Initial Study of Kiln Drying Clear Douglas Fir Planks

By

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SUMMARY

Checking was influenced by drying conditions. This influence was greatest before average moisture content reached 20 per cent, but tension in surface layers caused checking even below this point.

Neither high initial dry-bulb temperature nor initial conditions of high equilibrium moisture content were conducive to checking.

High temperature and high equilibrium moisture content conditions resulted in some darkening of lumber.

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INTRODUCTION

The present study concerned the effect of drying schedules on shrinkage and checking in wide, flat-grained, clear, Douglas fir lumber. The volume of such lumber to be dried is not large, but potential high value of the finished product makes care in drying worthwhile, if degrade from checking or discoloration can be kept low.

Work reported here was part of a broad investigation of stresses in drying lumber. Incomplete understanding of the effects of temperature and relative humidity on development and severity of stresses in drying lumber has led to various studies aimed at comprehension and control of such stresses.

Previous work

Stress development in lumber drying has been studied for hardwoods much more than for softwoods. Stress distribution was studied during drying of a 2- by 10-inch, flat-grained, heartwood sweet gum plank at the U.S. Forest Products Laboratory (1)*. This study, and subsequent studies on other hardwood species, involved stress slices--thin sections cut to measure strain and thus indicate type and severity of stress from surface to center of wood during drying. McMillen (2) investigated the effect of variation in relative humidity on tensile and compressive stresses, at right angles to grain, in drying 2-inch red oak at 110 F. He reported that it was possible to re-establish near-maximum tensile strain in the surface by abrupt reduction of relative humidity after the point of maximum strain had been passed. This reduction did not cause further surface checking. McMillen (3) also studied the effect of temperature variation from 30 F to 140 F on stresses in 2-inch red oak when a mild humidity schedule was used. He found that high temperatures increased tensile stress at the surfaces and, to a great extent, compression set in the core, thereby increasing over-all total shrinkage. Stress reversal at the surface layer occurred at about 30 per cent average moisture content.

Unreported preliminary studies of stress in 2-inch Douglas fir and West Coast hemlock clears at the Oregon Forest Products Laboratory, in which the same general techniques employed by McMillen were used, indicated that development of drying stress in softwoods differs somewhat from that of hardwoods. This difference is

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* Numbers in parentheses refer to literature cited at end of report.

primarily the comparatively low moisture content at which reversal of stresses occurs in Douglas fir and in West Coast hemlock. Tensile strain persisted in the surface layers with both species, although decreasing, until the average moisture content was about 17 per cent, at which point typical reversal of stresses took place. Magnitude of the strain measurements was only about half as great as that found in the hardwood studies. Use of this information in developing schedules for clear items of Douglas fir lumber was a factor of concern in the present study

Approach to the problem

The present study was designed to point out important variables that affect shrinking and surface checking. It was desired to learn when, and under what drying conditions, maximum danger of surface checking occurs, and what schedule patterns will minimize danger of surface checking.

PROCEDURE

Schedules

Nine different schedules were chosen arbitrarily to represent 3 temperature ranges and 3 EMC (equilibrium moisture content) series as follows:

Dry-bulb temperature

A. 120 to 180 F in steps
B. 170 F constant
C. 200 F constant

EMC Series

1. Based on average moisture content

Per cent	EMC
Green to 30	17-19
30 to 25	13
25 to 20	11
20 to 15	9
15 to final	7

2. Based on moisture content of wettest sample

Green to 20	15
20 to final	3

3. Based on moisture content of wettest sample

Green to 20	8
20 to final	5

The different charges were referred to by number for EMC condition and by letter for temperature; eg., 2C was dried with EMC steps of 15 and 3 per cent at 200 F dry-bulb temperature. A repeat charge of 1C was, however, designated as 1C-1. Rough-green planks were dried to about 11 per cent moisture content in two small dry kilns, according to the chosen schedules. No conditioning was done. Checking, shrinking, and weight loss were recorded after six hours of drying and daily thereafter.

Comparative schedules

Five commercial kiln schedules for drying wide, clear, two-inch Douglas fir lumber are given in Figure 6. Three of the five schedules show gradually decreasing EMC with increasing dry- and wet-bulb temperature. This treatment is similar to that in schedule 1A used in the research.

Material dried

Source. Twenty pieces, 2 by 12 by 30 inches in size, of flat-grain, C and Better Douglas fir lumber were chosen for each of the nine scheduled charges. Restriction to clear lumber reduced influence of knots on check development. Material was selected randomly from two sources in Oregon, Coos Bay and the western slope of the central Cascade mountains. Because of limited cold-storage facilities, the material had to be obtained in two batches, making a true random selection of lumber impossible. Pieces for the following schedules were end-matched: 1B with 1C, 2B with 1C-1, and 3B with 3C.

Condition. Rough-green material was obtained in 12-foot lengths to minimize effect of end-drying. Average moisture content ranged from 35 to 40 per cent, and checking was negligible. Most of the material was old-growth, with an average of 28 growth rings per inch (see Figure 1). Average specific gravity was 0.47 on a green volume basis.

Preparing specimens

Each 12-foot plank was halved, and pairs of 30-inch kiln samples were cut from each 6-foot length, as shown in Figure 7. A 1-inch cross section for specific gravity determination was removed between each pair of pieces. Three sections were cut from ends and between each 6-foot pair to ascertain initial moisture content. Average ring count per inch was determined also. The ends of each 30-inch sample were coated with a urea resin to retard end-drying, and the mid-length was marked across the width and depth.

Drying specimens

Two charges of 20 pieces each were dried simultaneously. Other pieces awaiting seasoning were stored at 35 F and EMC of about 20 per cent. The 20 pieces to be dried in a kiln charge were piled and stickered in one vertical tier crosswise to the air flow. Potentiometer readings were made periodically to check the kiln's recording instruments.

Recording data

Periodic measurements of shrinkage during drying were made at the mid-length with an adjustable square having two miters. This method gave a reading of maximum thickness or width, rather than the distance from point to point between centers of width and depth.

After six hours of drying and daily thereafter, checks, shrinkage, and weight loss of the pieces were recorded. Checks were classified according to definitions of the West Coast Lumbermen's Association as follows:

Large checks; Over 10 inches long or over 1/32 inch wide
Medium checks; 4 to 10 inches long, up to 1/32 inch wide
Small checks; Less than 4 inches long.

Only those checks intersecting the mid-length line of the bark-side face of the pieces were tallied. Theoretically, maximum checking develops on the bark-side face of flat-grain lumber, since this face is more truly tangential than is the pith-side face. At completion of drying, a 1-inch cross section was sawed from the center of each piece and was oven-dried to determine final moisture content and to adjust the periodic approximations of moisture content.

RESULTS

A review of data for each charge is given in Tables 1, 2 and 3. Drying time varied from 6 days to 15 days; the shorter time was with schedules having low EMC conditions and high temperature. A total of from 12 to 24 hours kiln down-time was required for periodic inspection of each charge. Final averages of moisture content varied from 9.5 to 12.2 per cent among the charges.

Check development

Check development is shown in Figures 3 and 4, with kiln schedules for reference. Checks, especially large ones evident after surfacing, tended to increase until moisture content was about 20 per cent. Checks tended to close thereafter, even when conditions were changed to allow lower EMC. This performance indicated a reversal of stress in the drying specimens. Pieces in charge 2C, however, showed some increase in numbers of large checks after an abrupt change from 15 to 3 per cent EMC conditions at 20 per cent average moisture content. This is the trend that McMillen (2) reported; namely, that it is possible to increase tensile strain in the surface by abrupt reductions of relative humidity after the maximum has been passed. Some increase in medium and small checks below 20 per cent average moisture content was caused by closing of previously existing checks, by large checks becoming medium, and by medium checks becoming small. The cause for numerous large checking in charge 3A was not fully understood. No medium or small checks were evident after the sample pieces were surfaced.

Schedules 2B and 1C appeared to cause least severe checking; the re-run of schedule 1C verified this conclusion. Drying schedules and drying rates for charges showing least (1C-1) and most (3A) severe checking are diagramed in Figure 5.

Frequency of the three types of checks for each charge of 20 specimens is shown in Table 4. Frequency is represented as the maximum percentage of pieces with each type of check. For example, in schedule 1B, 20 per cent of the charge (4 pieces, developed large checks during drying.

Shrinkage

Shrinkage values at 28, 20, and 12 per cent moisture content are shown in Tables 1, 2, and 3. There was some indication that shrinkage was low with low dry-bulb temperature and low EMC conditions, as in schedule 2A. This low shrinkage may have been caused by increased external tension set, as shown in McMillen's work (3). Most shrinkage values were erratic, however. Radial exceeded tangential shrinkage in all schedules except 2B and 2C. If average values of tangential and radial shrinkage at 28, 20 and 12 per cent moisture contents are plotted, and the resulting curves extrapolated to the oven-dry point, shrinkage values approach those published (4), namely 5.0 per cent radial and 7.8 per cent tangential shrinkage from green dimensions to oven-dry dimensions.

The method of measuring might account for erratic shrinkage values, particularly in radial dimensions, encountered in the present study. The 3 1/2-inch miters on the square used to measure thickness change could extend to only about a quarter of the sample width to measure radial dimensions. Rapid edge-drying at beginning of runs would cause greater shrinkage at edges than at center of width. Radial shrinkage, therefore, might appear to exceed tangential shrinkage.

Color

There was some indication that high dry-bulb temperature and EMC conditions darkened the lumber (see Figure 2). This reaction seemed to extend through the entire thickness and could not be removed by planing.

CONCLUSIONS

On the basis of work performed, the following conclusions are apparent:

- Checking.
  - a. Maximum checking usually occurred before average moisture content decreased to 20 per cent. Tension in surface layers persisted even below this point. Continued check development to 20 per cent moisture content indicated need for careful changes in EMC conditions to relatively late in the run.
  - b. Neither high initial dry-bulb temperature, in general, nor high initial EMC conditions were conducive to checking.
  - c. Medium and small checks were not evident after surfacing the lumber.
- Lowering EMC after lumber was dried to 20 per cent average moisture content accelerated rate of drying with little further checking.
- Large checks began to close at 20 per cent moisture content, indicating the start of stress reversal.
- High temperature and EMC conditions resulted in some darkening of lumber.
- Shrinkage values were erratic; there was some indication that shrinkage decreased with low dry-bulb temperature and low EMC conditions.

LITERATURE CITED

1. Kiln Certification. U.S. Forest Products Laboratory. ANC Bull. 21. Aeronautical Board, Washington, D.C., 157 pp., illus. 1945.

2. McMillen, J. M. "Drying Stresses in Red Oak." Forest Products Journal, Vol. V, No. 1, pp. 71-77. February 1955.

3. ____________. "Drying Stresses in Red Oak: Effect of Temperatures." Forest Products Journal, Vol. V, No. 4, pp. 230-240. August 1955.

4. Wood Handbook. U.S. Forest Products Laboratory. Agriculture Handbook No. 72. U.S. Department of Agriculture, Washington, D.C., 528 pp., illus. 1955.

Table 1. Summary of Data for Schedules Used in Drying 2- by 12-inch Douglas Fir Lumber From Green to 28 Per Cent Moisture Content.

Schedule	Average initial moisture content	Elapsed time	Preceding conditions		Centerline checks[1]			Shrinkage	
			Dry-bulb	EMC	Large	Medium	Small	Tangential	Radial
	Per cent	Hours	F	Per cent				Per cent	Per cent
1A	40.6	80	120-140	19-14	2	1	44	0.70	1.50
1B	37.5	41	170	18	1	3	25	0.35	1.20
1C	38.8	65	200	17	0	0	27	0.40	1.10
1C-1	36.9	21	198	16	0	0	39	0.75	1.45
2A	36.2	35	120-130	15	0	0	39	0.50	1.15
2B	37.1	22	170	15	0	0	18	0.85	0.50
2C	42.1	54	200	15	8	3	116	1.60	1.55
3A	35.8	21	120-122	8	11	10	33	0.45	0.60
3B	34.7	14	170	8	4	2	28	0.55	1.90
3C	35.4	11	200	8	4	1	60	0.50	1.60

1 Number of checks per charge of 20 pieces.

Table 2. Summary of Data for Schedules Used in Drying 2- by 12-inch Douglas Fir Lumber From 28 to 20 Per Cent Moisture Content.

Schedule	Elapsed time	Preceding conditions		Centerline checks[1]			Shrinkage	
		Dry-bulb	EMC	Large	Medium	Small	Tangential	Radial
	Hours	F	Per cent				Per cent	Per cent
1A	146	140-160	14-11	5	2	45	1.80	2.50
1B	144	170	18-13	3	5	32	1.30	2.25
1C	125	200	17-10	1	1	43	1.20	1.85
1C-1	65	200	16- 9	0	0	25	1.95	2.75
2A	190	130-170	15	0	1	57	1.45	1.55
2B	120	170	15	0	0	22	2.00	1.50
2C	140	200	15	5	5	53	2.95	2.45
3A	86	122-140	8	18	5	42	1.50	1.85
3B	62	170	8	6	3	47	1.75	3.35
3C	43	200	8	6	2	56	1.60	2.60

[1] Number of checks per charge of 20 pieces.

Table 3. Summary of Data for Schedules Used in Drying 2- by 12-inch Douglas Fir Lumber From 20 to 12 Per Cent Moisture Content.

Schedule	Elapsed time	Preceding conditions		Centerline checks[1]			Shrinkage	
		Dry-bulb	EMC	Large	Medium	Small	Tangential	Radial
	Hours	F	Per cent				Per cent	Per cent
1A	261	160-180	11-8	2	3	34	3.60	3.70
1B	268	170	13-8	2	5	22	2.80	3.10
1C	210	200	10-7	1	0	37	3.25	2.70
1C-1	134	200	9-7	0	0	10	3.50	3.90
2A	336	170-180	3	0	0	35	2.85	2.45
2B	187	170	3	0	0	11	3.65	3.15
2C	178	200	3	6	5	60	4.25	3.35
3A	160	140-180	5	12	13	32	3.20	3.55
3B	176	170	5	1	2	33	3.35	4.40
3C	118	200	5	0	3	40	2.95	3.60

[1] Number of checks per charge of 20 pieces.

Table 4. Maximum Percentage of Pieces Having Checks During Drying.

Check type	Schedule									
	1A	1B	1C	1C-1	2A	2B	2C	3A	3B	3C
	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Small	80	40	60	90	70	60	100	85	75	90
Medium	15	15	5	0	5	0	15	55	15	15
Large	15	20	5	0	0	0	20	65	15	20

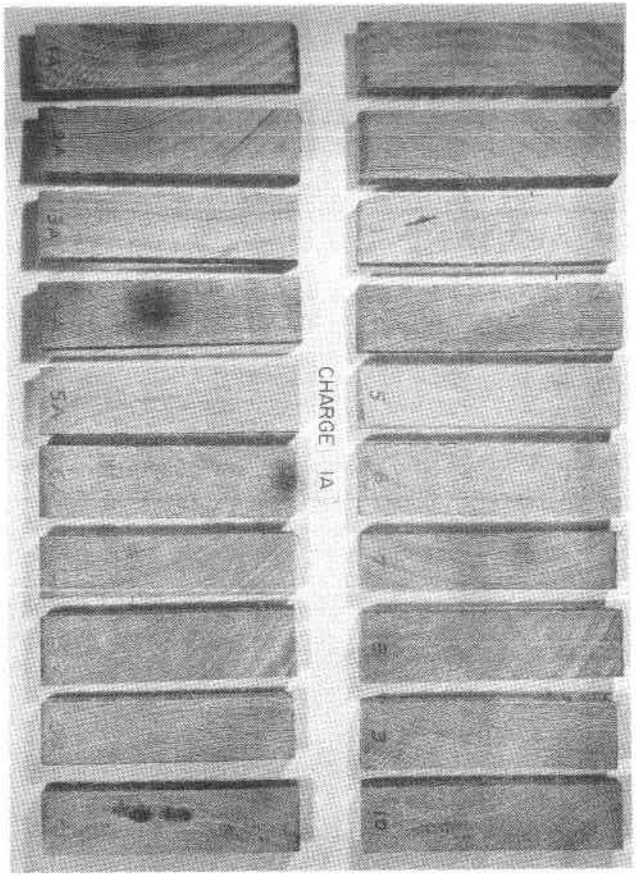

Figure 1. Typical cross sections of 2- by 12-inch flat-grain Douglas fir planks before kiln drying.

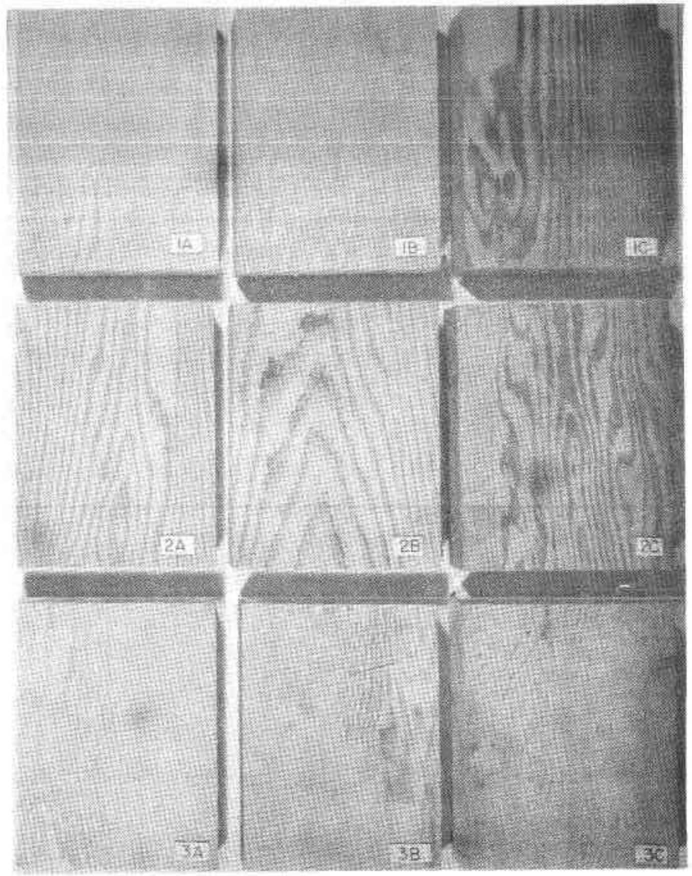

Figure 2. Relative darkening of charges: Charge 3A had lowest temperature and EMC conditions; charge 1C had the highest.

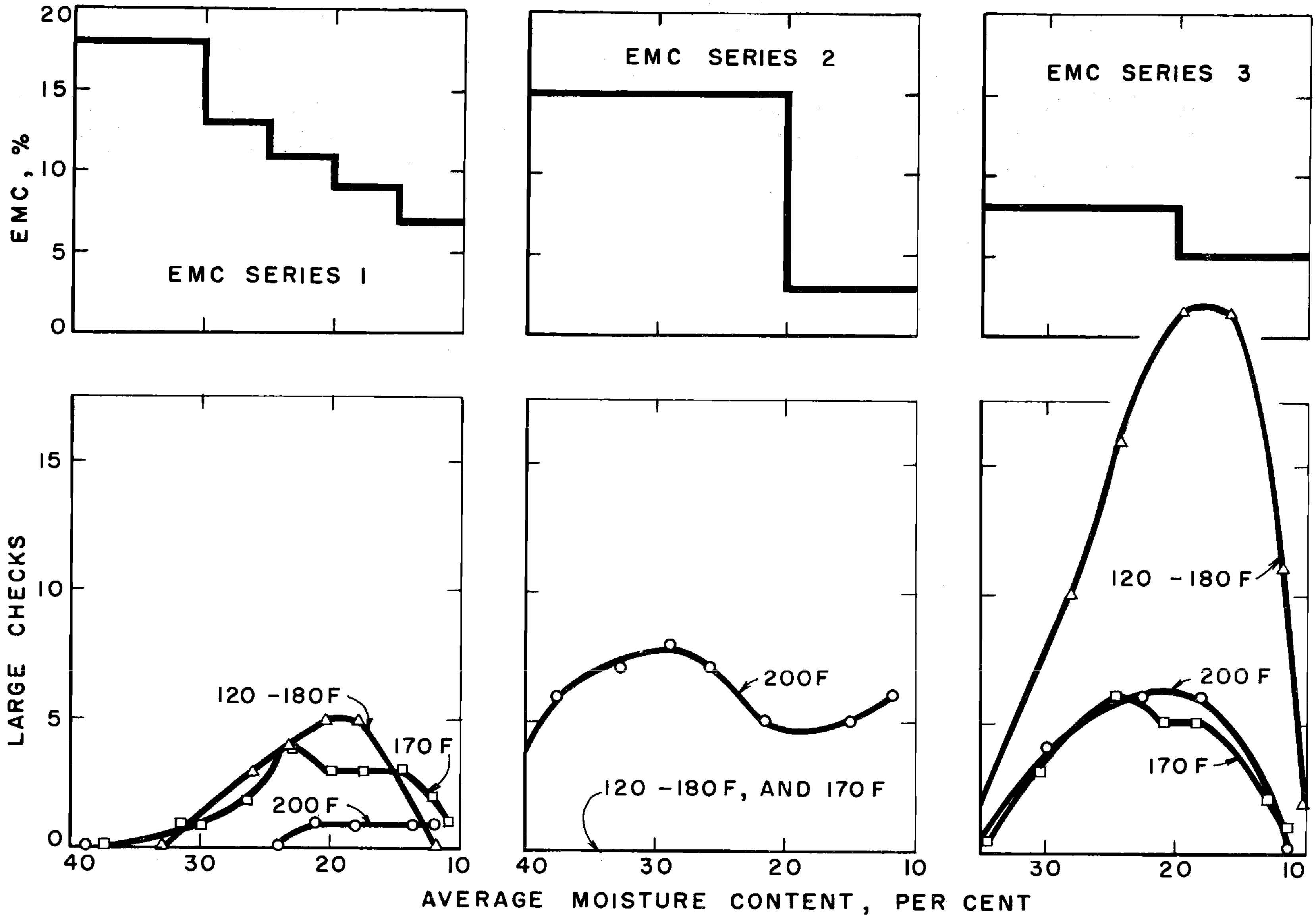

FIGURE 3. RELATIONSHIP BETWEEN LARGE CHECKS PER CHARGE AND AVERAGE MOISTURE CONTENT IN 9 KILN-DRIED CHARGES OF FLAT-GRAIN 2-INCH DOUGLAS FIR.

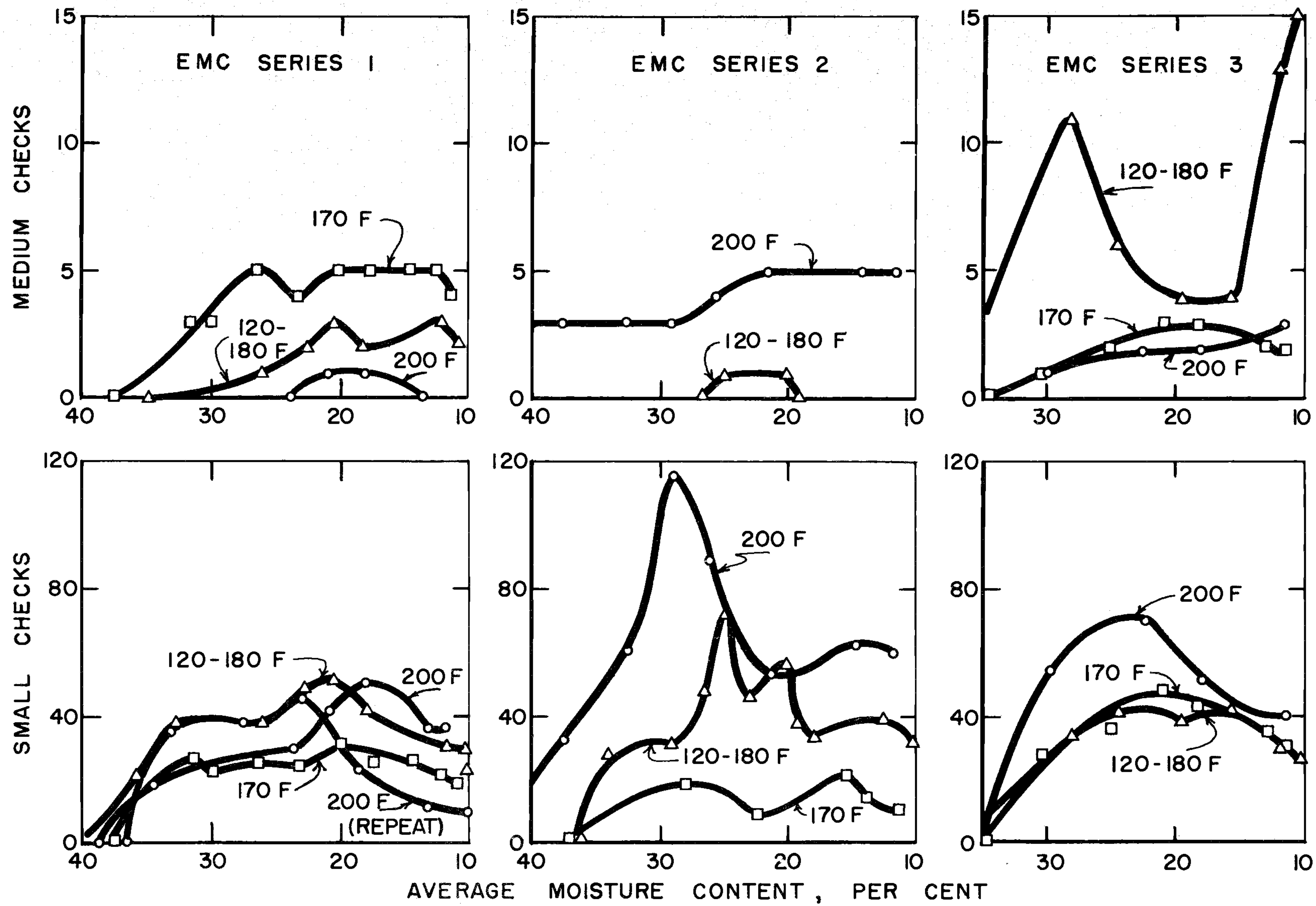

FIGURE 4. RELATIONSHIP BETWEEN MEDIUM OR SMALL CHECKS PER CHARGE AND AVERAGE MOISTURE CONTENT IN 9 KILN-DRIED CHARGES OF FLAT-GRAIN 2-INCH DOUGLAS FIR.

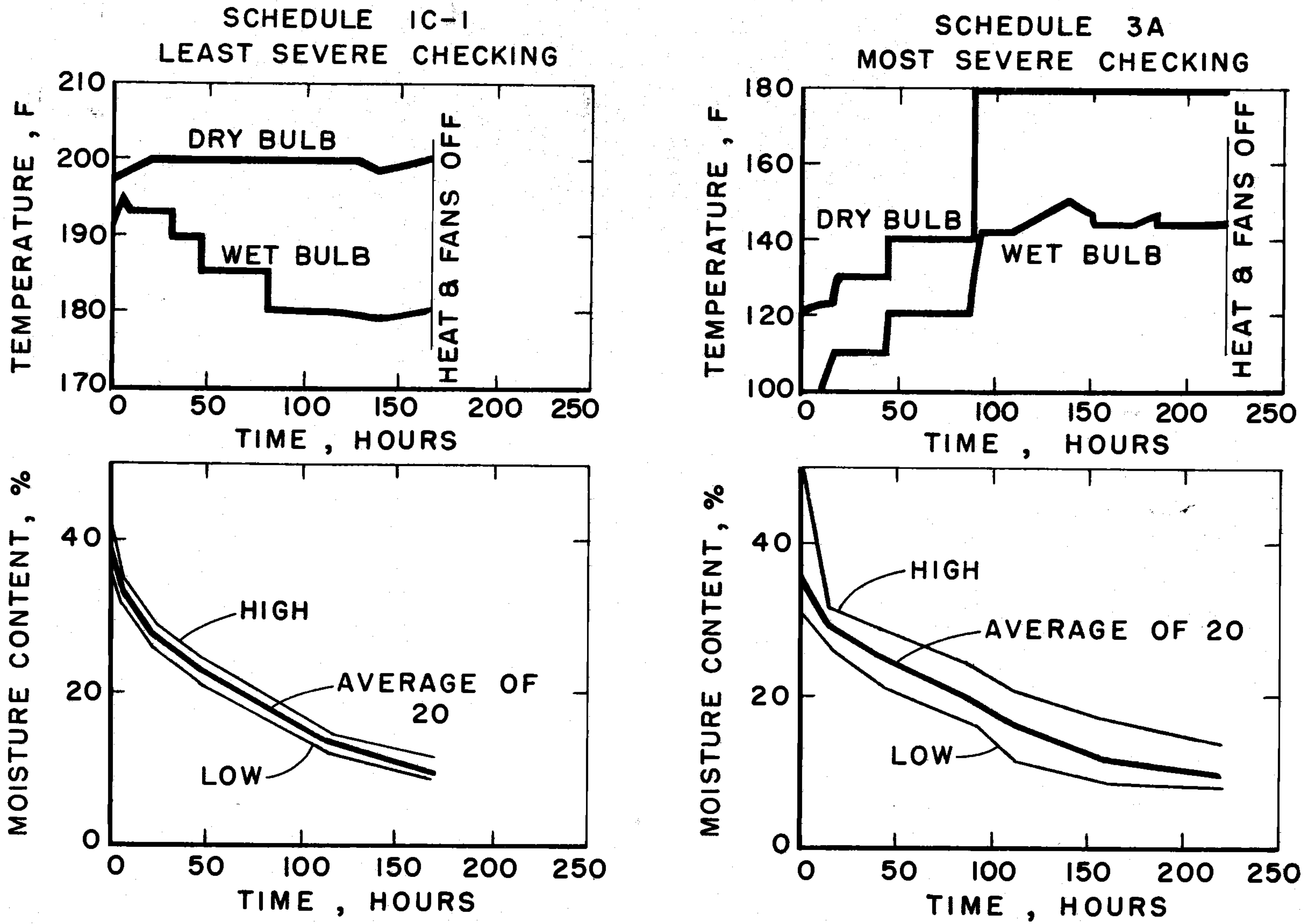

FIGURE 5. KILN SCHEDULES AND DRYING RATES FOR SCHEDULES WITH LEAST AND MOST SEVERE CHECKING IN 2-INCH FLAT-GRAIN DOUGLAS FIR.

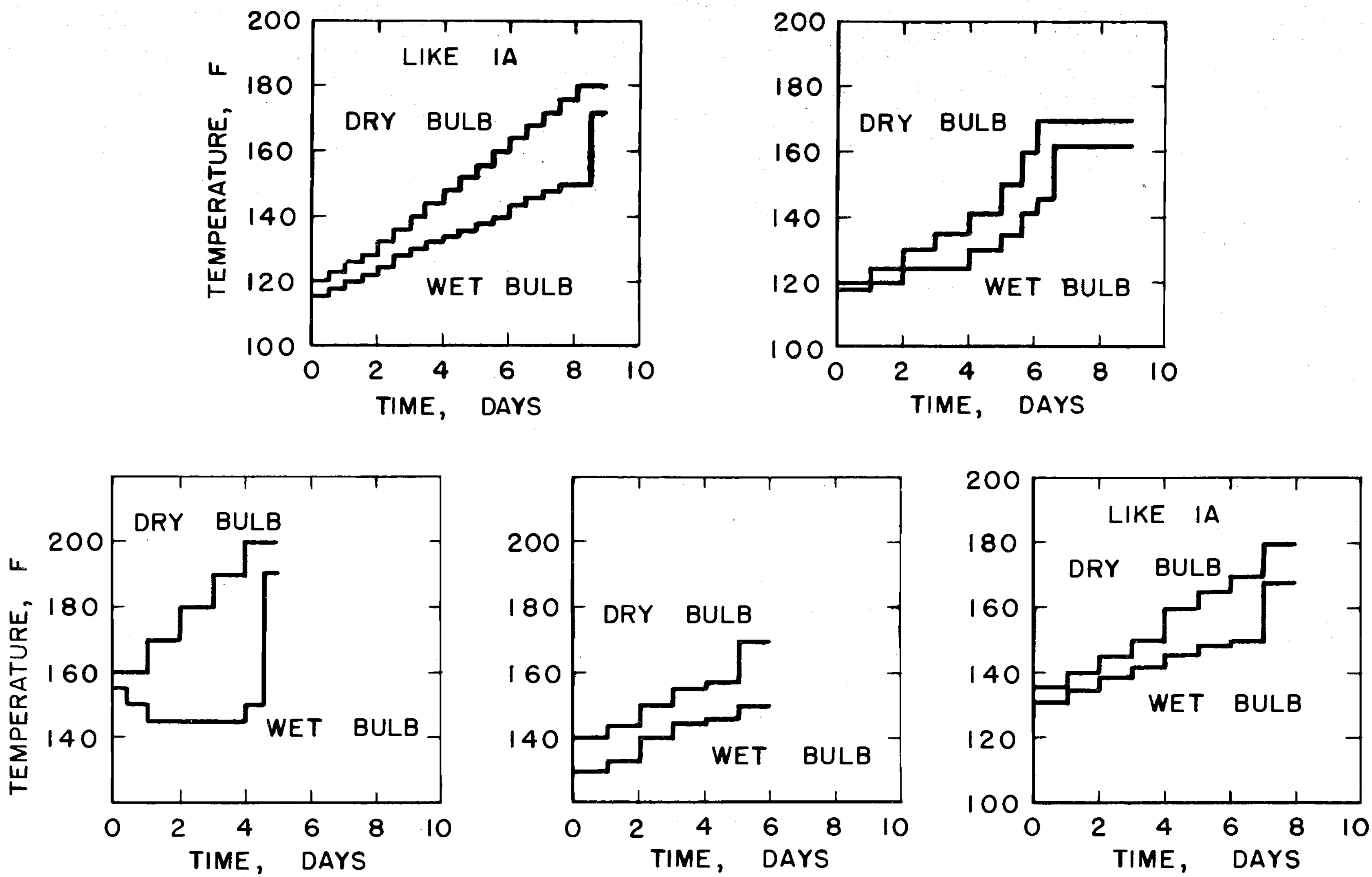

FIGURE 6. SCHEDULES USED FOR DRYING 2- BY 12-INCH FLAT-GRAIN DOUGLAS FIR LUMBER TO 11 PERCENT MOISTURE CONTENT AT VARIOUS MILLS NEAR EUGENE, ORE.

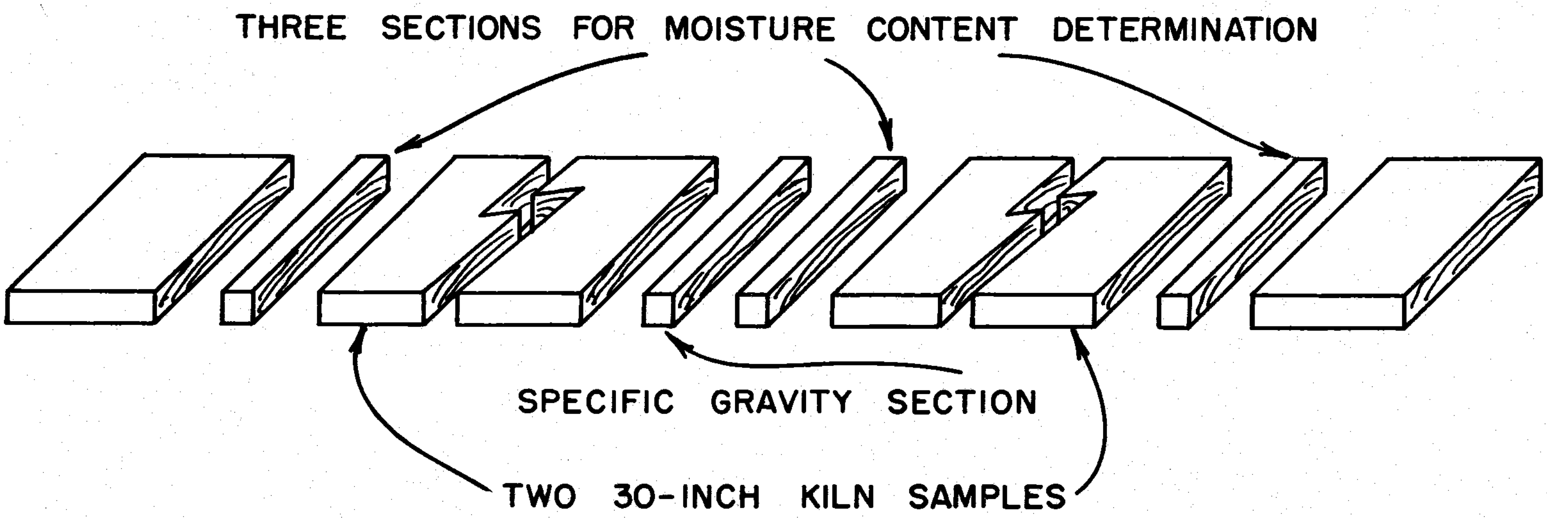

FIGURE 7. METHOD FOR SECTIONING 2- BY 12-INCH FLAT-GRAIN DOUGLAS FIR.