are in Table 4. The statistical evaluation of the regression equation and other related statistics for each of four categories of the two series is found in Tables 6 and 7.

Truss Deflection as Influenced by the Combined Interrelated Effects of EI and Moisture Content

Simple regressions relating one independent variable to deflection were considered insufficient since, in actuality, at least two independent variables simultaneously act on deflection. Therefore, multiple regressions were deemed necessary.

The results were grouped into the eight categories of Table 4. Multiple regression equations relating two independent variables to the dependent variable deflection (D) for each category are shown in Tables 8 and 9. The two independent variables are EI and either MC or ΔMC.

TABLE 6.--Correlation and regression of deflection on moisture content, Series I.

Category	Number of Observations	Reg. Coef. $b_{\delta MC}$	Std. Error of Reg. Coef. S_b	Corr. Coef. R	Coef. of Determination R^2	Std. Error of Est. S	Predicting Equation
WCH-A-MC	6	-0.015	0.057	-0.130	0.017	0.623	δ=5.803-0.015(MC)
DF-A-MC	7	0.043	0.055	0.326	0.106	0.753	δ=4.767+0.043(MC)
DF-B-MC	6	0.100	0.108	0.420	0.176	1.448	δ=5.741+0.100(MC)
DF-C-MC	8	-0.004	0.063	-0.026	0.001	0.997	δ=7.624-0.004(MC)

TABLE 7.--Correlation and regression of deflection on change in moisture content, Series II.

Category	Number of Observations	Reg. Coef. $b_{\delta \Delta MC}$	Std. Error of Reg. Coef. S_b	Corr. Coef. R	Coef. of Determination R^2	Std. Error of Est. S	Predicting Equation
WCH-AΔMC	6	-0.024	0.036	-0.315	0.099	0.287	δ=6.222-0.024(ΔMC)
DF-A-ΔMC	5	0.067	0.068	0.498	0.248	0.591	δ=5.127+0.067(ΔMC)
DF-B-ΔMC	7	-0.009	0.093	-0.044	0.002	1.035	δ=6.558-0.009(ΔMC)
DF-C-ΔMC	6	-0.052	0.061	-0.391	0.153	0.620	δ=6.443-0.052(ΔMC)

TABLE 8.--Correlation and regression of deflection on EI and MC.

Category	No. of Observ.	Partial Reg. Coef. $b_{\delta EI \cdot MC}$	Partial Reg. Coef. $b_{\delta MC \cdot EI}$	Std. Error of Partial Reg. Coef. S_b	Corr. Coef. R	Coef. of Det. R^2	Std. Error of Est. S	Predicting Equation
WCH-A-MC	6	-.154		.47				
			.020	.12	.22	.05	.71	δ=7.58+.02(MC)-.15(EI)
DF-A-MC	7	-.347		.25				
			.040	.05	.63	.40	.69	δ=9.42+.04(MC)-.35(EI)
DF-B-MC	6	.027		.56				
			.101	.13	.42	.18	1.67	δ=5.37+.10(MC)+.03(EI)
DF-C-MC	8	-.270		.20				
			-.007	.06	.51	.26	.94	δ=11.04-.01(MC)-.27(EI)

TABLE 9.--Correlation and regression of deflection on EI and ΔMC.

Category	No. of Observ.	Partial Reg. Coef. $b_{\delta EI \cdot \Delta MC}$	Partial Reg. Coef. $b_{\delta \Delta MC \cdot EI}$	Std. Error of Partial Reg. Coef. S_b	Corr. Coef. R	Coef. of Det. R^2	Std. Error of Est. S	Predicting Equation
WCH-AΔMC	6	.036		.09				
			-.034	.29	.32	.10	.33	δ=5.78-.03(ΔMC)+.04(EI)
DF-A-ΔMC	5	-.212		.13				
			.031	.06	.83	.69	.47	δ=8.20+.03(ΔMC)-.21(EI)
DF-B-ΔMC	7	-.350		.21				
			-.109	.10	.64	.40	.89	δ=11.96-.11(ΔMC)-.35(EI)
DF-C-ΔMC	6	-.283		.17				
			.022	.07	.75	.56	.52	δ=9.59+.02(ΔMC)-.28(EI)

A three dimensional scatter diagram was excluded since it is often difficult to interpret. Also included in Tables 8 and 9 are related statistics.

Influence of Moisture Content History on Creep

Typical creep curves are shown in Figure 12. The increase in deflection under a constant upper chord load of 100 plf and a lower chord load of 20 plf as time increased from 0.10 minutes is shown in column 3 of Table 3. Column 4 shows the corresponding elapsed time from 0.10 minutes to the moment when the final deflection reading was recorded at the "creep limit." The tabulated values were taken from the original data sheets.

Effect of Lower Chord Load on Truss Deflection

As was shown in Test Procedure, the midspan deflection after creep had stopped was recorded for the initial 20 plf upper chord load. A similar deflection reading was read after a subsequent 20 plf lower chord load was added. The difference in deflection between the two readings is listed for the 51 trusses in Table 10. The moisture history and classification of each truss is contained in the specimen code.

TABLE 10.--Deflection of lower chord.

Code	Lower Chord δ^1
WCH-A-16.5-F20.0-T9.5-1	0.201
WCH-A-15.4-F20.0-T9.5-2	0.187
WCH-A-15.5-F18.5-T9.9-3	0.236
WCH-A-14.9-F18.5-T9.8-4	0.268
WCH-A-13.9-F13.1-T10.1-5	0.207
WCH-A-13.3-F13.1-T8.7-6	0.163
WCH-A-13.0-F7.5-T7.5-7	0.114
WCH-A-16.9-F20.0-T20.0-8	0.162
WCH-A-14.8-F18.5-T18.5-9	0.080
WCH-A-14.0-F13.1-T13.1-10	0.113
WCH-A-14.4-F10.6-T10.6-11	0.135
WCH-A-14.3-F10.4-T10.4-12	0.165
DF-A-12.3-F24.0-T9.5-1	0.179
DF-A-10.8-F24.0-T9.8-2	1.196
DF-A-11.4-F20.4-T9.9-3	0.160
DF-A-15.9-F20.4-T10.4-4	0.169
DF-A-13.1-F13.3-T9.6-5	0.169
DF-A-12.8-F24.0-T24.0-6	0.175
DF-A-13.1-F20.4-T20.4-7	0.145
DF-A-14.6-F20.4-T20.4-8	0.147
DF-A-13.4-F13.5-T13.5-9	0.072
DF-A-11.6-F13.0-T13.0-10	0.155
DF-A-14.9-F9.9-T9.9-11	0.144
DF-A-12.8-F10.5-T10.5-12	0.156
DF-B-11.1-F24.0-T10.4-1	0.172
DF-B-11.5-F24.0-T10.4-2	0.180
DF-B-13.5-F18.0-T8.9-3	0.162
DF-B-12.8-F18.0-T8.9-4	0.149
DF-B-11.0-F13.7-T9.9-5	0.196
DF-B-15.5-F13.6T10.8-6	0.168
DF-B-16.3-F13.6-T9.2-7	0.143
DF-B-11.6-F24.0-T24.0-8	0.116
DF-B-14.6-F24.0-T24.0-9	...*
DF-B-15.4-F13.7-T13.7-10	0.146
DF-B-12.9-F13.3-T13.3-11	0.187
DF-B-13.4-F13.7-T13.7-12	0.167
DF-B-12.9-F10.1-T10.1-13	0.148

TABLE 10.--Continued.

Code	Lower Chord δ[1]
DF-C-16.0-F24.0-T9.5-1	0.130
DF-C-13.0-F24.0-T10.4-2	0.170
DF-C-12.5-F18.4-T9.8-3	0.170
DF-C-15.3-F18.4-T9.9-4	0.144
DF-C-12.1-F13.9-T10.9-5	0.196
DF-C-11.6-F13.9-T9.0-6	0.117
DF-C-13.0-F24.0-T24.0-7	0.074
DF-C-12.1-F24.0-T24.0-8	0.143
DF-C-12.0-F18.4-T18.4-9	0.158
DF-C-12.3-F13.9-T13.9-10	0.200
DF-C-16.4-F10.3-T10.3-11	0.117
DF-C-10.9-F10.9-T10.9-12	0.172
DF-C-12.2-F10.9-T10.9-13	0.160
DF-C-10.8-F10.3-T10.3-14	0.210

[1]Midspan deflection under a 20 plf upper chord load and a 20 plf lower chord load minus the midspan deflection under an initial 20 plf upper chord load.

CHAPTER VI

DISCUSSION OF RESULTS

Preliminary Continuous Time Tests

A preliminary investigation was conducted in order to determine the influence of time lag between successive 20 plf upper chord loadings on creep and "creep limit" deflection. Two trusses, truss 1 and truss 2, were fabricated with Douglas Fir lumber and type A plates. The time lag between load increments was greater for truss 1 than for truss 2. The test method was the same as that described in Test Procedure with the exception that the time was recorded continuously throughout the test duration.

The continuous time vs. deflection plots of the two trusses are shown in Figure 14. The solid curves were drawn through the plotted data points. The load intensity, in plf units, is written above each creep curve.

Although the time lag differed in the two cases, the nature of the creep curves of both trusses were the same. Also the "creep limit" deflections were in close agreement.

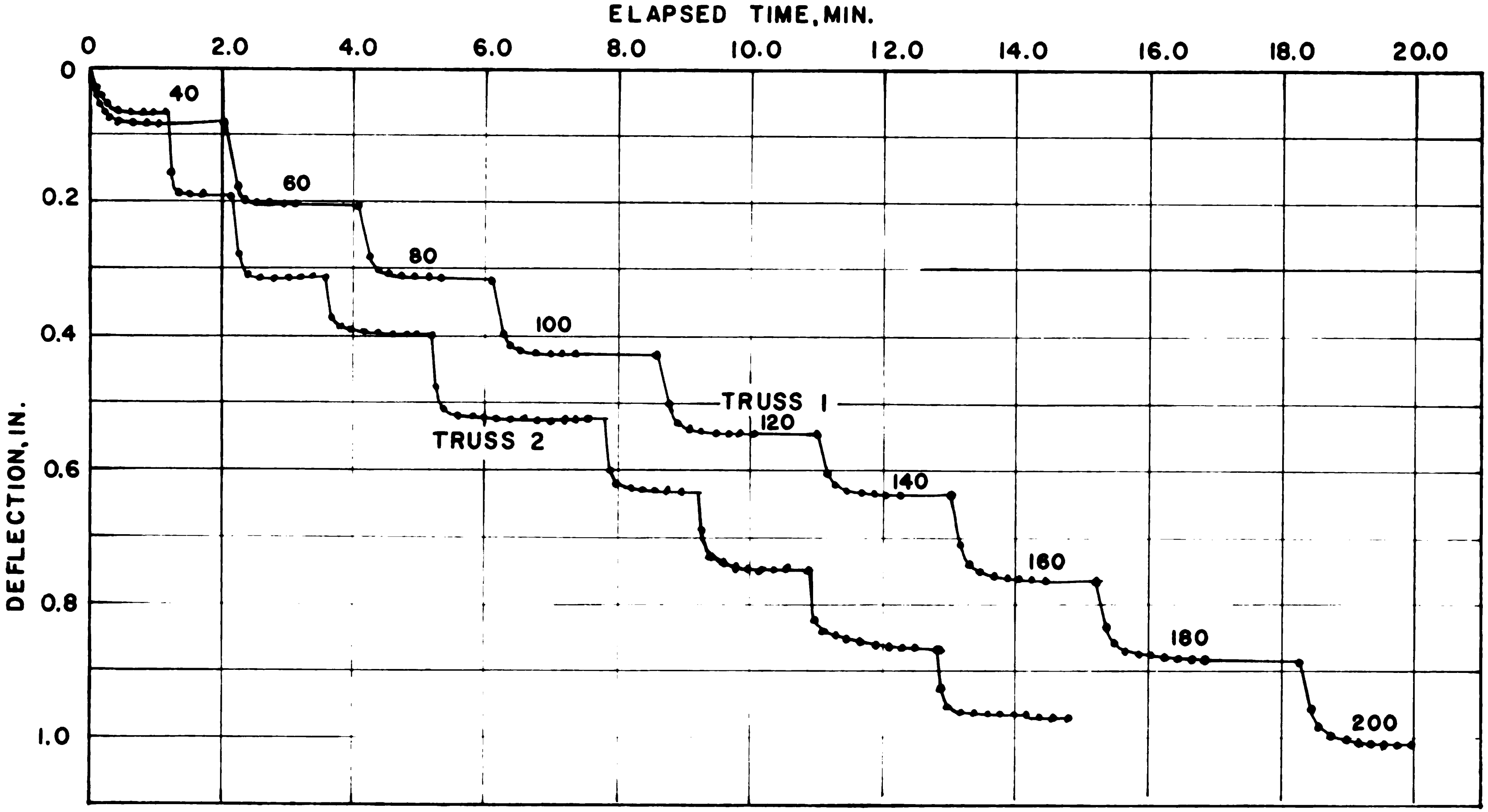


FIGURE 30
CONTINUOUS TIME VS. DEFLECTION

Truss Deflection as a Function of Lumber EI

For each of the eight categories, scatter diagrams were made for midspan deflection-upper chord load ratios versus EI (average stiffness factor for lumber in each truss). These plots are shown in Figures 14-21. Each point plotted represents a truss test result and is identified by the number of that truss.

The linear regression for each category was statistically calculated to investigate the degree of trend and reliability. A linear regression was used as an indication of the trend because there was no apparent consistent curvilinear relation between δ and EI. The linear regression lines are shown as solid lines in Figures 14-21. The regression equation is also given in each diagram.

All of the regression coefficients (slopes) were negative, suggesting a trend where an increase in EI would result in a decrease in deflection. The magnitude of the coefficient varied among categories. The range of the EI regression coefficient for the eight categories was from -0.032 to -0.354. The regression coefficients indicate the change in deflection (in inches x 10^{-3}/plf upper chord load) associated with a 1 x 10^{6} lb-inches^{2} change in EI.

It must be emphasized that due to the small sample size within each category, along with the degrees of freedom, the statistical tests would be expected to be somewhat inconclusive. The large degree of scatter in each category, the large values for the standard error of estimate, and the low coefficients of determination (see Table 5 for the statistics of each category) clearly indicate that the regressions given cannot be interpreted as design or predictive equations. These regressions are presented merely to indicate trends among groups which show consistency of behavior.

In the two following discussions, the same facts must be applied.

Deflection vs. Moisture Content of Truss Lumber

The effect of moisture content history was divided into two series. The Series I trusses were fabricated and tested at the same moisture content (MC). Four scatter diagrams with deflection plotted against base moisture content are shown in Figures 22, 24, 26, and 28. A regression line is plotted and the regression equation given with each diagram. The related statistics are tabulated in Table 6.

The large standard error of estimate of each of the four categories (Table 6) indicates a substantial scatter about the regression line. This is also visibly apparent in the scatter diagrams. The coefficients of determination were low in all cases. The regression coefficients (slopes) were not consistent in sign. However, in three of the four cases, the magnitude of the regression coefficient was small, indicating a minor effect of base moisture content on truss

TABLE 5.--Correlation and regression of deflection on EI.

Category	Number of Observations	Reg. Coef. $b_{\delta EI}$	Std. Error of Reg. Coef. S_b	Corr. Coef. R	Coef. of Determination R^2	Std. Error of Est. S	Predicting Equation
WCH-A-MC	6	-0.089	0.212	-0.206	0.042	0.614	δ=6.908-0.089(EI)
WCH-AΔMC	6	-0.059	0.113	-0.252	0.064	0.293	δ=6.910-0.059(EI)
DF-A-MC	7	-0.354	0.240	-0.550	0.303	0.665	δ=10.157-0.354(EI)
DF-A-ΔMC	5	-0.237	0.102	-0.801	0.642	0.408	δ=8.856-0.237(EI)
DF-B-MC	6	-0.032	0.527	-0.030	0.001	1.595	δ=7.817-0.032(EI)
DF-B-ΔMC	7	-0.212	0.173	-0.480	0.230	0.909	δ=9.268-0.212(EI)
DF-C-MC	8	-0.269	0.185	-0.509	0.259	0.858	δ=10.911-0.269(EI)
DF-C-ΔMC	6	-0.247	0.113	-0.738	0.544	0.455	δ=9.296-0.247(EI)

deflection. The exception, DF-B: Series I, exhibited more scatter about the regression than the other three cases.

The range of the regression coefficients of the four categories was from -0.004 to +0.1000. The range shows the variation in the influence of base moisture content on deflection (in inches x 10^{-3}/plf upper chord load) per 1.0% base moisture content units.

In Series II the trusses were tested after drying from a higher fabrication moisture content. The plotted data, regression lines and regression equations are given in Figures 23, 25, 27, and 29 for each case. There was an appreciable amount of scatter in Series II. This was also shown by the high standard of errors (Table 6) of the four categories. The coefficients of determination were small.

Three of the Series II categories had negative regression coefficients. All four regression coefficients differed appreciably in magnitude. Thus, there was no consistent trend. This contrasts to the decrease in stiffness discovered by Radcliffe and Sliker (14) under a similar change in moisture content. However, the Radcliffe and Sliker results were based only on one change in moisture content from an approximate fabrication moisture content of 18% to a test moisture content of about 6%. Their report was merely a ratio of two averages. Whereas in this investigation, ΔMC covered a general range, i.e. 24% to 10%, 18.4% to 10%, etc. Also, this study included a wide EI range and many lumber defects, while Radcliffe and Sliker had a narrow EI range and no defects.

The range of the four regression coefficients was from -0.009 to 0.067. The regression coefficients show the change in deflection (inches x 10^{-3}/plf upper chord load) per 1.0% change in moisture content.

The lumber in both series was often substantially warped, due to drying at the time of the test which may have distorted the results. The effect of EI was also hidden in the results. Statistical tests of significance were inconclusive for the reasons mentioned in Truss Deflection as a Function of Lumber EI.

Truss Deflection as Influenced by the Combined Interrelated Effects of EI and Moisture Content

Multiple regression equations approximated the combined interrelated effects of EI and moisture content on deflection. These regressions along with related statistical functions are given in Tables 8 and 9. EI and base moisture content (MC) are the independent variables in the four categories of Table 8, while EI and a change in moisture content (ΔMC) are the independent variables in Table 9.

In all categories, the standard errors of estimates were large, indicating substantial scatter, and the coefficients of determination were low.

In the six of the eight categories, the EI partial regression coefficients were negative. In the six cases, the magnitude of the partial regression coefficients was similar to those obtained in the simple regressions. The coefficients of determination of the multiple regressions were slight. In the remaining two categories, the positive partial regression coefficients were relatively small in magnitude.

The MC and ΔMC partial regression coefficients were not consistent in sign. But the magnitudes were small. These results are similar to those found in the simple regressions. The moisture content coefficients of determination of the multiple regressions were small.

Influence of Moisture Content History on Creep

Two measures of creep were used in this study: (1) the duration of time required to reach the "creep limit" under a given load level, and (2) the increase in deflection under the load for the forementioned time interval. The arbitrary measure of duration of time was the increase in time from an elapsed time of 0.1 minutes immediately after a 100 plf upper chord load was reached to the time at which the "creep limit" occurred. The increase in deflection was the difference between the deflection at an elapsed time of 0.1 minute and the deflection at the creep limit.

In two of the base moisture content categories (MC), an increase in moisture content corresponded to a slight increase in creep deflection and elapsed time. No consistent influence of moisture content on creep and elapsed time was found within the four change in moisture content series (ΔMC). Also, no consistent effect between the two series was found.

Effect of Lower Chord Load on Truss Deflection

The increment of deflection caused by the application of the 20 plf lower chord alone is shown in Table 10 for each of 51 trusses. The increase in deflection caused by the 20 plf lower chord load was substantially greater than the increase in deflection caused by a 20 plf upper chord load increment. The average deflection due to the lower chord load (.160 in.) divided by the average deflection at a 20 plf upper chord load (.126 in.) for the 51 trusses results in a ratio of 1.27:1.00. The ratio of the two mean deflections indicates that generally a 20 plf lower chord deflection is 27% greater than the deflection caused by a 20 plf upper chord load.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

1. Without regard for moisture content history, EI classification, and lumber species, the trusses fabricated with type A plates (nail-on) had less average midspan deflection than type B and type C as shown below.

Species	Plate Type*	Average Deflection (inches x 10^{-3}/plf)	Range (inches x 10^{-3}/plf)	No. of Trusses
W.C. Hemlock	A	5.82	4.90-6.44	12
Douglas Fir	A	5.61	4.88-6.75	12
Douglas Fir	B	6.90	5.22-9.29	13
Douglas Fir	C	6.89	5.01-9.21	14

*The plate type refers to sheet metal fasteners: type A, nail-on plates; type B, corrugated with triangular, hooked prongs; and type C, flat with rectangular teeth.

2. In the trusses fabricated with type A plates, the trusses manufactured with 1500 f grade Douglas fir had approximately the same average midspan deflection as those manufactured with clear West Coast hemlock lumber without regard for moisture content history and EI classification as shown above.

3. As average member stiffness EI, increased, the midspan deflection of the truss decreased.
4. Moisture content history (as either a base moisture content or a change in moisture content from fabrication to test) had a minor influence on truss deflection.
5. Moisture content history had no determinable effect on creep behavior characteristics.
6. In 2, 3, and 4 above, statistical significance was not found because of the small sample size, the small number of degrees of freedom, and scatter. Thus, the magnitude of the effects was not established. However, the consistent trends presented above existed.
7. Lower chord load had a substantially greater influence on truss deflection than a comparable upper chord load.
8. In order to determine whether the influence of any independent variable on deflection is statistically significant, it would be necessary to increase the sample size for the specific category to be studied. The research should be predesigned statistically so as to make statistical inference possible. Besides assuring an adequate sample size for each predesignated level within the range of the independent variable, all other variables would have to be controlled to close limits of variation.
9. Additional test data are needed to determine the effects of independent variables on the behavior of the joints

alone. A test program of joint behavior should be statistically designed as to number in samples. A rigid control of variables should be exercised.

APPENDIX I

Notation

a . . . . Y intercept

b . . . . Regression coefficient

D . . . . Deflection constant in inches per plf of upper chord load

EI . . . . Product of Young's Modulus of Elasticity and moment of inertia in lbs.-in.^{2}

L . . . . Span in inches

MC . . . . Base moisture content in %

ΔMC . . . . Decrease in truss moisture content from fabrication to test in %

P . . . . Concentrated load in pounds.

R . . . . Correlation coefficient

R^2 . . . . Coefficient of determination

S . . . . Standard error of estimate

S_b . . . . Standard error of the regression coefficient

X . . . . Independent variable

Y . . . . Dependent variable

δ . . . . Deflection in inches per plf of upper chord load

Δ . . . . Deflection in inches

APPENDIX II

Statistical Methods Used

In this investigation, statistical analyses were made in order to determine the influences of various factors on overall truss stiffness. Statistical determination of the dispersion, experimental error, and degree or correlation of the experimental data were also made. The relations between independent variable, truss deflection were statistically evaluated individually in simple regressions and jointly in multiple regressions. Extensive use of the Control Data 3600 digital computer operated by Michigan State University was made to compute the regressions and related statistics. Programming was simplified through the use of statistical CORE (COrrelation and REgression analyses) programs devised by Michigan State University's computer personnel (102). Computer output included regression coefficients, correlation coefficients, coefficients of determination, standard errors of estimates, means, and standard deviations. A discussion of these statistics will follow.

In some cases, the data suggested power series, logarithm or other non-linear curves as best fitting the data (see Figures 14-29). However, since there was no consistency in this regard among similar scatter diagrams, linear regressions were used as a best general form of equation to employ. Statistical tests of significance were not made because of the small sample sizes and the associated small degrees of freedom. However, measures of dispersion such as standard error of estimate and correlation coefficient were made.

Simple regressions relate one independent variable to the dependent variable. The relationship may be determined by locating a linear central trend through the plotted data points. This is mathematically accomplished by the least squares technique (104) where the sum of squares of y deviations of points about the line is minimized. The regression line passes through the intersection of the means of x and of y (the centroid of the data). The regression line of y on x is of the following form:

$$y = a + b_{yx}\, x \qquad (2)$$

where a is the y intercept and b_{yx} is the slope. The sequence of subscript, yx, indicates a regression of y on x or established y as the dependent variable.

The correlation between x and y is indicated in part by the slope, b_{yx} (called the regression coefficient). Should $b_{yx} = 0$, a horizontal line parallel to the x axis would result. Thus, any value of x would predict the general mean of y and no correlation would exist. Should b_{yx} be other than zero, then the best estimate of y would depend upon x and a correlation would exist. See Figure 31 for a graphical illustration of the simple regression line method.

In this study, D (in 10^3 in/plf units was always the dependent variable y). The independent variable was EI (in 10^6 lb-in^2 units), base moisture content (MC in % units), or the change in moisture content (ΔMC in % units).

The degree of dispersion of scatter must also be established. The standard error of estimate (S) measures the degree of association between actual y and the estimated y (y value calculated from the regression equation). The larger the standard error of estimate, the greater the scatter about the regression line. The standard error of estimate is in y units.

The standard error of the regression coefficient is calculated from:

$$S_b = \frac{S}{\sqrt{x^2}} \qquad (3)$$

It is used in tests of significance which will not be discussed in this investigation.

Another measure of the degree of association is the correlation coefficient (R). However, R is unitless and is used to compare the relative correlation of the

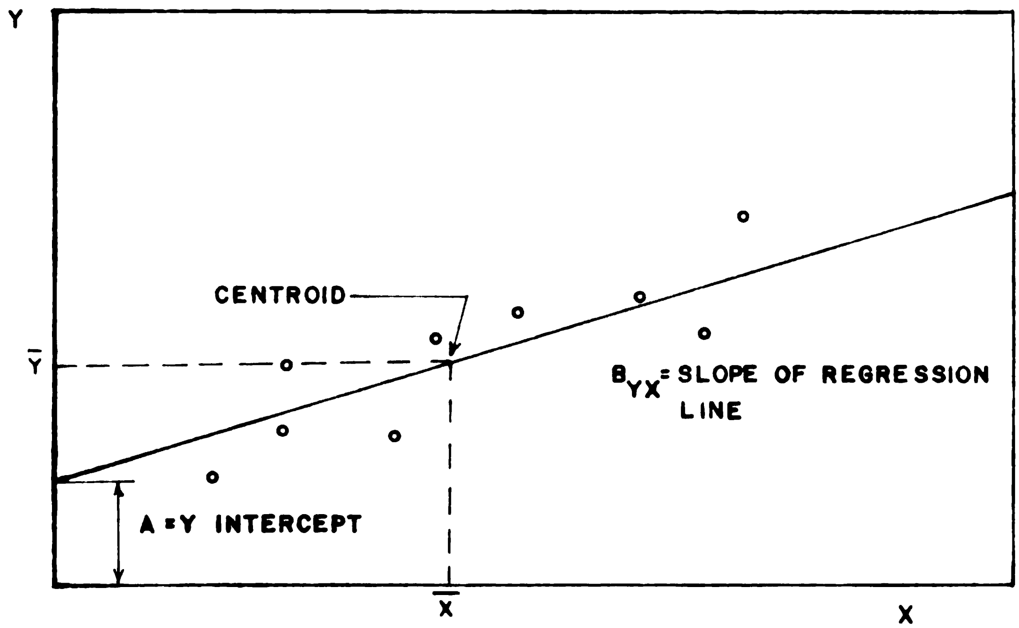


FIGURE 31

DIAGRAGRAMMATIC SKETCH OF THE REGRESSION: $Y = A + B_{YX}X$

regression to an R of another relationship. A perfect correlation results when R = 1.00 and no correlation results when R = 0.00. The coefficient of determination is the square of the correlation coefficient or R^2. The coefficient of determination multiplied by 100% indicates the per cent variance in y associated with the variance in x.

Multiple regression relates two or more independent variables, x, x_2, x_n, to the dependent variable y. The independent variables in this study were EI and either base moisture content (MC) or the change in moisture content (ΔMC). The deflection constant D was the dependent variable. A multiple regression equation represents the plane most closely associated with the volume of data points by having the sum of squares of y deviations of points about the plane minimized. The equation with two independent variables is of the following general form:

$$y = a + b_{y1.2}x_1 + b_{y2.1}x_2 \qquad (4)$$

where a is the y intercept and $b_{y1.2}$ and $b_{y2.1}$ are the partial regression coefficients. The sequence of subcripts, for instance, y1.2, indicates a net regression of y on x_1 allowing for x_2. Correlation is determined in a manner similar to the case for simple regression.

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