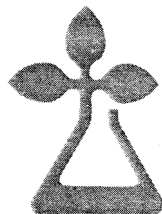


U. S. FOREST SERVICE
RESEARCH PAPER
- FPL 30 -
MAY 1965

SHRINKAGE OF COAST-TYPE
DOUGLAS-FIR AND
OLD-GROWTH REDWOOD
BOARDS



U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE

FOREST PRODUCTS LABORATORY

MADISON, WIS.

Summary

Information is presented on the shrinkage of coast-type Douglas-fir and old-growth redwood boards dried to near equilibrium at 6 percent and 12 percent moisture content. Linear regressions for shrinkage as a function of moisture content were determined for the radial and tangential shrinkage of each species using the method of least squares. Shrinkage values predicted from the regression equations compare very closely with other shrinkage information taken at moisture levels intermediate between green and oven-dry.

SHRINKAGE OF COAST-TYPE
DOUGLAS-FIR AND OLD-GROWTH REDWOOD BOARDS

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Introduction

Considerable information is available on the shrinkage of most commercial woods. Most of this, however, deals with the total shrinkage of short wood sections and is not necessarily representative of board-sized material. Furthermore, shrinkage data for moisture content values intermediate between the fiber saturation point and the oven-dry condition are very limited. Such information, especially for board-sized material, is important for a number of technical and practical reasons.

In 1928 Peck (4)² published curves showing shrinkage-moisture content relationships for Douglas-fir, ponderosa pine, and southern pines. Redwood shrinkage data were also obtained but not published. The study was unique in that mild drying conditions were used on board-sized specimens of flat- and edge-grained material. This report is a reanalysis of Peck's data using statistical techniques to establish the best fitting linear regression relationships between tangential and radial shrinkage and moisture content for coast-type Douglas-fir and old-growth redwood. Values from these regressions are used to calculate average width and thickness shrinkage from green to 15 percent moisture content for boards having different average growth ring angles. The application of this shrinkage information for calculating equivalent green and dry sizes and for calculating dimensional changes in dry lumber associated with changes in moisture content is described in the Appendix.

¹Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

²Underlined numbers in parentheses refer to the Literature Cited at the end of this report.

Background

The shrinkage of wood is defined as the reduction in dimension of lumber due to the loss of moisture and it is always expressed in the United States as a percentage of the green dimension. The relationship between shrinkage and moisture content has been thoroughly studied. One method of approximating the shrinkage of wood to any given moisture content assumes a linear relationship between shrinkage and moisture content from the fiber saturation point to the oven-dry condition (8). The average fiber saturation point for all species of wood is considered as 30 percent moisture content. This procedure gives reasonably accurate shrinkage determinations, but it has two basic limitations. First, the true relationship between shrinkage and moisture content is not exactly linear and second, the fiber saturation point, or more appropriately the shrinkage intersection point, is not a constant value for all species. It may, in fact, vary within species as well as between species.

Several investigators have indicated that the relationship between shrinkage and moisture content is essentially linear from near oven-dry up to 16–20 percent moisture content (1), (2), (6). Wilson (6) suggests about 4 percent moisture content as the lower limit for the linear relationship. Beyond these upper and lower limits the shape of the curve is sigmoid. If a true linear relationship between shrinkage and moisture content is established within the range of 4 to 18 percent moisture content, then the shrinkage from green to any moisture content within this range can be accurately predicted. The errors due to the variable fiber saturation point and the nonlinear portions of the shrinkage–moisture content relationship are avoided.

To predict shrinkage in board material to a given moisture content it is also important to consider growth ring orientation. MacLean (3) determined the effect of ring angle on the shrinkage in width and thickness of boards that were not true flat- or edge-grained. The following equations apply:

$$S_{\text{width}} = S_T \cos^2 \theta + S_R \sin^2 \theta \quad (1)$$

$$S_{\text{thickness}} = S_T \sin^2 \theta + S_R \cos^2 \theta \quad (2)$$

where: S_{width} = percent shrinkage in width

$S_{\text{thickness}}$ = percent shrinkage in thickness

S_T = percent tangential shrinkage

S_R = percent radial shrinkage

q = angle between growth rings and flat face of the board

Equations (1) and (2) in conjunction with the regression equations, which are given later in the report for tangential and radial shrinkage, can be used to calculate the shrinkage in width and thickness for lumber drying to any moisture content in the range of 4-18 percent and having any assumed or known average ring angle.

Materials and Methods

Two types of samples were used, flat-grained or plainsawed boards, and edge-grained or quartersawed boards. Only those boards which had nearly perfect grain orientation were used. The specimens were 7/8 inch thick by 5-1/2 inches wide by 8-1/2 inches long and were end coated with a mixture of aluminum powder and shellac to prevent end drying. In the analysis of redwood specimens, 77 flat-grained and 35 edge-grained boards were used, There were 93 flat-grained and 82 edge-grained Douglas -fir boards.

The Douglas-fir was all coast-type material obtained from four mills. The redwood was all old-growth material obtained from two mills in the redwood region. Previously published data indicate that the shrinkage of second-growth redwood is slightly greater than that of old growth (5), (8), and the shrinkage of coast-type Douglas-fir is greater than that of the intermediate or Rocky Mountain type (8). On this basis, the information presented in this report should be considered as applying strictly to coast-type Douglas-fir and old-growth redwood.

The schedule used for drying the material was devised to simulate air drying. The temperature was held at 90° F. throughout the schedule. The specimens were dried to near equilibrium with two different relative humidities; (1) 60-65 percent relative humidity giving an approximate equilibrium moisture content of 12 percent, and (2) 30 percent relative humidity with an approximate equilibrium moisture content of 6 percent.

Some of the specimens of redwood did not approach equilibrium at 60-65 percent relative humidity. In this case specimens in excess of 18 percent moisture content were eliminated from the data, since the shrinkage curve above 18 percent is no longer linear. Measurements were made at the green condition, near

equilibrium at 60-65 percent relative humidity, and near equilibrium at 30 percent relative humidity. The specimens were then oven-dried and the oven-dry dimensions determined.

The measurements made on all specimens were width, thickness, and weight. Thickness and width were measured to the nearest 0.001 inch and weight was measured to the nearest gram. Width was measured at the midpoints on the specimens and thickness was measured at midlength 1 inch from one edge of the boards. The width data of flat-grained boards and the thickness data of edge-grained boards were used to calculate tangential shrinkage. Radial shrinkage was calculated from the thickness of flat-grained and the width of edge-grained boards. Shrinkage percentages were based on green dimension. Moisture content values based on oven-dry weight were calculated from the weight data. These shrinkage and moisture content values were used to establish linear relationships between shrinkage and moisture content.

The data were analyzed using the least squares method to obtain the linear regression relationships between shrinkage and moisture content in the tangential and radial directions. Regressions were initially determined from both types of boards separately and two tangential and two radial shrinkage regressions resulted. There were differences between the two types of boards, but they were relatively small and not consistent. Therefore, all subsequent analysis was made by combining the data from the two types of boards to obtain radial and tangential shrinkage information.

Discussion of Results

To illustrate the nature of the shrinkage information and the amount of variability that occurs in shrinkage of wood dried to near equilibrium moisture content, the individual tangential shrinkage measurements have been plotted as scatter diagrams from 1 mill for both Douglas-fir (fig. 1) and redwood (fig. 2). The regression relationship obtained from that information is plotted on the same graph. The variation about the regression line illustrates the wide variation in shrinkage between boards even within a given species. Thus, the shrinkage values predicted from the regression equations cannot be applied with accuracy to individual boards, but they can be applied to quantities of lumber for accurate average shrinkage predictions.

The regression lines obtained from the various mills along with the average from all mills are shown in figures 3 to 6. There are some differences between mills. A statistical evaluation of the residual sum of squares accounted for by

using separate regressions for the individual mills indicates that the regressions for the individual mills are significantly different at the 99 percent level of significance for Douglas-fir, but not significantly different for redwood. The differences, while statistically significant, are actually small relative to the amount of shrinkage occurring. Since these mills are randomly located throughout the producing regions for each of these species, the agreement of the various regression equations indicates that the true average regression is probably quite close to the average observed here.

The average regression equations for Douglas-fir are as follows:

$$S_T = 6.962 - 0.2622 M$$

$$S_R = 4.321 - 0.1470 M$$

where \underline{S}_T and \underline{S}_R are as defined previously and \underline{M} is percent moisture content.

For redwood the regression equations are:

$$S_T = 3.951 - 0.1831 M$$

$$S_R = 2.274 - 0.0991 M$$

The analyses of variance for Douglas-fir and redwood are shown in tables 1 and 2 respectively. The F ratios are in all cases very highly significant as expected. This means that the relationship between shrinkage and moisture content is real and not due to chance.

The mean squares about regression in tables 1 and 2 are estimates of the variances about the mean shrinkage values calculated from the regression equations. The square root of the mean square is an estimate of the standard deviation. In the strictest sense, this mean square applies only at the mean moisture content of the data used in the computation, which was about 9 percent for Douglas-fir and 11 percent for redwood. However, the mean squares given could be applied at other moisture content levels without excessive error.

The effect of growth ring angle on the shrinkage in width and thickness of board material is shown in table 3. Shrinkage values were calculated for ring angles of 0°, 15°, 30°, and 45° at 15 percent moisture content. Equations (1) and (2) and the regression relationships were used to calculate these values.

The shrinkage values determined from the equations were compared with other shrinkage information at intermediate moisture content values. Espenas³ and others have determined the shrinkage to a moisture content of 15 percent of randomly selected Douglas-fir 2- by 8-inch-dimension lumber. This lumber was not selected for ring angle and the shrinkage which occurred was neither truly radial nor tangential but represented average shrinkage for an average ring angle. The shrinkage values determined were 2.73 percent in width and 2.35 percent in thickness measured at a distance of 2 inches from the board edge. A slightly smaller thickness shrinkage, 2.26 percent, was observed at midwidth. The average ring angle for this material was 29°. Comparing the shrinkage values in table 3 for a 30° ring angle of 2.80 percent in width and 2.34 percent in thickness with the values of Espenas, it is evident that they agree very closely.

Wood and Soltis (7) have studied the shrinkage of randomly selected joists of Douglas-fir. They found the shrinkage to 15 percent moisture content to be 2.7 percent in width and 2.2 percent in thickness, which also agrees well with the values given here at a 30° average ring angle. Schniewind (5) has published information on the shrinkage of old-growth redwood in the radial and tangential directions to various moisture levels in the hygroscopic range. These shrinkage values are compared with the values calculated from the regression equation for the appropriate moisture content values in table 4. These also agree very closely.

Summary and Conclusions

Linear regression relationships between shrinkage and moisture content were calculated from tangential and radial shrinkage information on Douglas-fir and old-growth redwood boards using the least squares method. Previous research indicates that these should be applicable in the range of about 4 to 18 percent moisture content.

Previously derived equations, relating thickness and width shrinkage of boards to ring orientation, tangential shrinkage, and radial shrinkage were used to calculate thickness and width Shrinkage for various ring angles at 15 percent moisture content. The tangential and radial shrinkage values obtained from the regression equations were used in these calculations.

There is considerable variation in shrinkage about the regression equations and predicted values of shrinkage apply only to averages and not to individual boards.

Shrinkage values predicted from the regression equations are in good agreement with other data on shrinkage to intermediate moisture content values.

³Espenas, L. D., Snodgrass, J. D., and Kozlik, C. J. 1963. Shrinkage of 2 by 8 inch Douglas-fir lumber. Preliminary Report, Forest Research Laboratory, Oregon State University, Corvallis.

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APPENDIX

Application of Shrinkage Data to Calculate Change in Lumber

Size With Change in Moisture Content

Industry practices in the surfacing of lumber vary with respect to the moisture content at which it is surfaced. Lumber may be surfaced in the green condition or at some lower moisture content. In service, lumber will come to a moisture content consistent with the surrounding environment regardless of the moisture content at which it was manufactured. If a standard size is established for lumber at a moisture content approaching that which it might reach in service, lumber which is surfaced green must have a somewhat greater thickness and width than the standard to compensate for the reduction in size which will occur in drying from green to the reference moisture content. That green size which will, on the average, yield dimensions equal to the standard size at the reference moisture content, is termed the equivalent green size in this paper.

Another useful determination is the change in lumber dimension which may occur between two levels of moisture content in the hygroscopic range. For instance, if a sample of lumber at a low moisture content is below the specified size, it may be desirable to have a means of estimating the change in dimension that could occur between two moisture content values. Knowing the expected change one can judge whether the deficiency in dimension resulted from a moisture content change or from some other factor.

This Appendix illustrates methods for using the shrinkage data given in the body of the paper. It presents a method for calculating the size to which green lumber should be surfaced in order that, at some given lower moisture content, it may be expected to be the same size as lumber surfaced at the lower moisture content. Also, it presents a method for estimating the change in size of lumber subjected to a change in moisture content in the hygroscopic range.

In general, shrinkage is defined by the following equation:

$$S_M = \left(\frac{D_G - D_M}{D_G} \right) \times 100 \quad (3)$$

Where: S_M = Shrinkage from green to M percent moisture content (percent)

D_G = Dimension green

D_M = Dimension at M percent moisture content

Rearranging this equation, the green dimension can be expressed as a function of the dimension at moisture content M and the shrinkage to moisture content M.

$$D_G = \frac{D_M}{\left(1 - \frac{S_M}{100}\right)} \quad (4)$$

For purposes of illustration, 15 percent moisture content will be used as the reference and 30° as the ring angle. Width and thickness shrinkage values for Douglas-fir and redwood are given for these conditions in table 3. Using equation (4), and the thickness and width shrinkage values from table 3, the equations for equivalent green width and thickness of Douglas-fir are as follows:

$$\text{Thickness green} = \frac{\text{thickness at 15\% MC}}{0.9766}$$

$$\text{Width green} = \frac{\text{width at 15\% MC}}{0.9720}$$

For redwood, the corresponding equations are as follows:

$$\text{Thickness green} = \frac{\text{thickness at 15\% MC}}{0.9911}$$

$$\text{Width green} = \frac{\text{width at 15\% MC}}{0.9890}$$

To illustrate the method of calculating equivalent green sizes for Douglas-fir and redwood, several possible widths and thicknesses at 15 percent moisture content were used as a basis. The results given below are determined to the nearest 0.001 inch. The fractional equivalents in parentheses are obtained by rounding to the nearest 1/32 inch for thickness and to the nearest 1/16 inch for width.

<u>Size at 15</u> <u>moisture content</u>	<u>Equivalent green size</u>	
<u>In.</u>	<u>Coast-type Douglas-fir</u>	<u>Old-growth redwood</u>
	<u>In.</u>	<u>In.</u>
	<u>Thickness</u>	
3/4	0.768 (25/32)	0.757 (3/4)
1	1.024 (1-1/32)	1.009 (1)
1-1/2	1.536 (1-17/32)	1.513 (1-1/2)
1-9/16	1.600 (1-19/32)	1.576 (1-9/16)
1-5/8	1.664 (1-21/32)	1.640 (1-5/8)
	<u>Width</u>	
2-5/8	2.701 (2-11/16)	2.654 (2-5/8)
3-5/8	3.729 (3-3/4)	3.665 (3-11/16)
5-1/2	5.658 (5-11/16)	5.561 (5-9/16)
7-1/2	7.716 (7-11/16)	7.583 (7-9/16)
9-1/2	9.774 (9-3/4)	9.606 (9-5/8)
11-1/2	11.831 (11-13/16)	11.627 (11-5/8)

By using the linear regression relationships between shrinkage and moisture content as given in this paper and equations (1) and (2), accurate calculations of equivalent green sizes for Douglas-fir and old-growth redwood can be made for any combination of ring angle, dimension, and moisture content in the range of 4 to 18 percent.

The idea of equivalence here is based on an average. As illustrated in figures 1 and 2, there is considerable variability in the shrinkage of individual boards. There is also considerable variability in ring angle between boards produced commercially. Thus, when green lumber manufactured to an equivalent size dries to the reference moisture content, the dimensions of individual pieces will vary and some will be larger and some smaller than the size desired, but, on the average, equivalence may be expected.

Another valuable calculation is the change in dimension of a piece of lumber in drying from a higher to a lower moisture content within the hygroscopic range. Changes of this sort can also be predicted from the regression equations and equations (1) and (2) for ring angle adjustment. To arrive at the equation for this type of calculation, consider equation (4). For a given lot of lumber, the dimension green \underline{D}_G is constant and \underline{M} is any moisture content. Therefore,

$$\frac{D_{M1}}{\left(1 - \frac{S_{M1}}{100}\right)} = \frac{D_{M2}}{\left(1 - \frac{S_{M2}}{100}\right)} \quad (5)$$

where the subscripts M1 and M2 denote two different moisture content values. Rearranging to solve for the dimension at M2 yields

$$D_{M2} = \frac{D_{M1}}{\left(1 - \frac{S_{M1}}{100}\right)} \left(1 - \frac{S_{M2}}{100}\right) \quad (6)$$

As an example, consider the shrinkage in width of a Douglas-fir board in drying from 15 percent to 10 percent moisture content when its dimension at 15 percent is 7-1/2 inches. Assuming an average ring angle of 30°, the width shrinkage to 15 and 10 percent moisture content can be calculated from the two regression equations and equation (1). The values calculated are 2.80 and 3.97 percent respectively. The estimated width D_{M2} , at 10 percent moisture content, is then calculated as follows:

$$\begin{aligned} D_{M2} &= \left(\frac{7.500}{0.9720} \right) (0.9603) \\ &= 7.410 \text{ inches} \end{aligned}$$

Table 1. --Analysis of variance for Douglas-fir shrinkage regressions

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F ratio
<u>Radial</u>				
Due to regression	1	41.9980	41.9980	¹ 103.5
About regression	348	141.2032	0.4058	
Total	349	183.2012		
<u>Tangential</u>				
Due to regression	1	133.0779	133.0779	¹ 150.3
About regression	347	307.1948	0.8853	
Total	348	440.2727		

¹ Significant at the 99.9 percent level.

Table 2.--Analysis of variance for redwood shrinkage regressions

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F ratio
<u>Radial</u>				
Due to regression	1	14.7788	14.7788	¹ 113.8
About regression	222	28.8067	0.1298	
Total	223	43.5855		
<u>Tangential</u>				
Due to regression	1	50.3981	50.3981	¹ 200.5
About regression	222	55.8174	0.2514	
Total	223	106.2155		

¹ Significant at the 99.9 percent level.

Table 3. --Percent shrinkage to 15 percent moisture content for various ring angles

Species	Ring angle			
	0°	15°	30°	45°
Douglas-fir:				
Width	3.03	2.97	2.80	2.57
Thickness	2.12	2.18	2.34	2.57
Redwood:				
Width	1.20	1.18	1.10	1.00
Thickness	0.79	0.82	0.89	1.00

Table 4.--Comparison of old-growth redwood shrinkage as determined by the University of California Forest Products Laboratory (5) with shrinkage values obtained from the regression equations

Moisture content:		Tangential shrinkage:		Moisture content:		Radial shrinkage	
:California study		:Regression		:California study		:Regression	
Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
7.50	2.70	2.58	7.80	1.41	1.50		
13.00	1.45	1.57	13.40	0.70	0.95		
17.90	0.41	0.67	17.80	0.25	0.51		

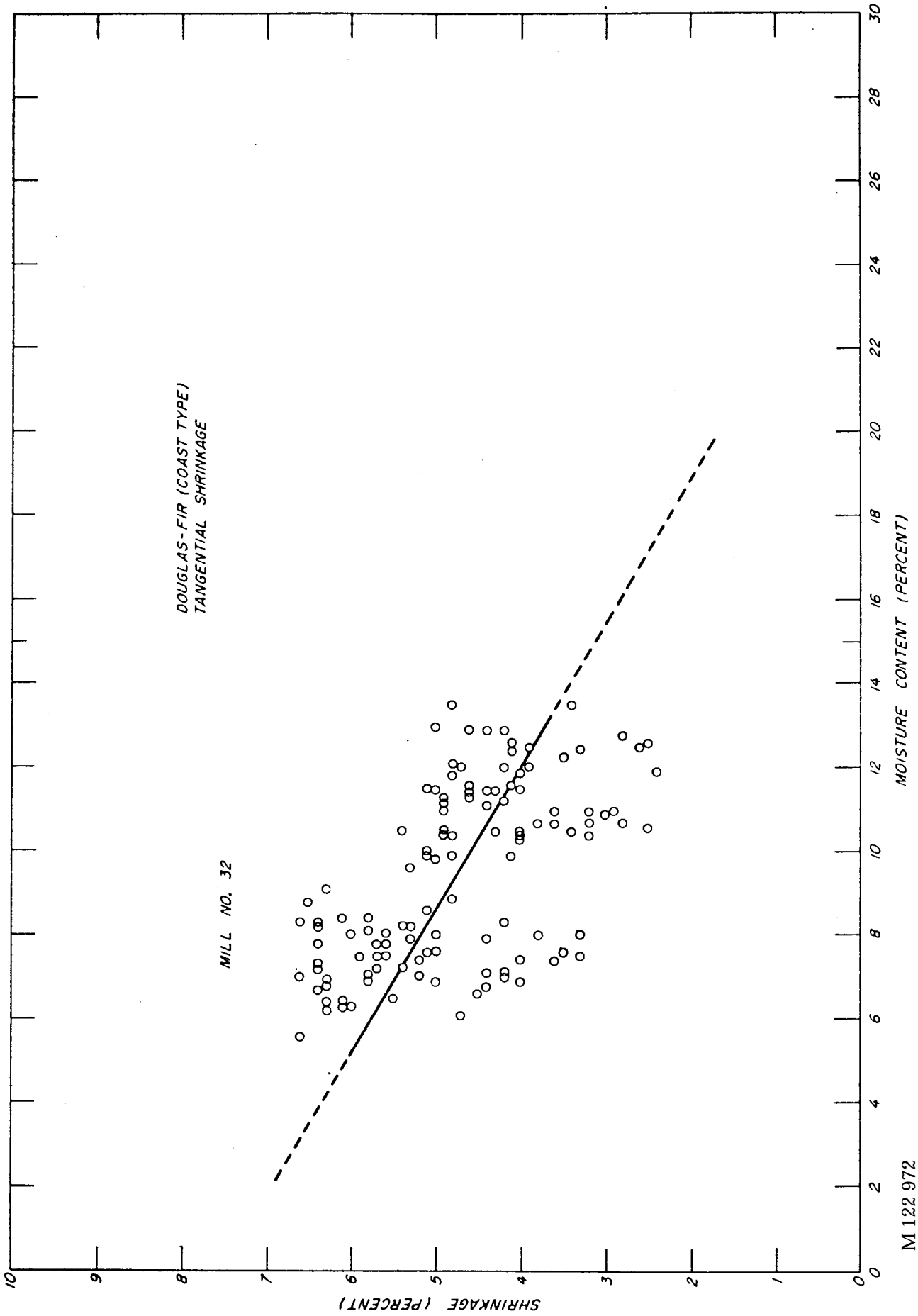
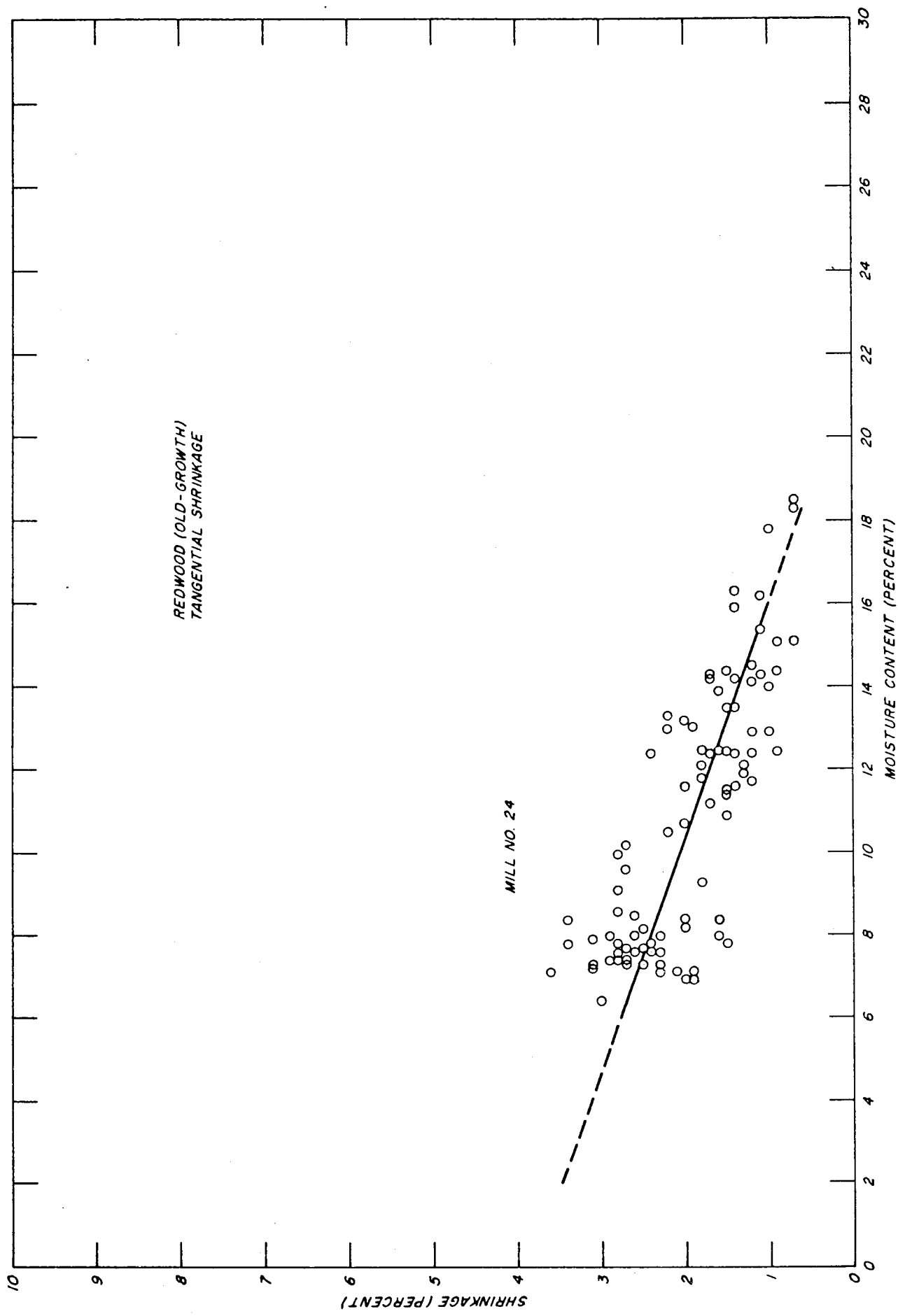


Figure 1.--Scatter diagram showing tangential shrinkage of individual samples and regression line for Douglas-fir from Mill 32.

M 122 972



M 128 068

Figure 2.--Scatter diagram showing tangential shrinkage of individual samples and regression line for old-growth redwood from Mill 24.

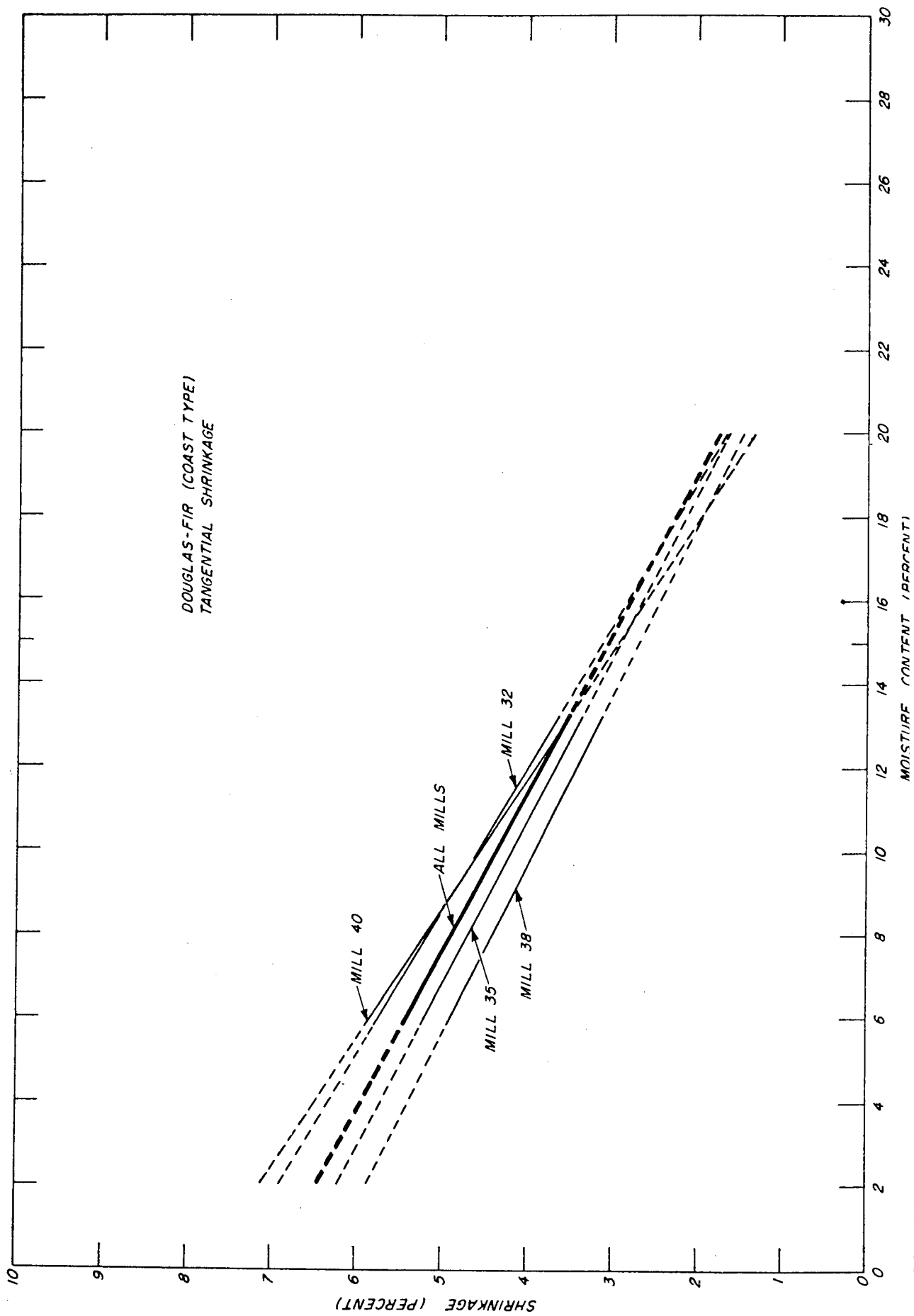


Figure 3.--Regression lines for tangential shrinkage of Douglas-fir from four mills.

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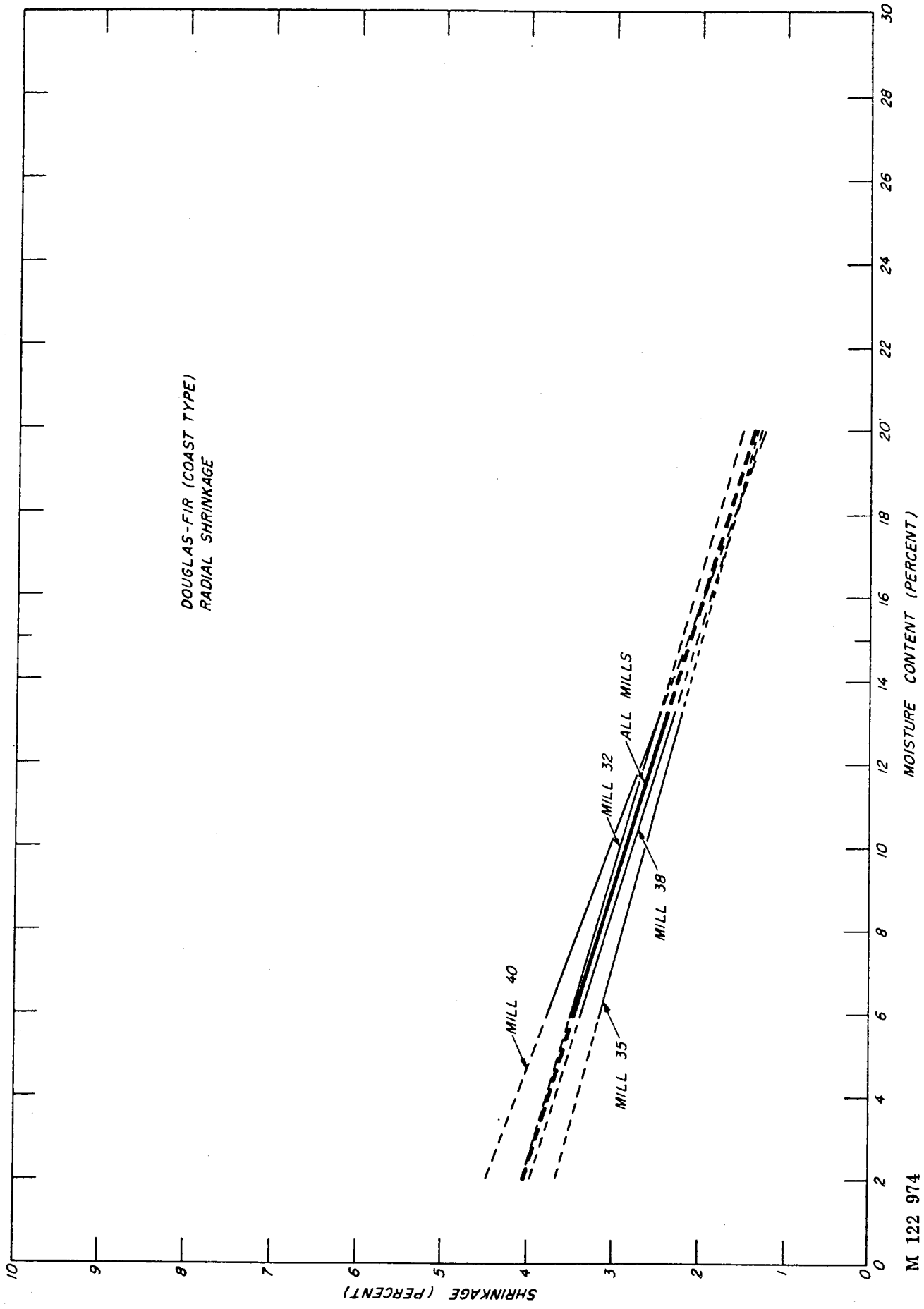


Figure 4.--Regression lines for radial shrinkage of Douglas-fir from four mills.

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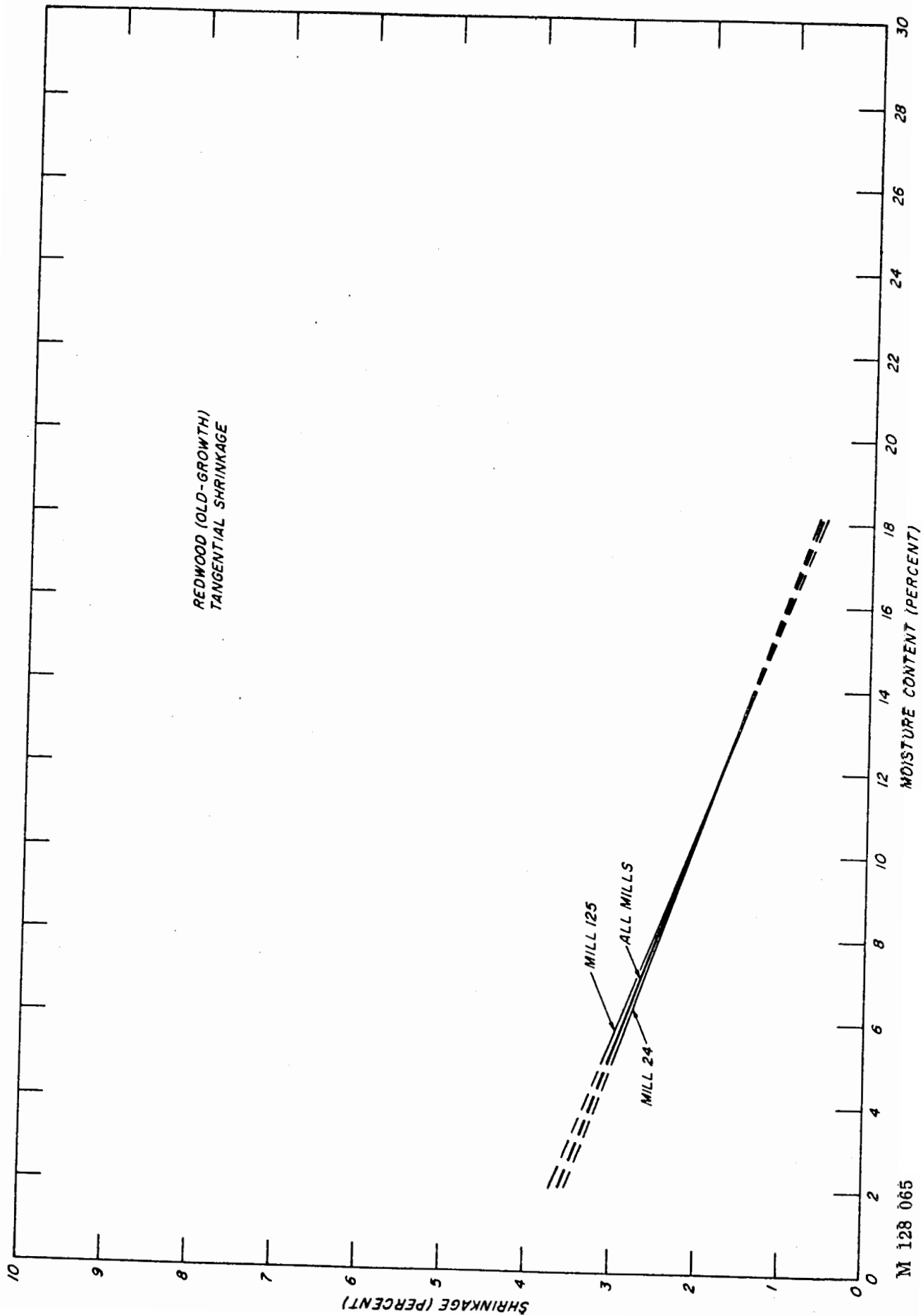
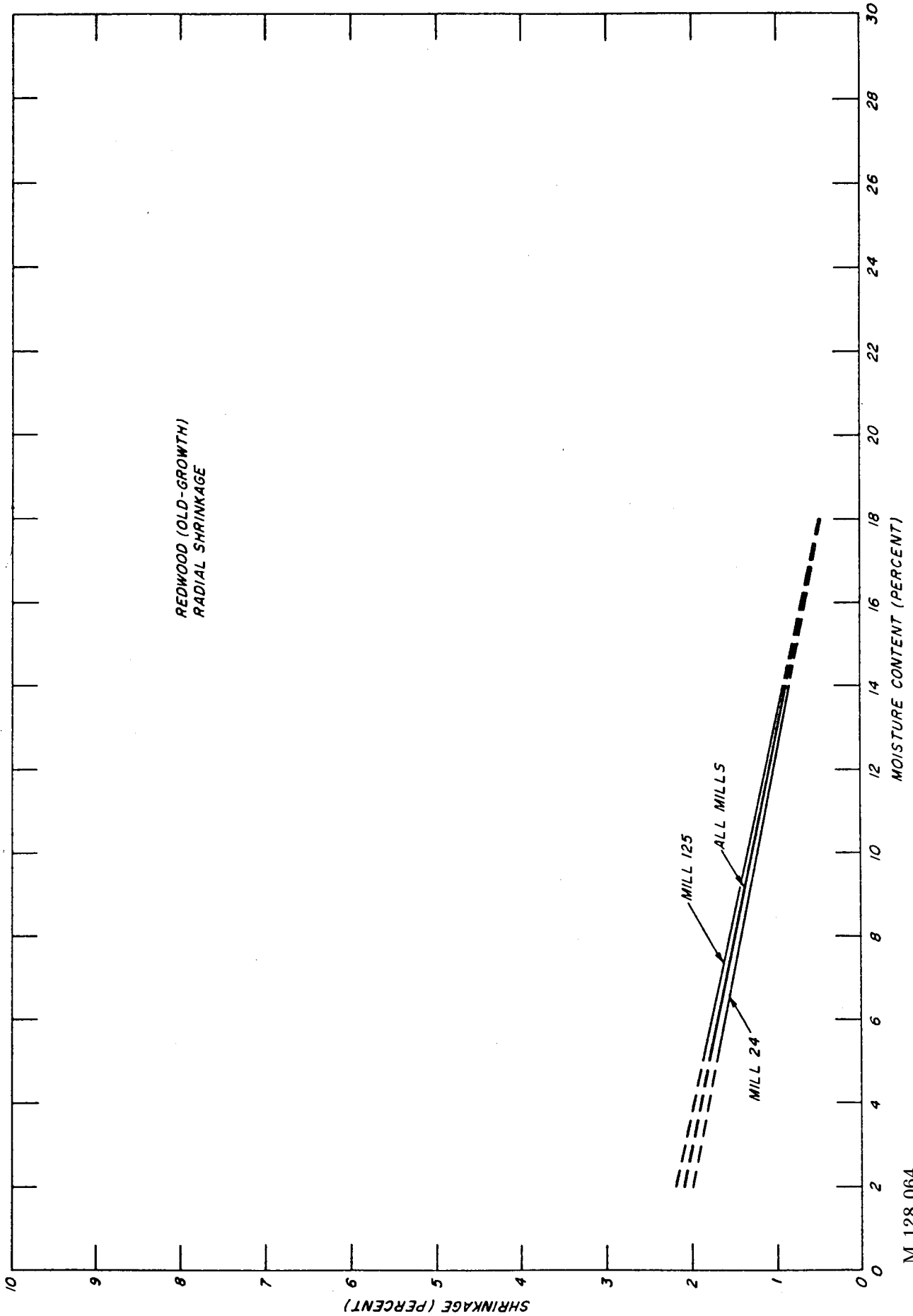


Figure 5.--Regression lines for tangential shrinkage of old-growth redwood from two mills.



M 128 064

Figure 6.--regression lines for radial shrinkage of old-growth redwood from two mills.

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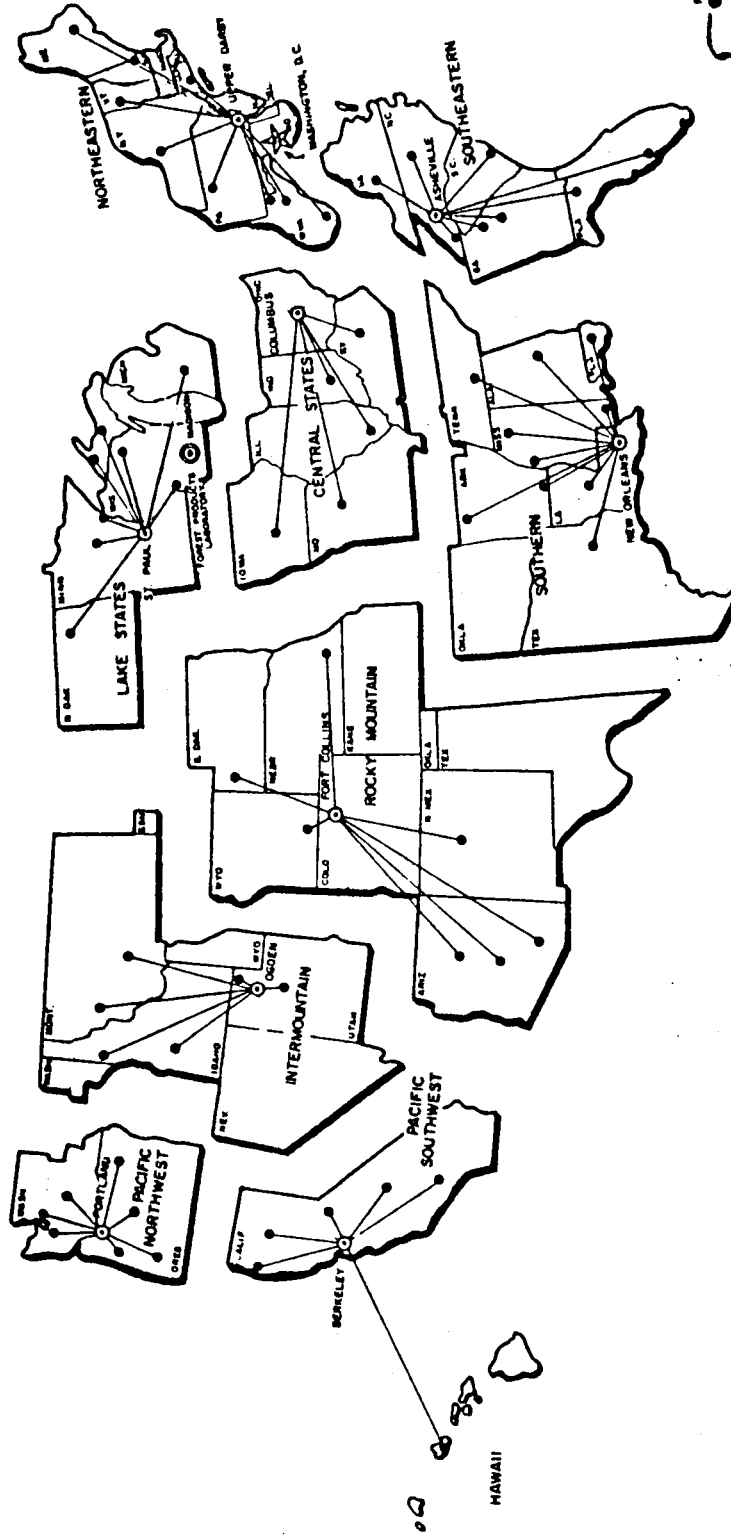
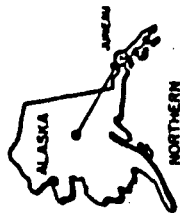
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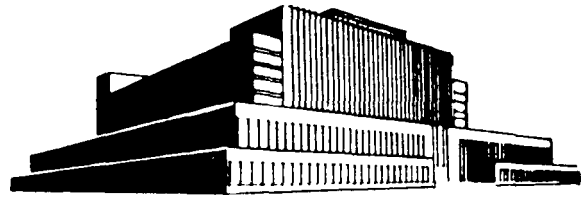
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