STRENGTH PROPERTIES OF MACHINE GRADED LUMBER

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ABSTRACT

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by Gerard J. Teitsma

One hundred-fifty nominal 2" by 8" Douglas fir boards were tested to determine the strength properties of machine graded lumber. The sample was composed of fifty boards each of three machine grades; 1500f, 2100f, and 2400f.

Each board was graded visually and subsequently subjected to major and minor tests. In the major tests, the boards were tested for modulus of elasticity and modulus of rupture using an approximately uniform load over a simply supported ten foot span. The modulus of elasticity was calculated for the condition of load applied to each of the four sides. The modulus of rupture was determined with members loaded as a joist. In the minor tests, small samples from each board were used to determine specific gravity, moisture content, and clear wood modulus of elasticity and rupture.

Bar charts were drawn to show the relationship between the modulus of rupture and each of the EMSR*and visual grades. Points were also plotted to show the modulus of rupture (MOR), as a function of plank modulus of elasticity (MOE), joist MOE, stiffness, slope of grain, specific gravity, and clear wood modulus of rupture. Additional graphs were drawn to show other relationships between major and minor test variables.

Test results indicated that neither EMSR or visual stress grading systems were reliable in predicting the ultimate strength

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*Electro Mechanical Stress Grade

of the board. Graphs plotted to show joist modulus of rupture as a function of plank modulus of elasticity resulted in a correlation coefficient of approximately 0.70. Calculating MOE as a joist did not result in a better correlation with joist MOR.

Specific gravity, slope of grain, and clear wood MOR had little influence on board MOR indicating that the breaking strength of the boards was due mainly to the defects in the boards.

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By

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INTRODUCTION

The mechanical properties of clear wood within a species vary because of generic and environmental factors which cannot be controlled by the forester or lumber manufacturer. Due to natural and manufacturing defects in commercial lumber, this variability is compounded. In order to estimate safe design values for mechanical properties for structural design purposes, systems for visually examining a board and predicting its strength have been in use for many years.

The upper limit criteria for the visual stress grades of joists and planks are the basic stress values established for clear sound wood within a species. The basic stresses are established by applying standard reduction factors to the average strength and stiffness properties as determined from large numbers of ASTM tests of small, clear specimens. The ASTM beam specimens are tested in a green condition (above the fiber saturation point) which eliminates variability due to moisture content. The moduli of rupture and elasticity are least for the green condition as regards the effect of moisture content. The average MOR value is multiplied by reduction factors as follows; 3/4 for sample variation, 9/16 for duration of load, 3/5 for a factor of safety and 9/10 to account for unknown service condition. Thus the basic MOR* value is about 22.8 percent of the average breaking strength of clear green ASTM beam specimens. The basic value for E, however, is about the same as the average found in tests reduced slightly for a depth factor value of about 9/10.

It is important to note that the application of such reduction factors results in a 95 percent lower confidence limit for each variable independently. By multiplying all such reduction factors together, it is assumed that the lower limit for every variable applies to every joist or plank in actual use. Thus, basic stress values for MOR are unrealistically low.

The basic strength values constitute the upper limit for arriving at the visual grades. According to the number, size, and location of strength reducing characteristics such as knots, slope of grain, wane, and seasoning defects, an 'f' grade (allowable flexural strength in psi) is assigned in accordance with standard published grading rules. There are several 'f' grades for every structural species in the joist and plank classification.

Even though the visual grading techniques have been shown to be inaccurate and overly pessimistic, visual grading has remained the standard method. This has been due primarily to an abundance of low cost lumber and lack of a better grading method. However, two factors have become increasingly important which require some better system of lumber grading be developed; (1) increase in cost of lumber compared to competitive structural

*Basic stress for extreme fiber in bending.

materials and (2) improved method of using other materials in light construction as a result of research and development by manufacturers and more wide spread increased mechanization of building techniques.

The most effective means of grading suggested has been some form of non-destructive evaluation of mechanical behavior of each board individually. Modulus of elasticity is a mechanical property which can be determined without destroying a piece of material. The problem then resolves itself into finding reliable empirical parameters to predict the ultimate strength values as functions of MOE which could be reduced by reasonable realistic safety factors to give allowable design stresses.

In the past five years, two stress grading machines have been developed and are commercially available. The designs of these machines are based upon exhaustive test results for determining a formula relating MOR to MOE. The equation which is used has reductions included, allowing for duration of load, depth factor, and safety factor. Both machines are calibrated so that the boards will have MOR values of 2.1 or greater times the working stress for the grade for 95 percent of the pieces produced. The 2.1 factor is a combination of load duration factor and other factors of the type traditionally applied.

Potlach Forest Industries developed one of these machines called the Industrial Sciences CLT-1 (Continuous Lumber Tester) in cooperation with Industrial Sciences of Portland, Oregon. The other stress grading machine was pioneered by the Western Pine Association and is being manufactured by the Tri-State Machinery Company of Dallas, Texas.

The four ton CLT-1 costs approximately $45,000. It is a highly sophisticated machine incorporating computer components and a memory storage system. At the infeed side of the machine, a roller system deflects the pieces 5/16 inch. The pieces are deflected 5/16 inch again in the opposite direction on the outfeed side of the machine, providing the average values of load required. The force required to deflect the piece 5/16 inch is measured by two transducers. The output of each transducer is stored into a capacitor storage system after every six inches of timber travel. The average voltage is fed into the grade decision section after the board has passed both transducers. Before the board leaves the machines, it is stamped with a grade. The machine can operate at speeds up to 1,000 feet per minute, handling two inch nominal lumber from six to twenty-six feet in length and from a nominal four to twelve inches wide.

The $13,000 Stress-O-Matic machine is set at a permanent speed (usually about four hundred feet per minute). Whereas the CLT-1 applies a small load, the Stress-O-Matic machine applies a much larger proof load. Lumber is fed into the machine by power rolls. Pressure is applied from above and fingers underneath the lumber measure calculated deflections to ascertain the grade. Tests are made in rapid succession, starting with the strongest 'f' grade (2400f) and progressing downward by predetermined grade levels. If a piece deflects too much for the stronger grade, succeeding tests are made until the proper grade is ascertained. This grade is then stamped on the piece at the out going end of the machine.

Much money and time was spent in the development of these machines and they are being used commercially at present. However, visual grading still predominates. Time will be necessary to answer all questions pertaining to machine grading and also to educate the users of stress graded material.

LITERATURE REVIEW

Publications discussing stress rating machines first appeared in 1961. In an initial report by R.J. Hoyle in June, 1961 (6), results of preliminary tests were presented for lumber which was stress rated by the CLT-1 machine (Continuous Lumber Tester). Hoyle stated that the test results demonstrated that moisture content of the board at time of testing was not critical. He also stated that temperature changes had little effect on the machine accuracy but advocated a seasonal change in adjustment. It was mentioned in this article that the Oregon Forest Research Center, Washington State University, and Professors John Howe and Arland Hopstrand of the University of Idaho had all contributed to the collection, testing, and analysis of the relationship between modulus of elasticity (MOE) and modulus of rupture (MOR). The correlation coefficient was found to be between 0.70 and 0.80.*

In October of 1961 an article (1) appeared in the Lumberman's Journal entitled "A Positive Stress Rater".

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*The correlation coefficient is a unitless indicator of the association between two variables. A perfect relationship results in a correlation coefficient of 1.00 and a value of zero for a wholly imperfect relationship. See Appendix I for further discussion.

This report described the early success achieved with the Western Pine Association's Stress-O-Matic machine. In 1963, articles (2,3,10) appeared in the Timber Trades Journal and in the Forest Industries magazine explaining internal mechanisms and operations whereby the two machines determined stress ratings. In 1964, L.W. Wood of the Forest Products Laboratory explained the differences between the two machines and pointed out some problems of correlation with final strength properties (12). At this time, he advocated the use of supplementary visual grading.

J. G. Sunley, W. M. Hudson, and W. T. Curry reported on the research on machine grading in Great Britain (10,11). They described a prototype at Princes Risborough which was capable of grading at speeds in excess of eighty feet per minute. Baltic Scots Pine and Norway spruce were tested. Data was included which compared visual and mechanical stress grading with actual strengths. Sunley and Hudson indicated a correlation coefficient of 0.836 between MOR as a joist and MOE as a joist. It was also stated that the correlation between MOR and MOE seemed to be independent of species. Although these boards were tested in all four directions, no mention was made about the effect of load being applied to different faces of the board.

In 1962, J.F. Senft, S.K. Suddarth, and H.D. Angleton of Purdue University reported test results of static bending tests on two hundred 10 foot 2 x 6 Douglas fir joists (9). The specimens were tested over a nine foot span using two point loading. The report showed a graphic representation of the simple correlation between MOR, density, MOE, slope of grain, and moisture content. In this study, the correlation between

MOR and MOE was found to be 0.681. These boards were kiln dried to 10, 15, and 30 percent moisture contents. It was found that moisture content had little effect on correlations.

PURPOSE

It was the purpose of this study to compare the allowable fiber stress in bending as specified by a CLT-1 lumber grading machine and as specified by visual stress grades with the values of modulus of rupture determined in laboratory tests of nominal 2" x 8" Douglas fir joists and planks. Strength and stiffness properties of the joists and planks were to be found by placing increasing magnitudes of evenly distributed load over a ten foot beam span.

TESTING PROCEDURE

Preparation and Description of Samples

A total of 150 intercoastal type Douglas fir 2"x8"x12' boards were secured from a West Coast sawmill. These boards were taken from regular commercial stock and were graded before shipment by a CLT-1 grading machine. They consisted of fifty boards each of three machine grades - 1500f, 2100f, and 2400f.

For every board, all defects including knots, wane, checks, splits, and pitch pockets were recorded on a grid as well as the growth ring orientation at one end of the plank. All four sides of the board were sketched. The knots were classified according to their narrow diameter in inches, their type (tight or loose), and the amount of grain deviation around the knot (mild, normal, or extreme). The depth of the splits or checks was determined and the area of wane on each face was measured.

According to ASTM standards (D198-27(24)), when loading to failure, the load was to be applied to the poorer of the loading faces. Since the modulus of rupture was always determined with the load applied to the bottom edge, the board was oriented so that the poorest edge was recorded as the bottom edge when the faces were recorded on the grid.

After all the defects were recorded, every board was visually graded according to WCLIB stress grading rules by a certified lumber grader, Mr. Lynn Gresham of the Detroit Lumberman's Association.

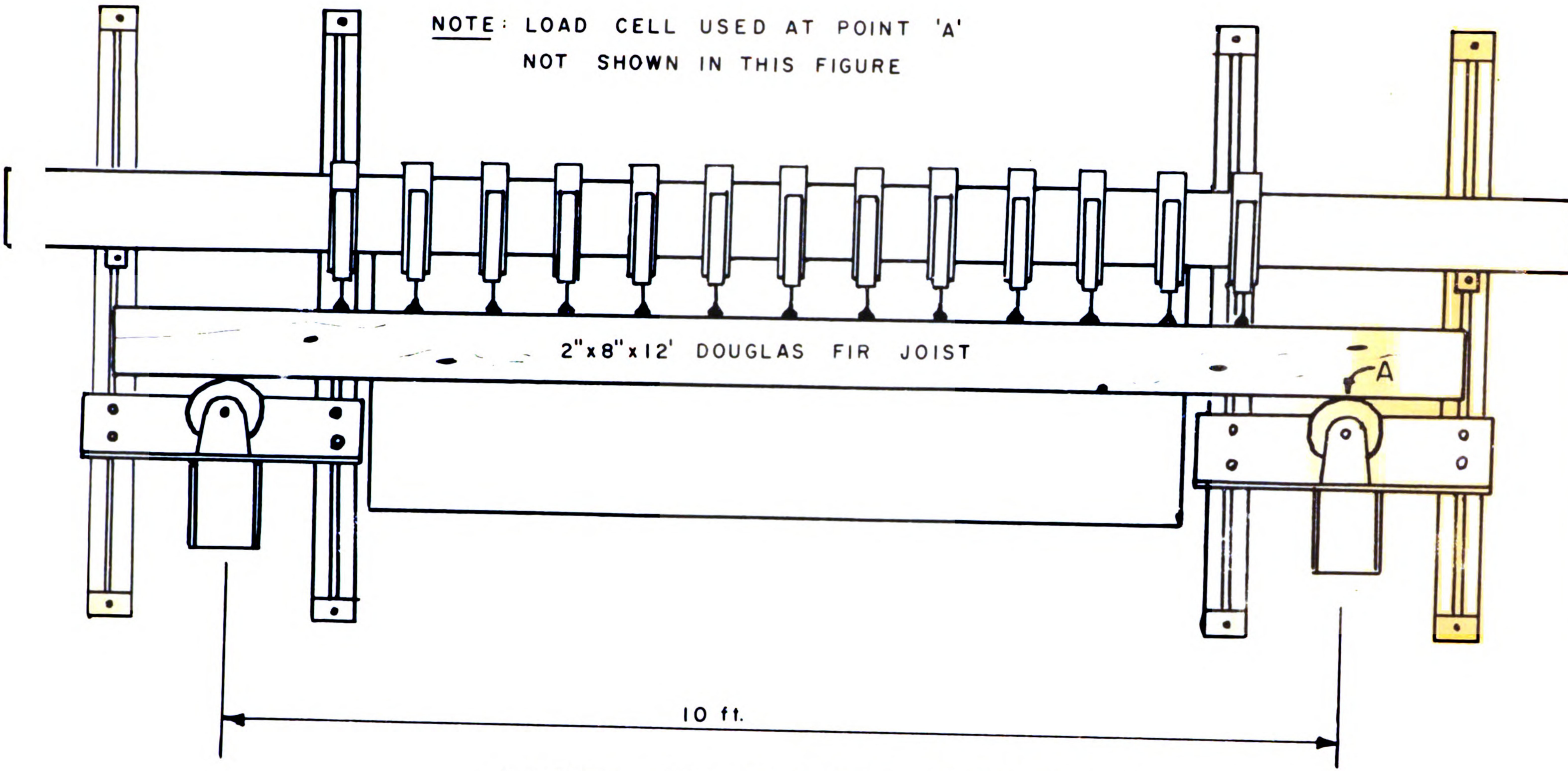
Prior to the large scale tests, the lumber was conditioned to a uniform 12 percent moisture content. Conditioning was by means of a dry kiln with a dry bulb temperature of 110°F and a wet bulb temperature of 100°F. Subsequently, the boards were stored in a controlled condition room at 12 percent EMC (69°F and 70 percent RH). The moisture content of each board was determined at time of testing as discussed under small scale test procedure.

Large Scale Test Procedure

Immediately prior to testing, each board was measured to determine the moment of inertia. Thicknesses were measured to the nearest 0.001 inches using an Ames caliper gauge (Figure 1). These measurements were taken at the center of the wide dimension at three places along the board - three feet from each end and in the middle of the board. An average thickness was determined from these numbers. Widths of the boards (larger dimensions) were measured to the nearest 0.001 inches at the same three positions along the members using a vernier caliper (Figure 1). These three measurements were also averaged.

Load deflection characteristics of each board were determined by means of special testing apparatus (Figures 2 and 3). The apparatus contained thirteen hydraulic cylinders to approximate a uniform load over a ten foot span. The cylinders were located one foot from each reaction point and

FIGURE 1.--Method of measuring boards to determine moment of inertia.



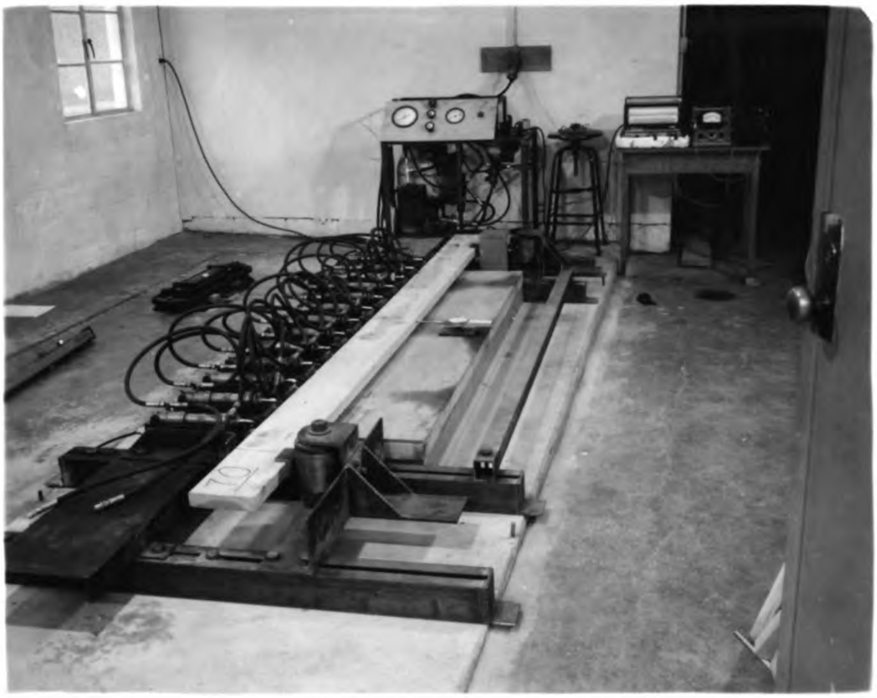
LARGE SCALE TEST APPARATUS

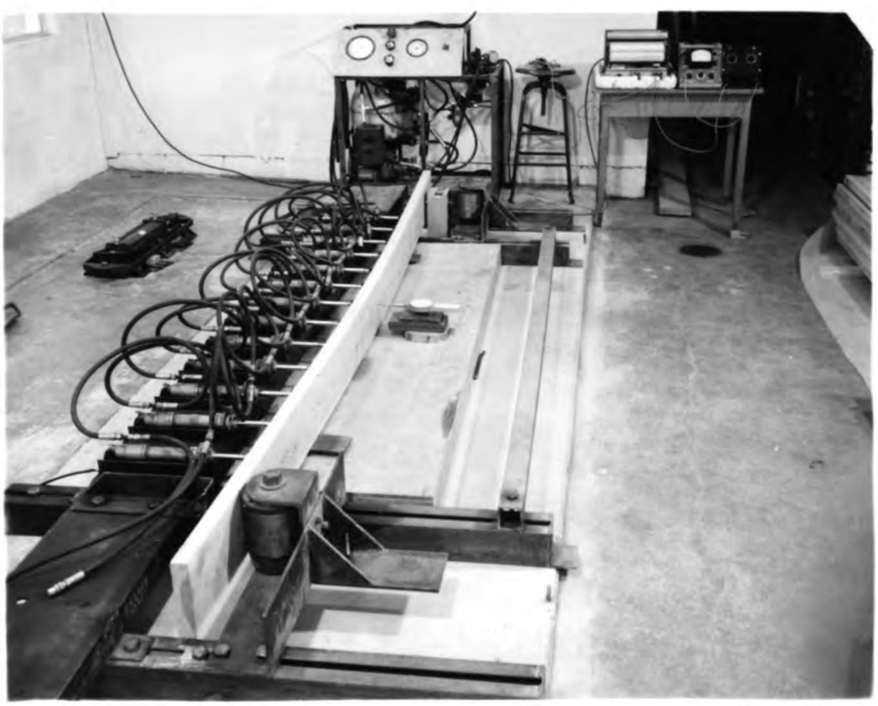
FIGURE 2

FIGURE 3.--Testing load deflection properties:

(a) as a joist

(b) as a plank.



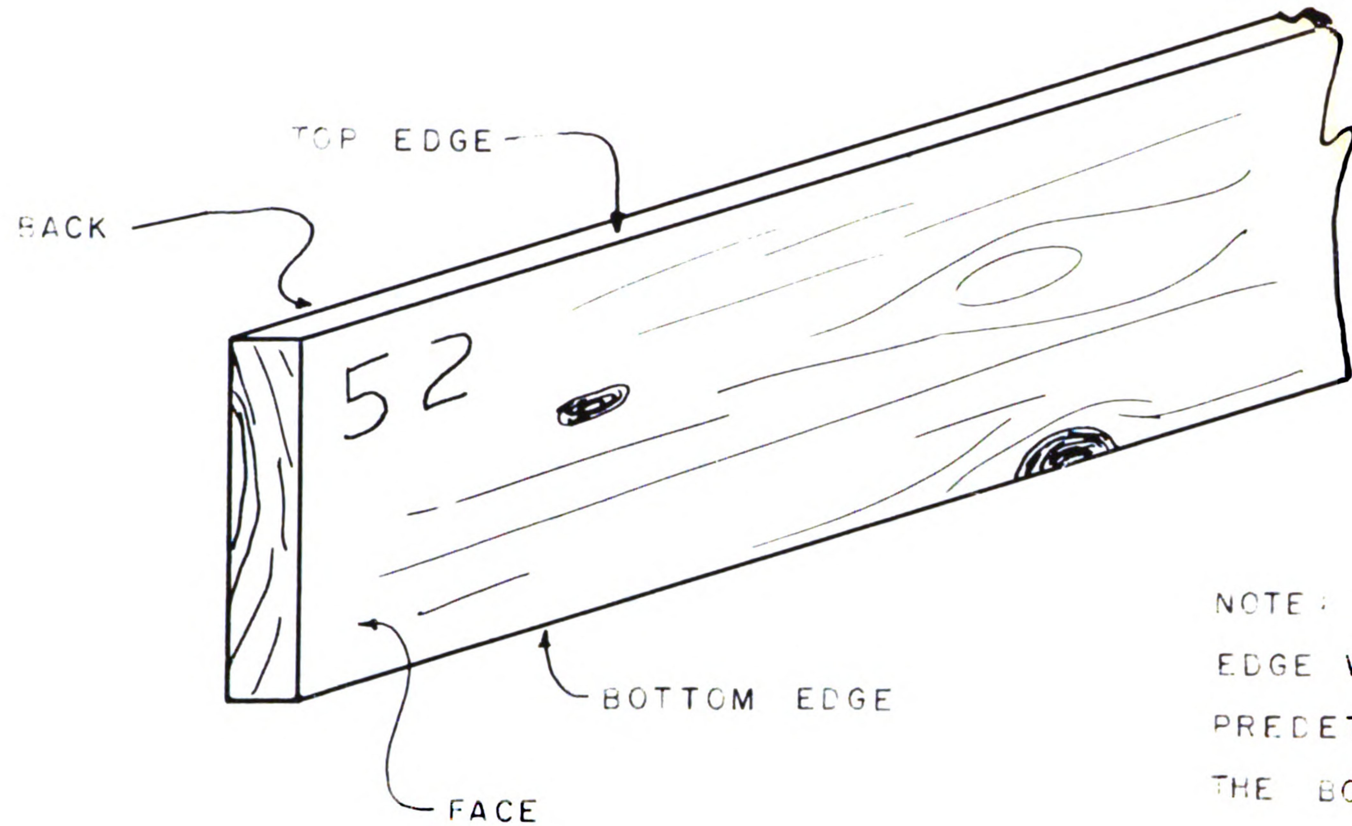


were then spaced every eight inches. The reaction supports were two large bearings which were free to rotate but which were restrained from translation. Two steel plates separated by roller bearings provided nearly frictionless movement between test members and supports. Buckling of the test boards was prevented by two pieces of 2 x 2 angle iron used as hold downs. These hold downs were supported by metal plates and roller bearings to prevent friction losses.

The load was measured at one reaction using a Baldwin SR-4, 10,000 pound load cell when testing as a joist. The load cells were inserted between the board and the reaction. Load cell signals went to an Ellis BAM-1 amplifier and from there into one channel of a two channel servo-recorder. The other channel was activated every 0.100 inches of deflection to indicate deflection at the different load levels. The deflection was always measured using an Ames dial gauge at the middle of the span.

The boards were tested for load deflection characteristics with load applied to each of the four faces and for breaking strength with load applied to the narrow face which contained the most serious combination of defects (bottom edge).

Each board was first loaded non-destructively as a plank with load applied to the face and then to the back. (See Figure 4 for direction of load terminology). In both cases, the load was applied along the length of the board at the centerline of the face or back. Before loading, all the cylinders were brought into contact with the board and the dial gauge was set at zero. Subsequent loading was applied so that the deflection



NOTE: THE WORST EDGE WAS ALWAYS PREDETERMINED TO BE THE BOTTOM EDGE.

FIGURE 4
DIRECTION OF LOAD APPLICATION

was increased 1.9 inches per minute to produce a rate of strain in the extreme fiber of .00015 inches per inch of fiber length per minute. The load was applied until the deflection reached 1.500 inches. The load necessary to deflect the plank 1.2 inches was determined by subtracting the load at 0.300 inches deflection from the load at 1.500 inches deflection. It was previously determined that within this range, the load deflection curves were linear and that the proportional limit was not exceeded.

In determining load-deflection properties as a joist, the load was applied at a rate to deflect the joist 0.25 inches per minute to produce a rate of strain of 0.0007 inches per inch of fiber length per minute. In bringing the cylinders in contact with the joist, a pre-load of approximately 100 pounds was applied in each case. The load required to deflect the joist 0.500 inches more than the pre-load deflection was used to determine MOE. Within this range, the load-deflection curve was linear.

After the bottom edge was subjected to the load to produce 0.500 inches of deflection, the dial gauge was removed and loading was continued at the same rate to failure. The ultimate load at failure was used in the calculation of the modulus of rupture (MOR) (Figure 5).

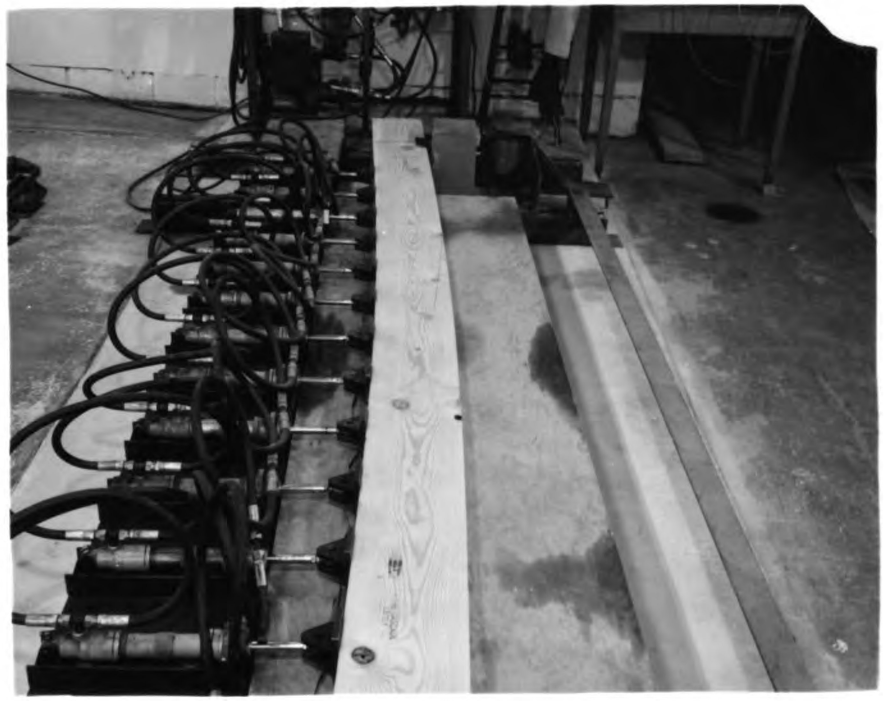
Small Scale Test Procedure

After a test board had been loaded to failure, small clear samples were cut from it to determine clear wood MOE, MOR, specific gravity, and board moisture content at time of test.

FIGURE 5.--Testing for modulus of rupture:

(a) under load

(b) failure.



The moisture content and specific gravity of each board were determined from two samples. They were taken from clear wood near the failure. These samples were of various sizes and shapes and weighed from 35 grams to 110 grams with an average weight of about 70 grams. Immediately after the samples were cut from the board, they were weighed and then placed in an oven to dry. The oven dry weights were recorded and the samples subsequently dipped in melted paraffin. Oven dry volumes were determined by the ASTM water displacement method.

Two 1-1/4 x 1-1/4 x 15 inch beams were also cut from clear wood near the failure to determine MOE and MOR. These samples were cut with the grain running along the long axis. After being cut roughly to size, they were finish planed to one inch square and measured to the nearest 0.001 inch using a micrometer dial caliper. These samples were stored and tested in a testing room at 69°F and 70 percent RH (12 percent EMC).

The samples were tested for MOE and MOR in a Dillon testing machine according to instructions for static bending in Part II, Secondary Method of ASTM D143-52. The reactions were 3/4 inch radius aluminum blocks. The load was measured with an SR-4 2500 pound load cell connected to one channel of a two channel servo-recorder. A fifty pound pre-load was applied to the sample before the dial gauge was set at zero. Then, load was applied at the prescribed rate until the deflection equalled 0.100 inches. At this time, the second channel of the servo-recorder was activated to indicate load at this deflection. This load (minus the initial 50 pounds) was used to determine MOE. Loading was continued to failure.

TEST RESULTS

Modulus of Rupture of Boards

The modulus of rupture (MOR) was calculated for each board after the load was applied to the bottom edge, until failure was achieved. The joist MOR values ranged from 2,031 psi to 11,700 psi, with an average of 5,856 psi and a standard deviation of 2,728 psi.

In Figures 7-20 and 24 respectively, MOR is compared with EMSR grade, visual grade, modulus of elasticity (MOE) (plank), MOE (joist), MOE (1500f EMSR), MOE (2100f EMSR), MOE (2400f EMSR), MOE (1200f visual), MOE (1500f visual), MOE (1900f visual), MOE (2050f visual), stiffness, slope of grain, specific gravity, and clear wood MOR.

EMSR and Visual Grades

The boards were originally machine graded and the sample consisted of 50 boards each of three grades — 1500f, 2100f, and 2400f. Upon visual grading, these 150 boards were classified into 43 - 1200f, 70 - 1500f, 19 - 1900f, and 10 - 2050f. In addition to these grades, six boards were judged defective under WCLIB grading rules and were graded utility. Due to oversight, the visual grade was not recorded for two boards.

Figure 6 compares the distribution of the test boards

VISUAL GRADE	1500 f	2100 f	2400 f
2050 f	0 BOARDS	0 BOARDS	10 BOARDS
1900 f	5 BOARDS	5 BOARDS	9 BOARDS
1500 f	26 BOARDS	27 BOARDS	17 BOARDS
1200 f	17 BOARDS	13 BOARDS	13 BOARDS

EMSR GRADE

COMPARISON BETWEEN VISUAL AND EMSR GRADE RESULTS

FIGURE 6

in the visual grades with their distribution in the EMSR grades.

Figures 7 and 8 show how the allowable design stresses of the EMSR and visual grades compared with the actual strength as shown by the calculated MOR. The three EMSR 'f' grades are broken down in Figure 7 in order to show the number of boards within each 'f' group that failed at different MOR levels. In each of the three 'f' grades, the X axis represents the MOR separated into 500 psi sections. The height of the bars show the number of boards within a grade that failed within a particular 500 psi MOR range. Within the 1500f grade, the average modulus of rupture was 4,265 psi with a standard deviation of 1,828.6 psi; within the 2100f grade, the average MOR was 5,064 psi with a standard deviation of 1,982 psi; within the 2400f grade, the average MOR was 8,164 psi with a standard deviation of 2,568 psi. The MOR range is shown on the bar chart.

The four visual stress grades are broken down in Figure 8 with the same purpose and procedure as in the previously mentioned figure. Within the 1200f grade, the average MOR was 4,842 psi and the standard deviation was 2,402 psi; within the 1500f grade, the average MOR was 5,429 psi and the standard deviation was 2,453 psi; within the 1900f grade, the average MOR was 7,129 psi and the standard deviation was 2,396 psi; and within the 2050f grade, the average MOR was 10,035 psi and the standard deviation was 1,858 psi.

Not shown on this graph but also calculated was the MOR of each of the six boards graded utility. The MOR values ranged from 3,206 psi to 11,062 psi with an average of 6,582 psi.

Modulus of Elasticity

The MOE was calculated as a plank with load applied to face and back and as a joist with load applied to top edge and bottom edge. The MOE with load applied to face was used to represent the plank MOE instead of averaging MOE (face) and MOE (back) to avoid the possibility of a test from one side affecting a test from the opposite side. Also, the MOE with load applied to top was used to represent the joist MOE for the same reason. Furthermore, the two values of MOE as a plank compared well with each other and had a correlation coefficient of 0.98. Similarly, the two values of MOE as a joist were also close and had a correlation coefficient of 0.974.

In Figure 21, the plank MOE was compared with the joist MOE. The plank MOE values ranged from 1.183×10^6psi to 2.515×10^6psi with a mean of 1.649×10^6psi and a standard deviation of 0.311×10^6psi. Also, the joist MOE values ranged from 0.908×10^6psi to 2.352×10^6psi with a mean of 1.421×10^6psi and a standard deviation of 0.299×10^6 psi. Calculations show a correlation coefficient of 0.9200 between MOE plank and MOE joist.

In Figure 9, the joist MOR was compared with the plank MOE calculated with load applied to the face to illustrate the correlation between the two variables. The correlation coefficient was found to be 0.6951.

Points were also plotted to show the relationship between joist MOR and joist MOE. This relationship is found in Figure 10. The correlation coefficient between these two variables was found to be 0.7096.

In Figure 23, the MOE values calculated as a plank are plotted against the clear wood MOE for each board. These two variables had a correlation coefficient of 0.7750

Also, in Figure 23, the plank MOE values were plotted as a function of specific gravity. A correlation coefficient of 0.6374 resulted.

Stiffness Properties

The stiffness was calculated for each board by multiplying the plank MOE by its corresponding moment of inertia at time of test. These stiffness (or EI) values ranged from 3.090×10^6psi to 6.207×10^6psi with a mean of 4.2110×10^6psi and a standard deviation of 0.7454×10^6psi.

In Figure 18, the MOR values of the boards were plotted against the EI values with a correlation coefficient of 0.7030.

Slope of Grain

The slope of grain was measured on the back for all boards but only 50 boards had a measured slope. For these 50, the slope of grain ranged from one inch in 48 inches to one inch in eight inches with an average slope of one inch in 15.6 inches.

Previously mentioned plank MOE was shown as a function of specific gravity in Figure 22.

In Figure 26, the clear wood MOR is compared with specific gravity in Figure 27. The correlation coefficient between these two variables was 0.6049.

In Figure 20, the joist MOR was plotted against specific gravity with a resulting correlation coefficient of 0.4683.

Specific Gravity

Two clear wood samples were taken from each board to determine specific gravity. These specific gravities ranged from 0.35 to 0.61 with an average value of 0.464 and a standard deviation of 0.048.

In Figure 20, the joist MOR was shown as a function of specific gravity with a resulting correlation coefficient of 0.4683. When plank MOE was compared with specific gravity in Figure 22, the correlation coefficient was found to be 0.6374. In Figures 26 and 27 the clear wood MOR and MOE were shown as a function of specific gravity.

Clear Wood Modulus of Elasticity

MOE values were calculated from tests using two clear wood beams from each board and the average between the two values was used as the clear wood MOE for that board. The clear wood MOE ranged from 0.935×10^6psi to 2.054×10^6psi with an average of 1.405×10^6psi and a standard deviation of 0.224×10^6psi.

The plank MOE was shown as a function of clear wood MOE in Figure 23 and the clear wood MOE was compared with specific gravity in Figure 27.

Clear Wood Modulus of Rupture

The same two clear wood samples used to determine MOE were used to determine clear wood MOR and the average between the two was used to represent the clear wood MOR for the board. The clear wood MOR values ranged from 8,273 psi to 15,529 psi with an average of 11,628 psi and a standard deviation of 1,562 psi.

Figure 25 shows the previously discussed relationship between clear wood MOR and clear wood MOE.

The clear wood MOR was compared with specific gravity in Figure 26. The two variables had a correlation coefficient of 0.7401.

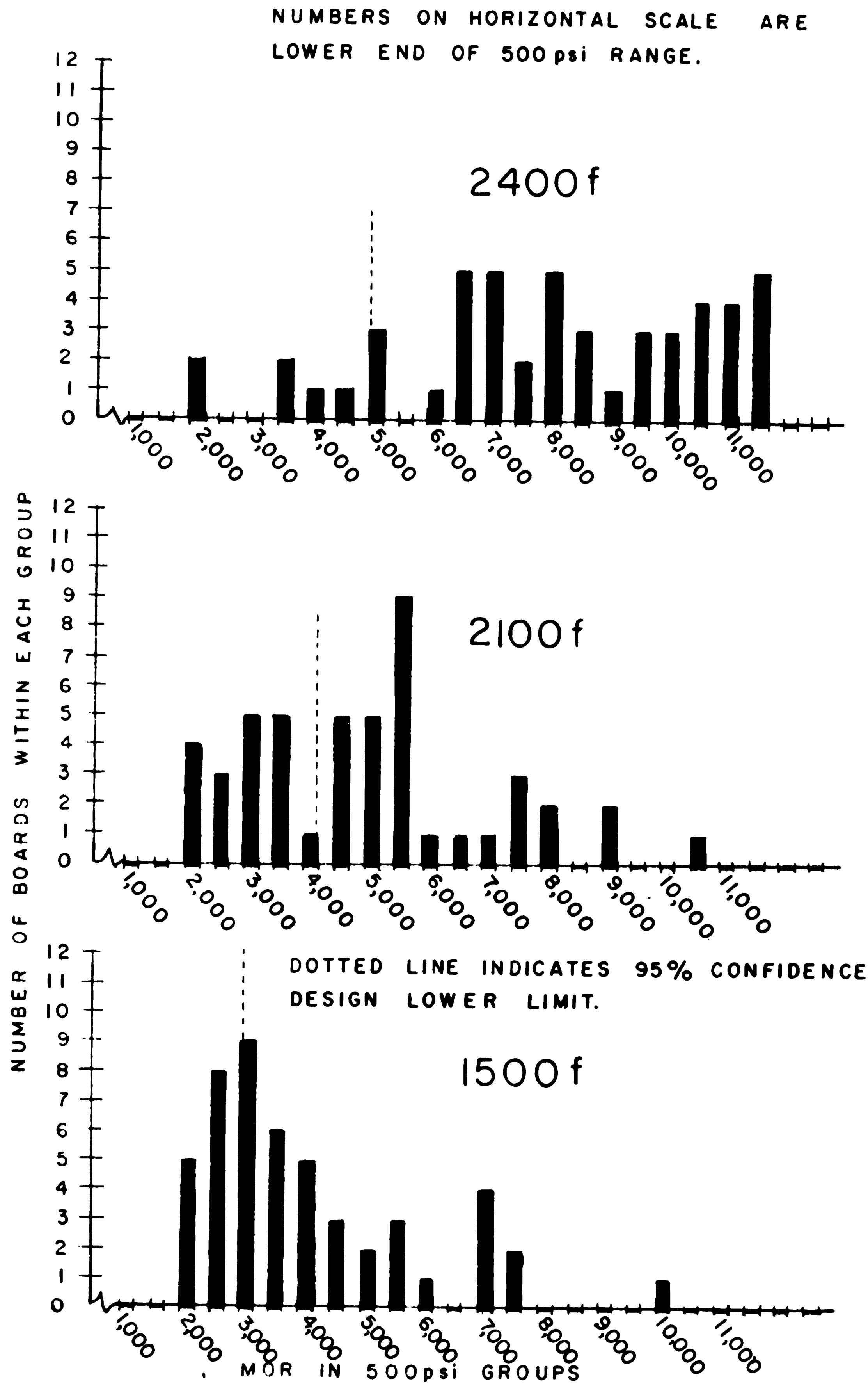
In Figure 24, the MOR of the board containing defects was compared with the clear wood MOR. Calculations resulted in a 0.5552 correlation coefficient.

Moisture Content

The same two clear wood samples from each board that were used to find specific gravity were used to determine moisture content at time of test. The moisture contents ranged from 11.0 percent to 12.9 percent with an average of 11.84 percent.

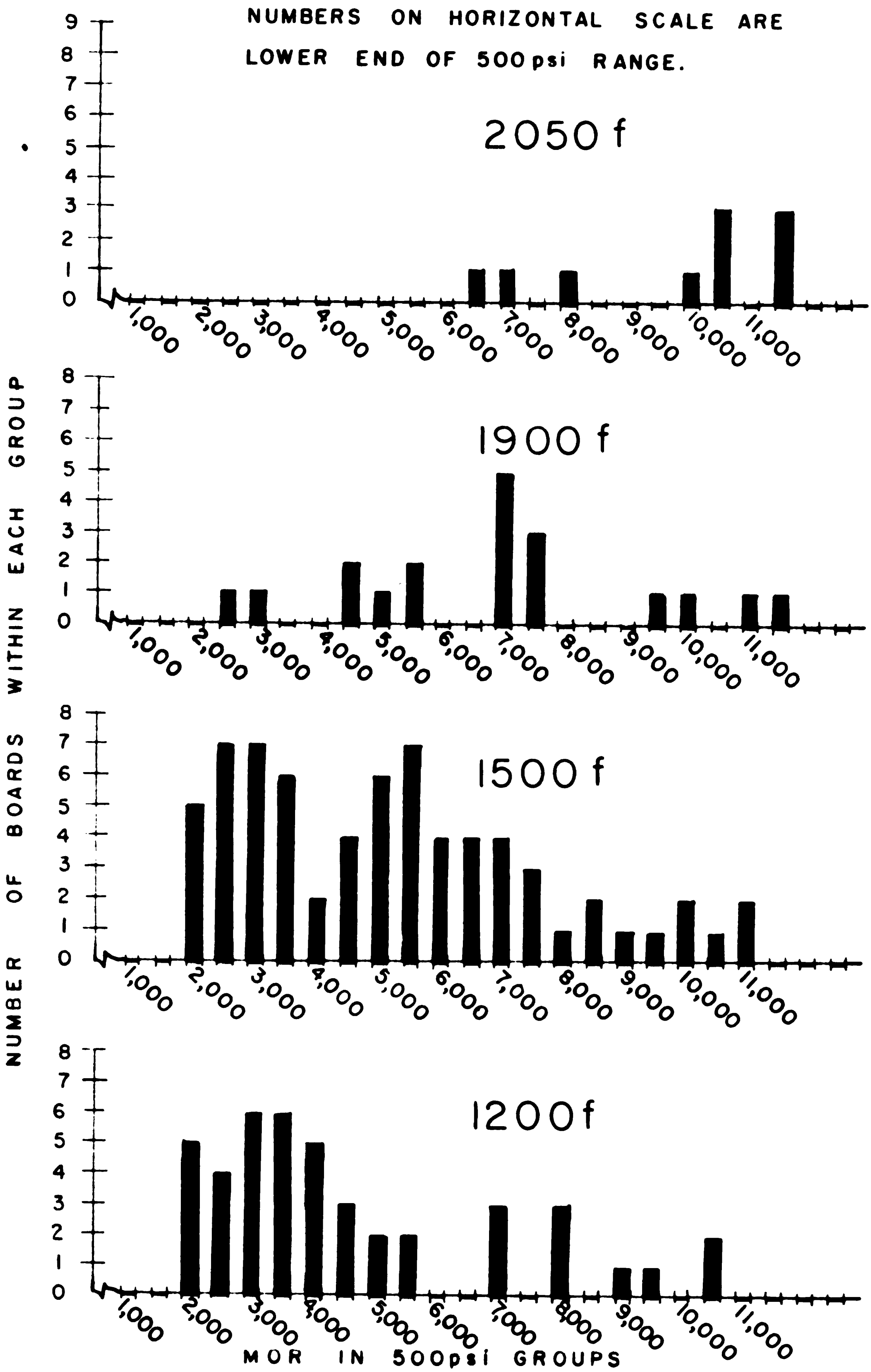
The moisture content of the small clear sample was also determined. A representative 23 samples were tested with a range of 11.5 percent to 13.7 percent and an average of 12.4 percent.

Comparison Between	Mean	Standard Deviation	R	R^2	Standard Error of Estimate	Regression Equation
MOR and MOE as a Plank	5855.7 1.649	2728.3 0.3113	0.6951	0.4832	1,967.9	MOR = 0.006091(MOE) - 4192.2
MOR and MOE as a Joist	5855.7 1.4211×10^6	2728.3 0.2995	0.7096	0.5036	1,928.7	MOR = 0.006464(MOE) - 3331.7
Clear Wood MOR and Clear Wood MOE	11,628.4 1.405×10^6	1561.5 0.2241	0.8461	0.7159	835.09	MOR = 0.005895(MOE) + 3343.5
Clear Wood MOE and Specific Gravity	1.405×10^6 .4644	0.2241 0.0482	0.6049	0.3659	.1797	MOE = 2.8206×10^6(Specific Grav.) + $.0952 \times 10^6$
Clear Wood MOR and Specific Gravity	11,630.2 .4644	1,566.6 0.0482	0.7401	0.5477	1,057.1	MOR = 24,047.3(Specific Grav.) + 463.6
Joist MOR and Clear Wood MOR	5,855.7 11,628.4	2728.3 1561.5	0.5552	0.3082	2,276.9	MOR = 0.9700(C.W. MOR) - 5,423.3
Joist MOR and Specific Gravity	5,855.7 .4644	2728.3 0.0482	0.4683	0.2193	2,417.9	MOR = 26,486(Specific Grav.) - 6,424.4
Joist MOR and Plank MOE (1500EMSR)	4,264.7 1,379,000	1828.6 133,300	0.3898	0.1519	1,701.8	MOR = 0.005346(MOE) - 3103.1
Joist MOR and Plank MOE (2100EMSR)	5,064.2 1,588,500	1,982.4 152,071	0.2546	0.0648	1,936.9	MOR = 0.00319(MOE) - 208.0
Joist MOR and Plank MOE (2400EMSR)	8,160.5 1,969,824	2,568.1 261,868	0.5482	0.3005	2,169.6	MOR = 0.00538(MOE) - 2,429.8
MOR and Slope of Grain	5984.8 1/15.6	2,728.2 1/40.3	0.1082	0.0117	2,740.3	MOR = 1.188(SLOPE) + 6,741.4
MOR and Stiffness (EI)	5855.7 4,211,040	2,728.3 745,468	0.7030	0.4942	1,946.9	MOR = 0.00257(EI) - 4978.7
Plank Elasticity and Clear Wood MOE	1,649,440 1,405,353	311,324 224,121	0.7751	0.6007	197,391	MOE (PLANK) = 1.0766(C.W. MOE) + 136,425
Plank MOE and Joist MOE	1,649,440 1,421,113	311,324 299,477	0.9200	0.8965	122,404	MOE (PLANK) = 0.9564(MOE JOIST) + 290,300
MOR and MOE (1200f Visual)	4,842.9 1,576,721	2,401.7 277,481	0.6693	0.4480	1,805.9	MOR = 0.00579(MOE) - 4,291
MOR and MOE (1500f Visual)	5,429.5 1,611,271	2,453.3 289,438	0.6803	0.4629	1,811.2	MOR = 0.00577(MOE) - 3,862.1
Joist MOR and Plank MOE (1900f Visual)	7,129.0 1,722,737	2,395.6 327,343	0.4512	0.2036	2,199.9	MOR = 0.0030(MOE) + 1,440.7
Joist MOR and Plank MOE (2050f Visual)	10,035.3 2,101,600	1,857.9 226,158	0.0465	0.0022	1,968.5	MOR = 0.00038(MOE) + 9,233.2
Plank MOE and Specific Gravity	1,649,886 .4644	312,326 .0482	0.6374	0.4063	241,479	MOE = 4,128,774 (Specific Grav.) - 267,361
Plank MOE (Face) and Plank MOE (Back)	1,649,440 1,661,547	311,324 312,715	0.9798	0.9599	62,520	MOE (FACE) = 0.9754 (MOE BACK) + 28,750
Joist MOE (Top) and Joist MOE (Bottom)	1,429,293 1,436,571	296,838 298,922	0.9742	0.9491	67,229	MOE (TOP) = 0.9674 (MOE BOTTOM) + 39,545



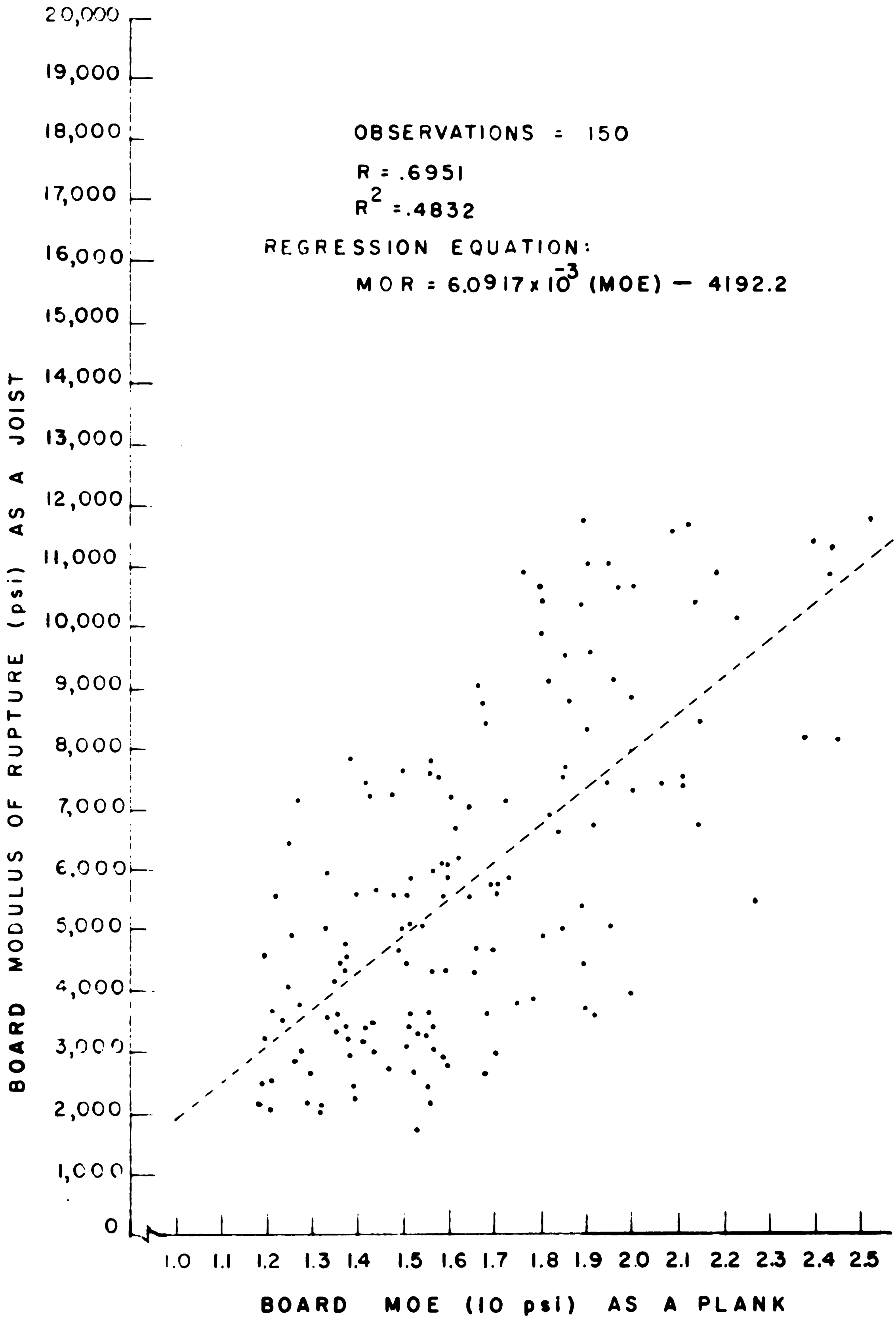
EMSR GRADE VS MOR

FIGURE 7



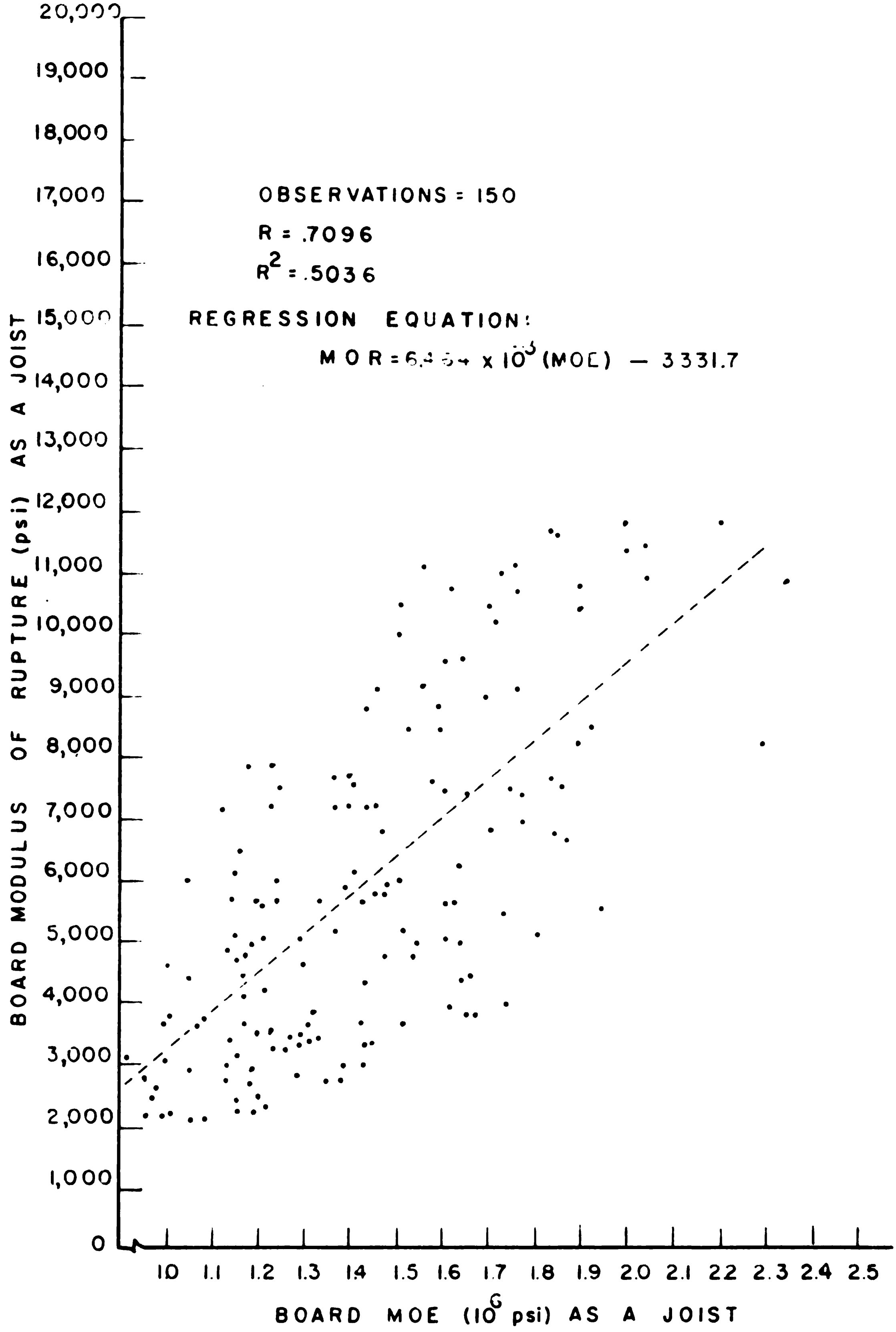
VISUAL GRADE VS MOR

FIGURE 8



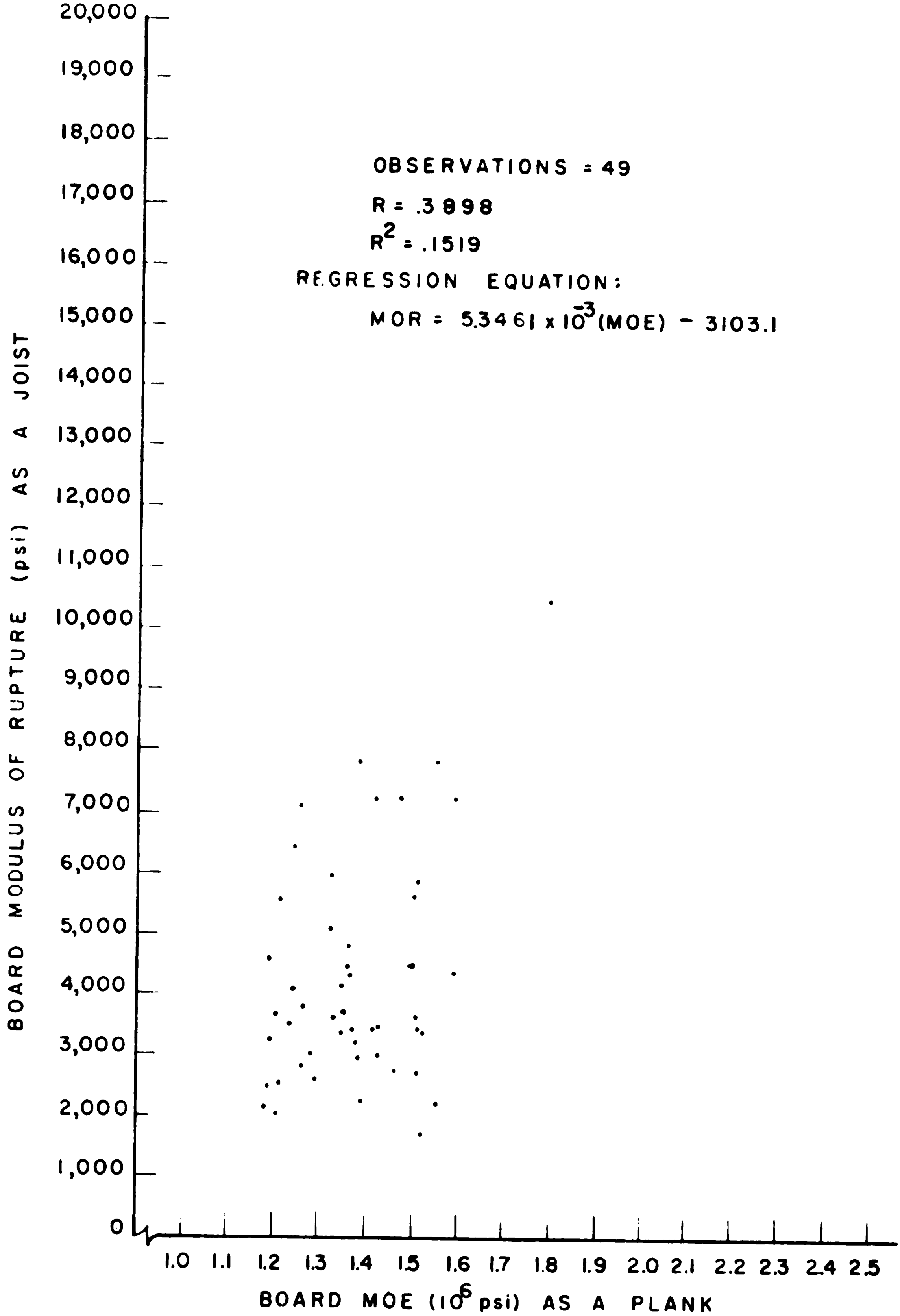
JOIST MOR VS PLANK MOE

FIGURE 9



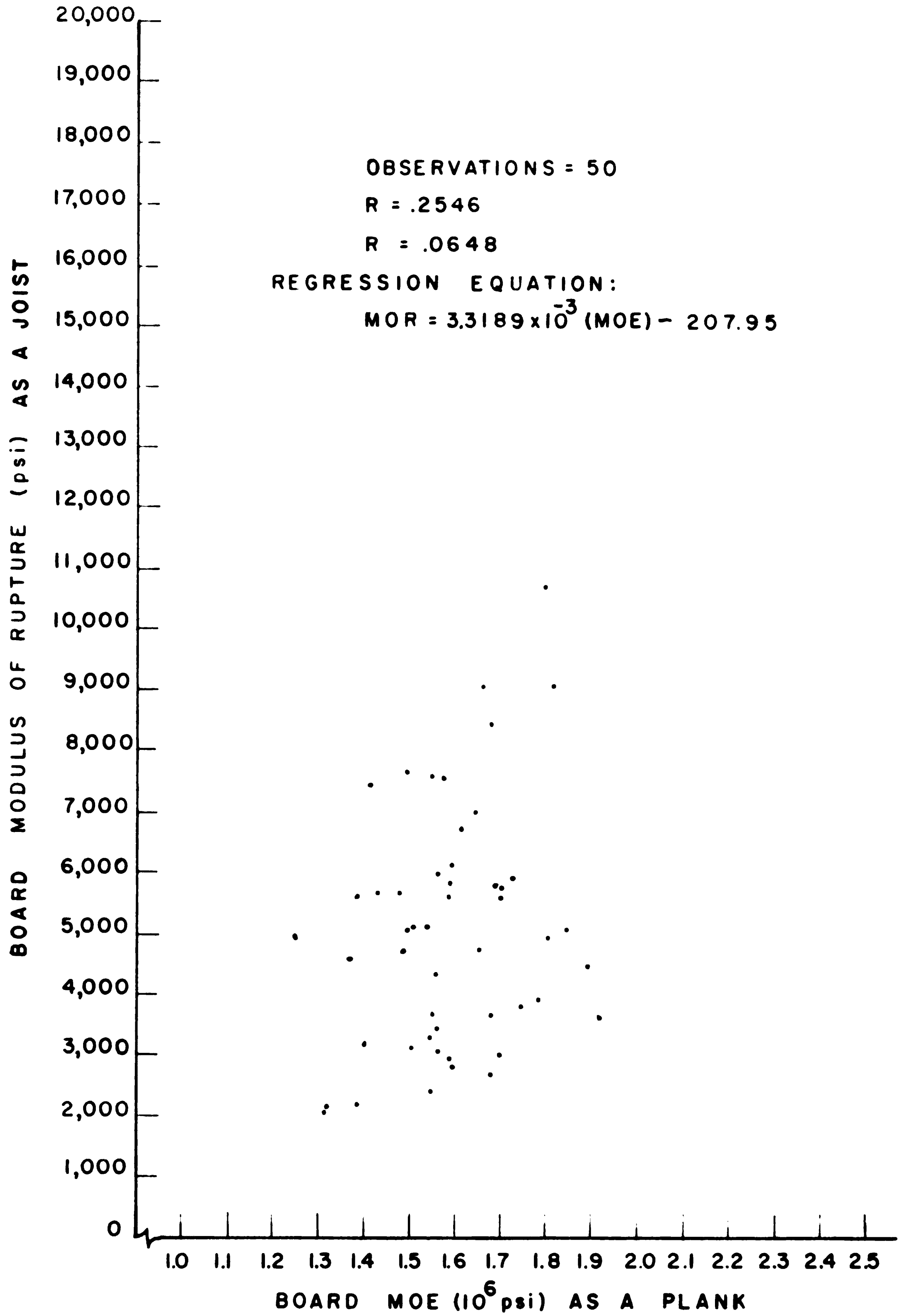
JOIST MOR VS JOIST MOE

FIGURE 10



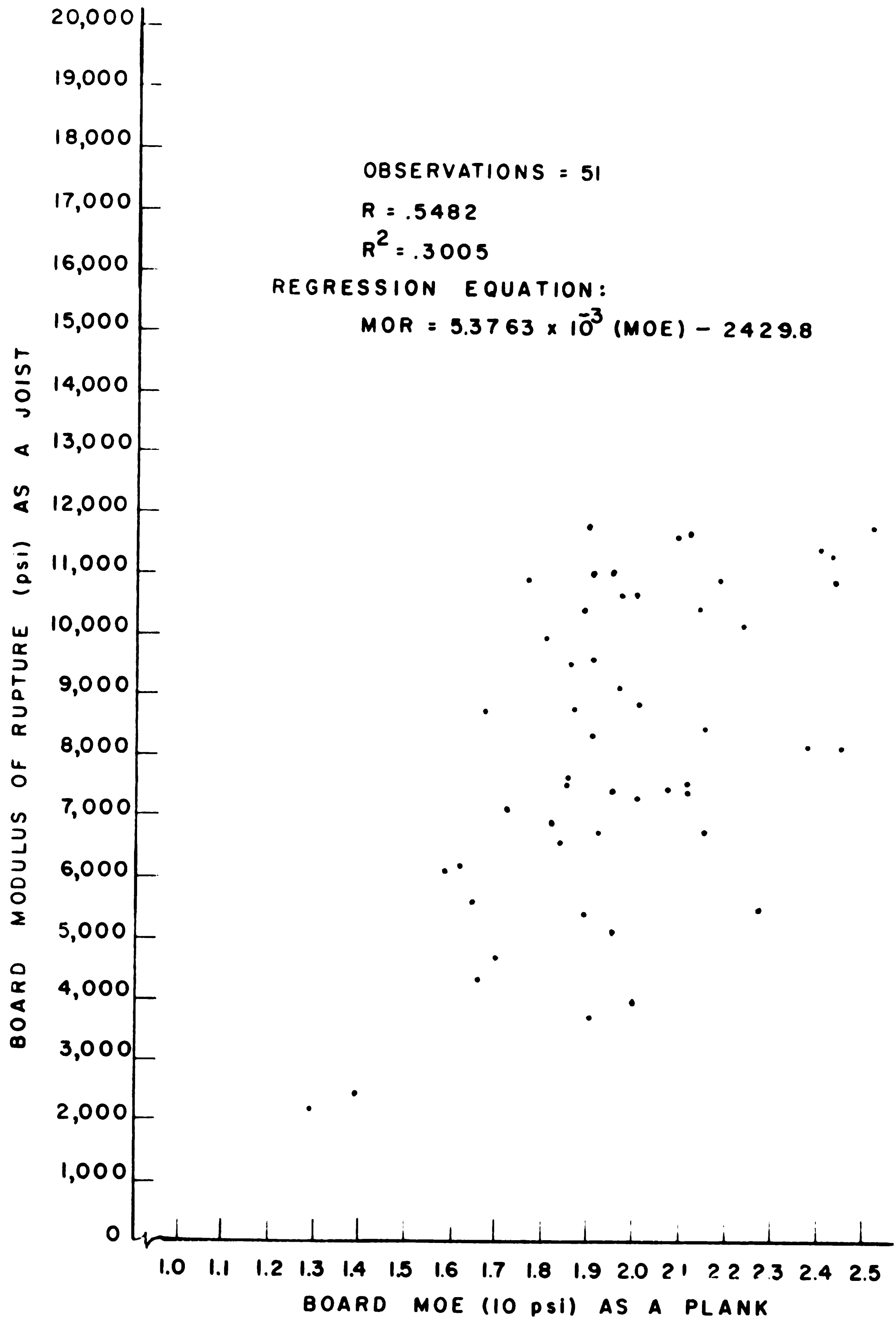
MOR VS MOE WITHIN 1500f EMSR GRADE

FIGURE 11



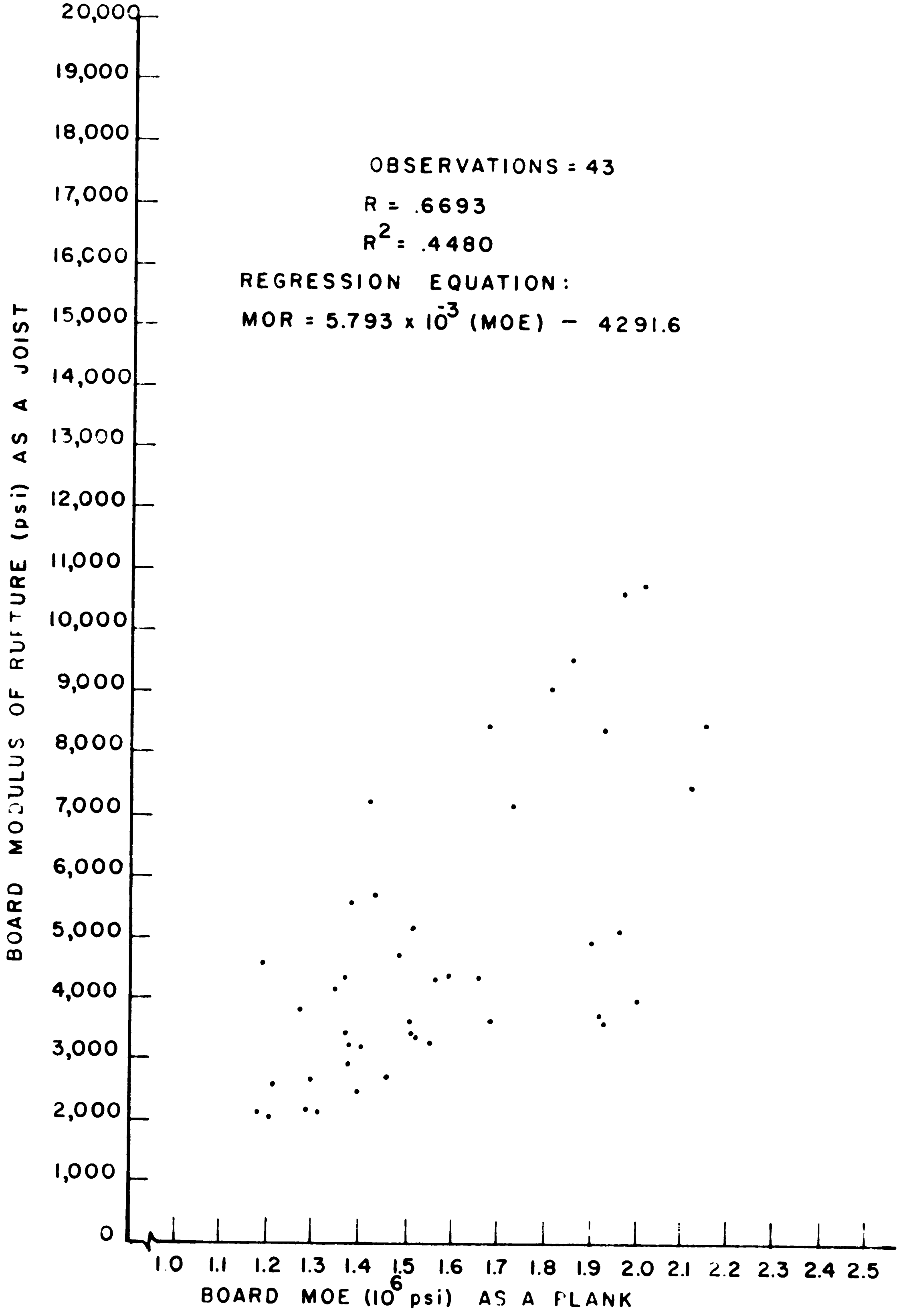
MOR VS MOE WITHIN 2100f EMSR GRADE

FIGURE 12



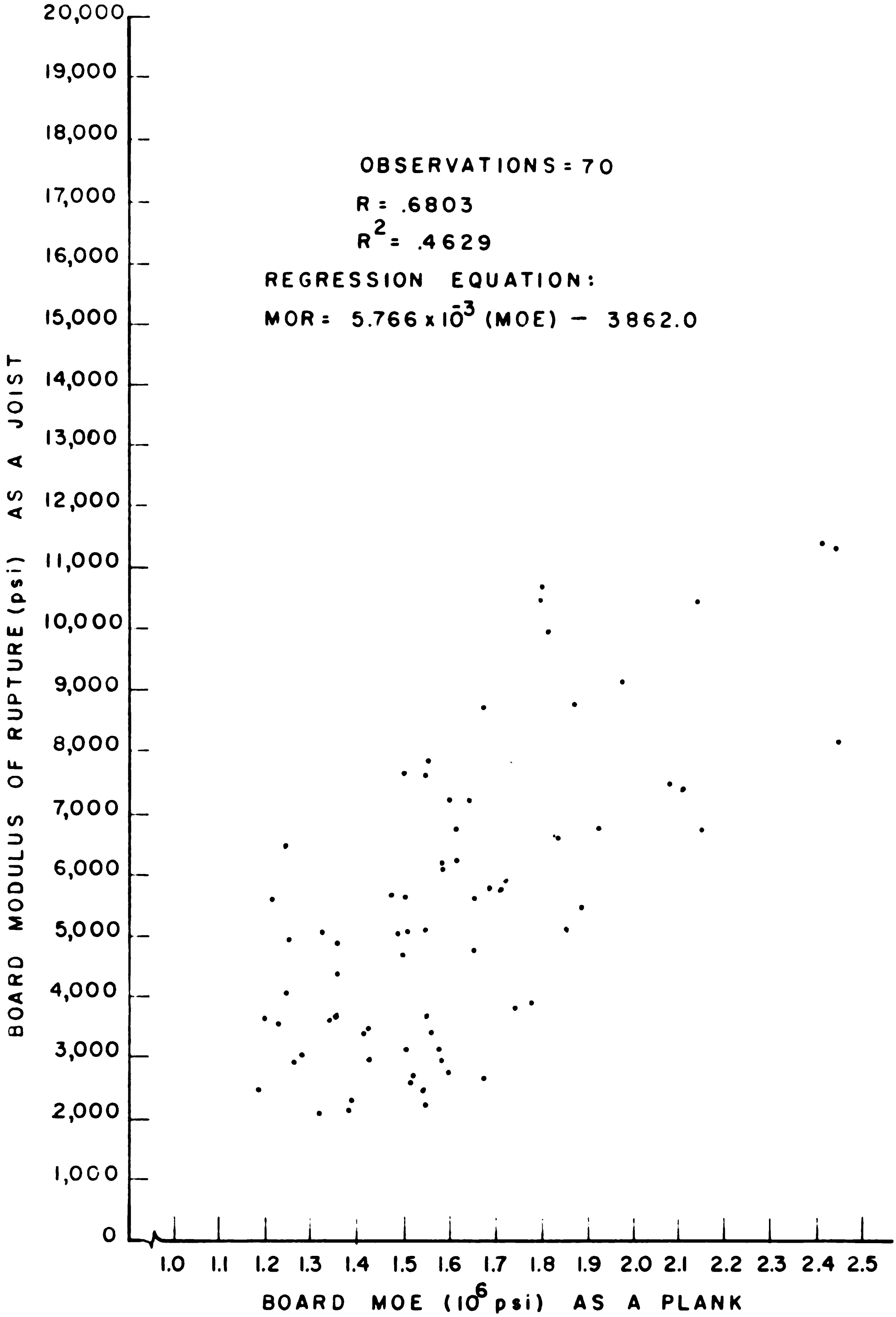
MOR VS MOE WITHIN 2400f EMSR GRADE

FIGURE 13



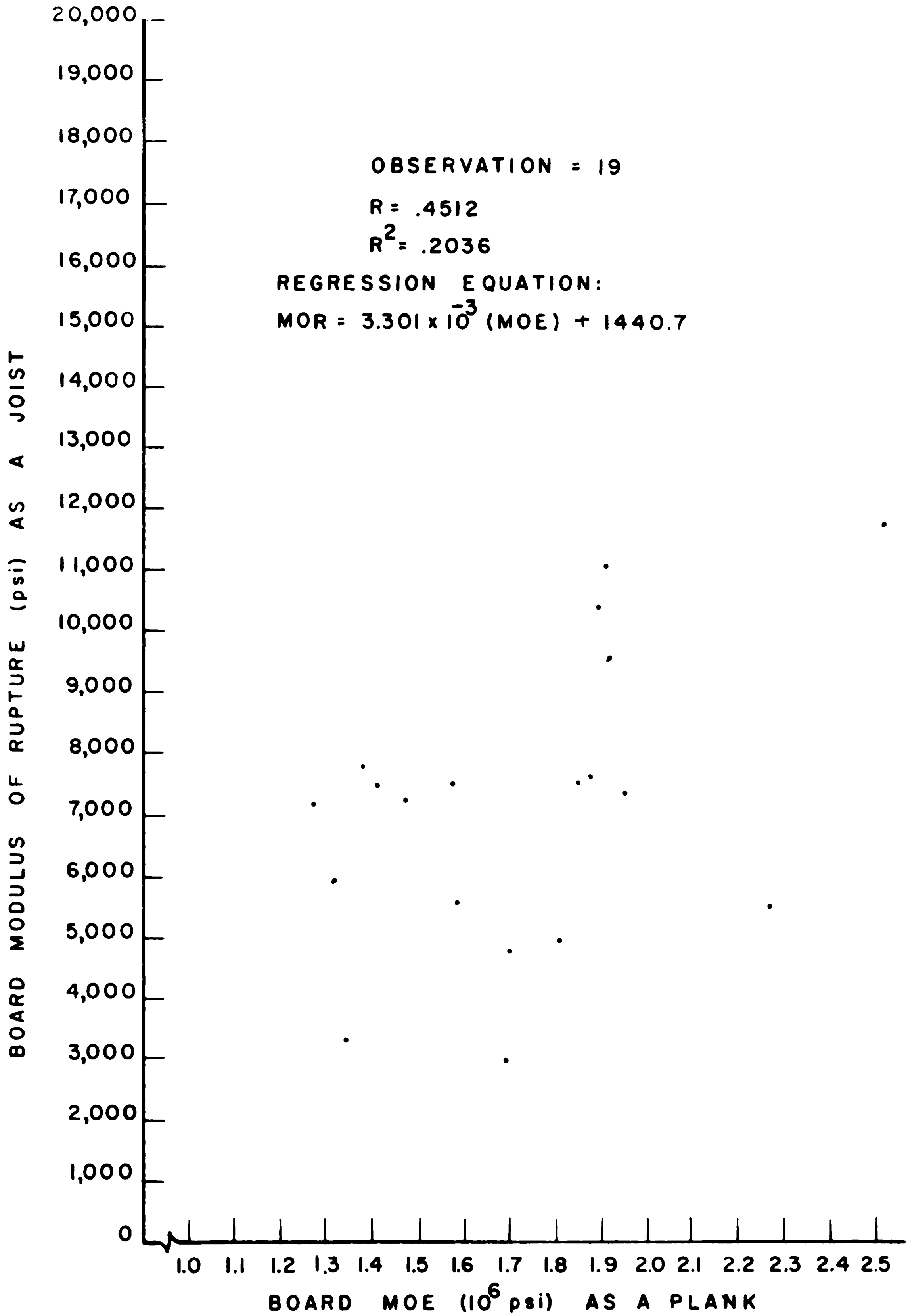
MOR VS MOE WITHIN 1200f VISUAL GRADE

FIGURE 14



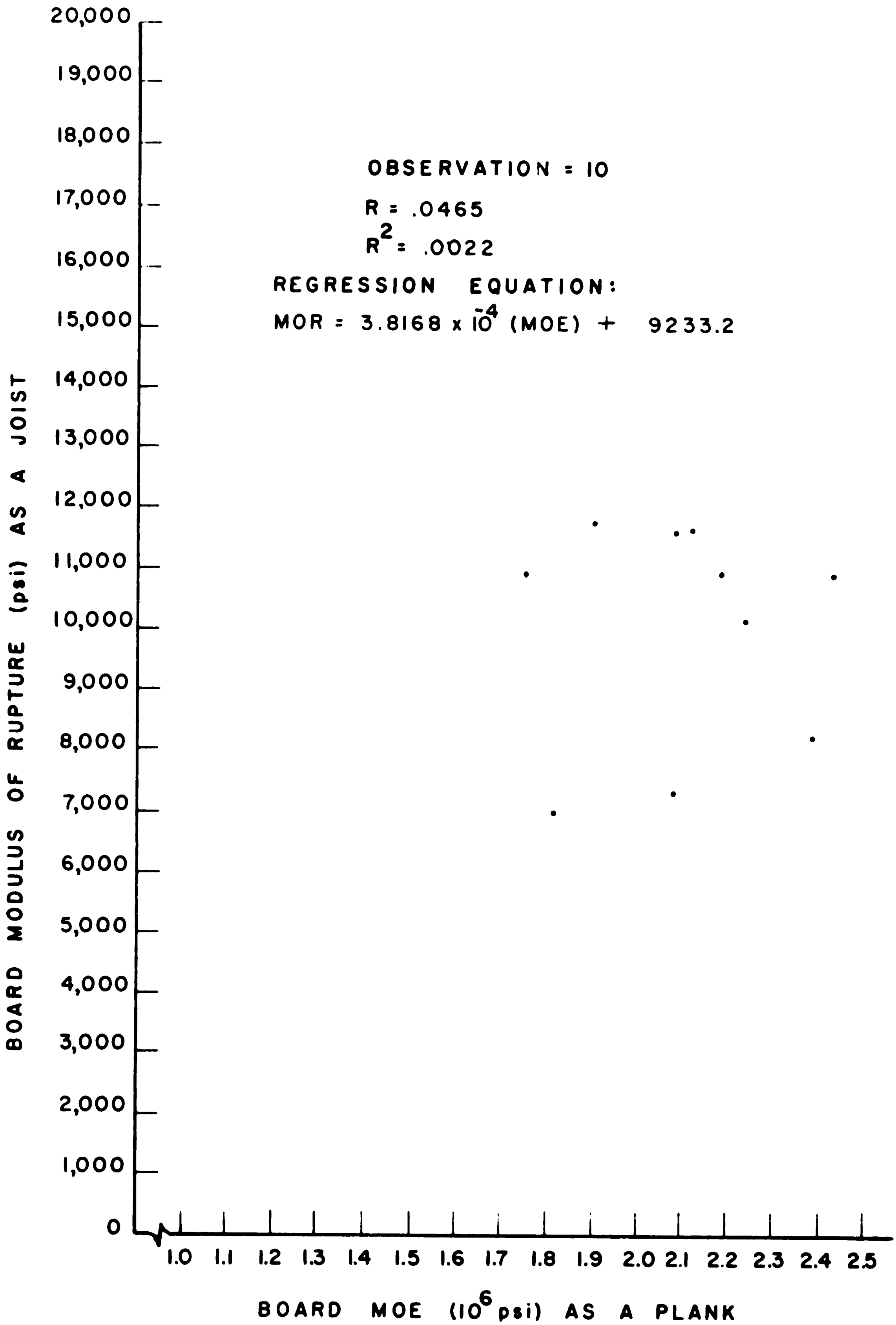
MOR VS MOE WITHIN 1500f VISUAL GRADE

FIGURE 15



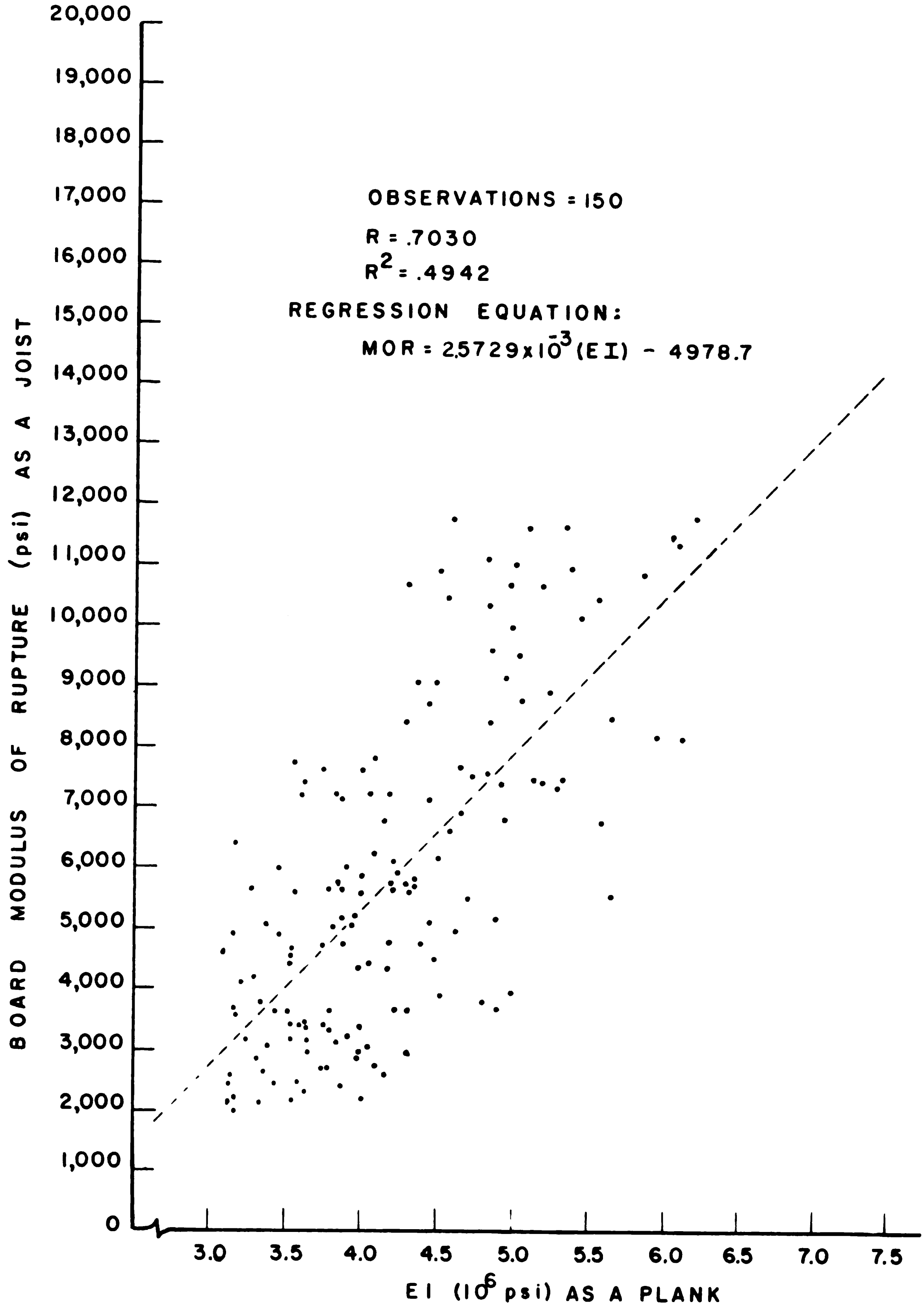
MOR VS MOE WITHIN 1900f VISUAL GRADE

FIGURE 16



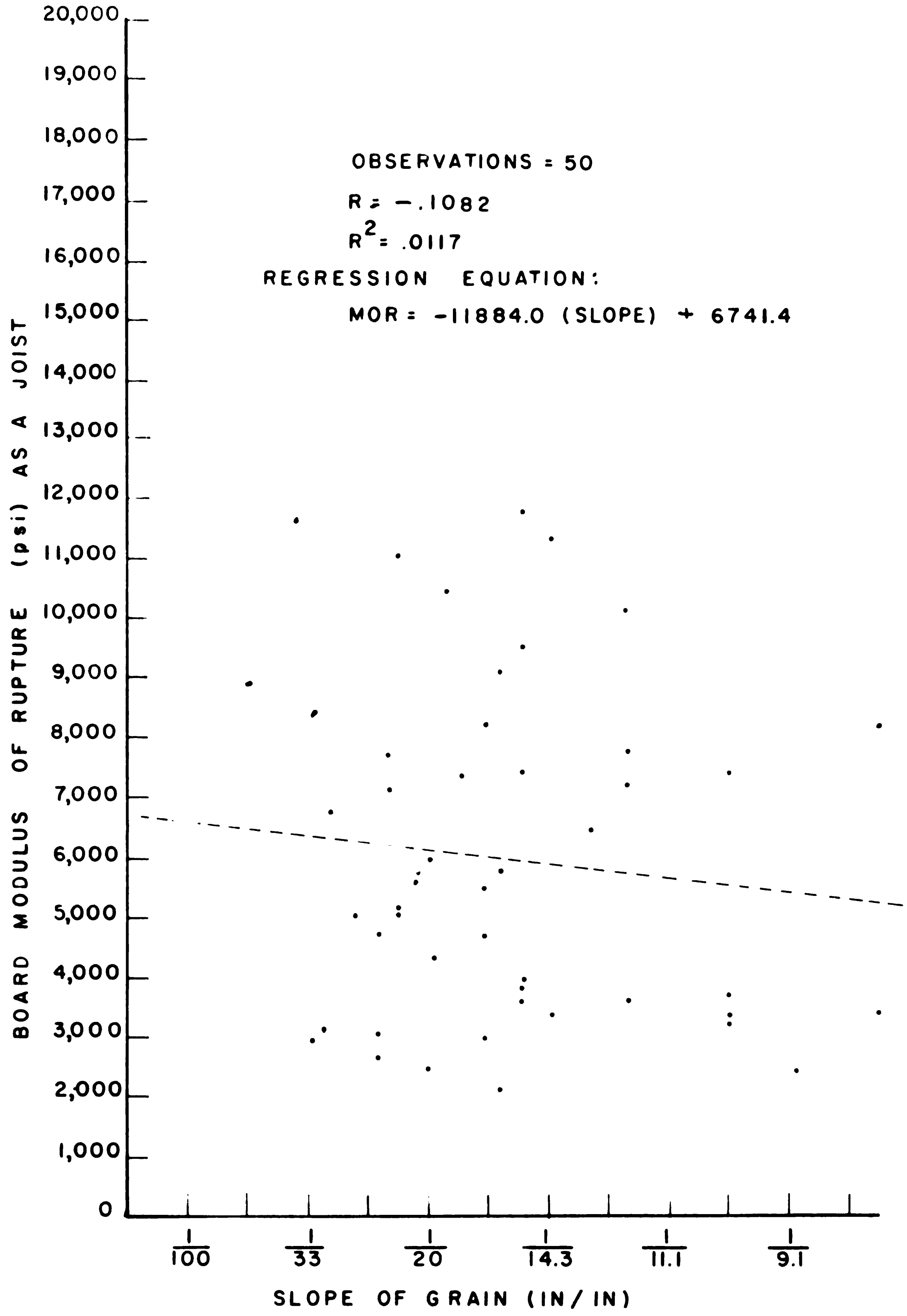
MOR VS MOE WITHIN 2050f VISUAL GRADE

FIGURE 17



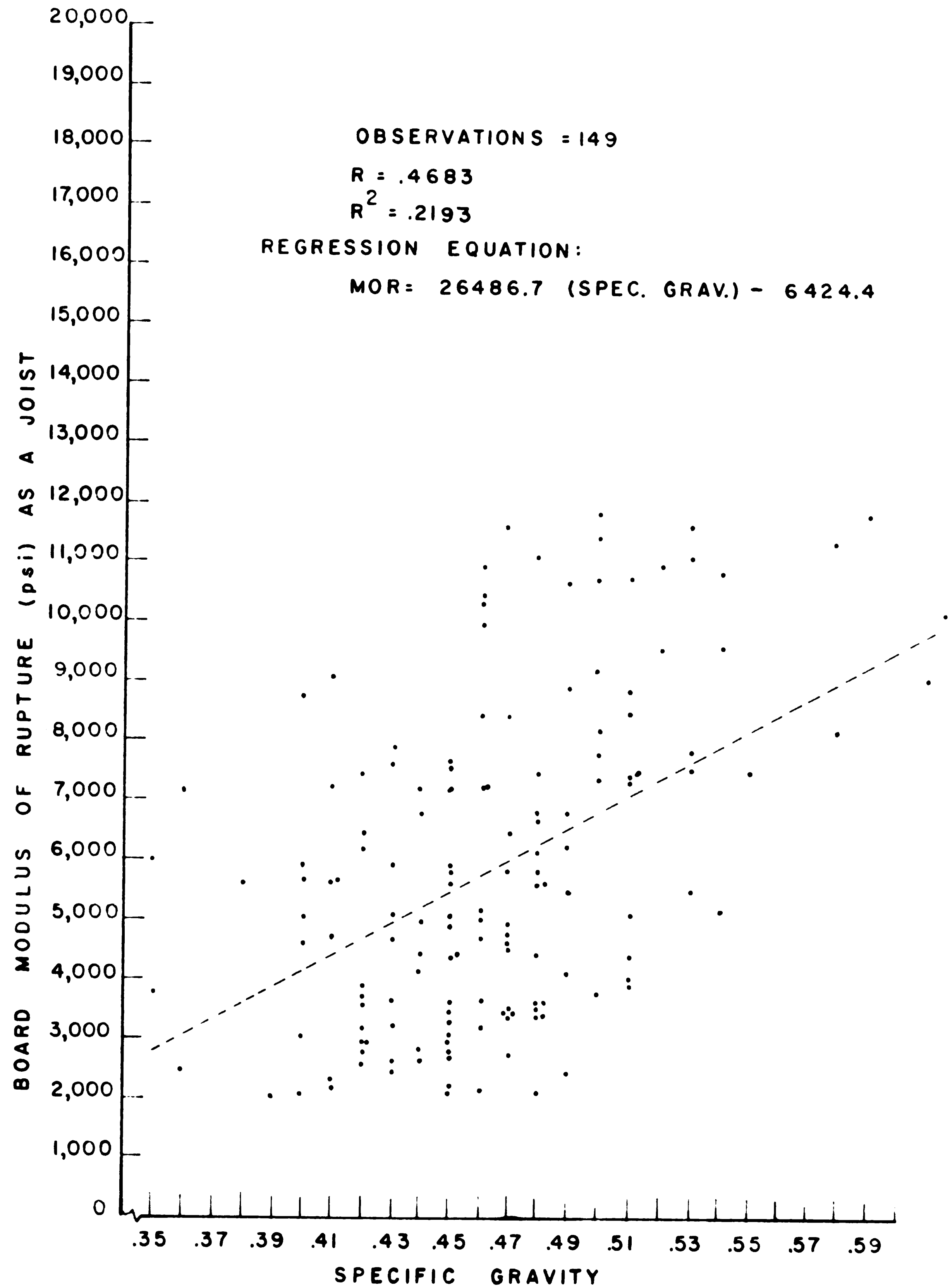
JOIST MOR VS STIFFNESS (EI)

FIGURE 18



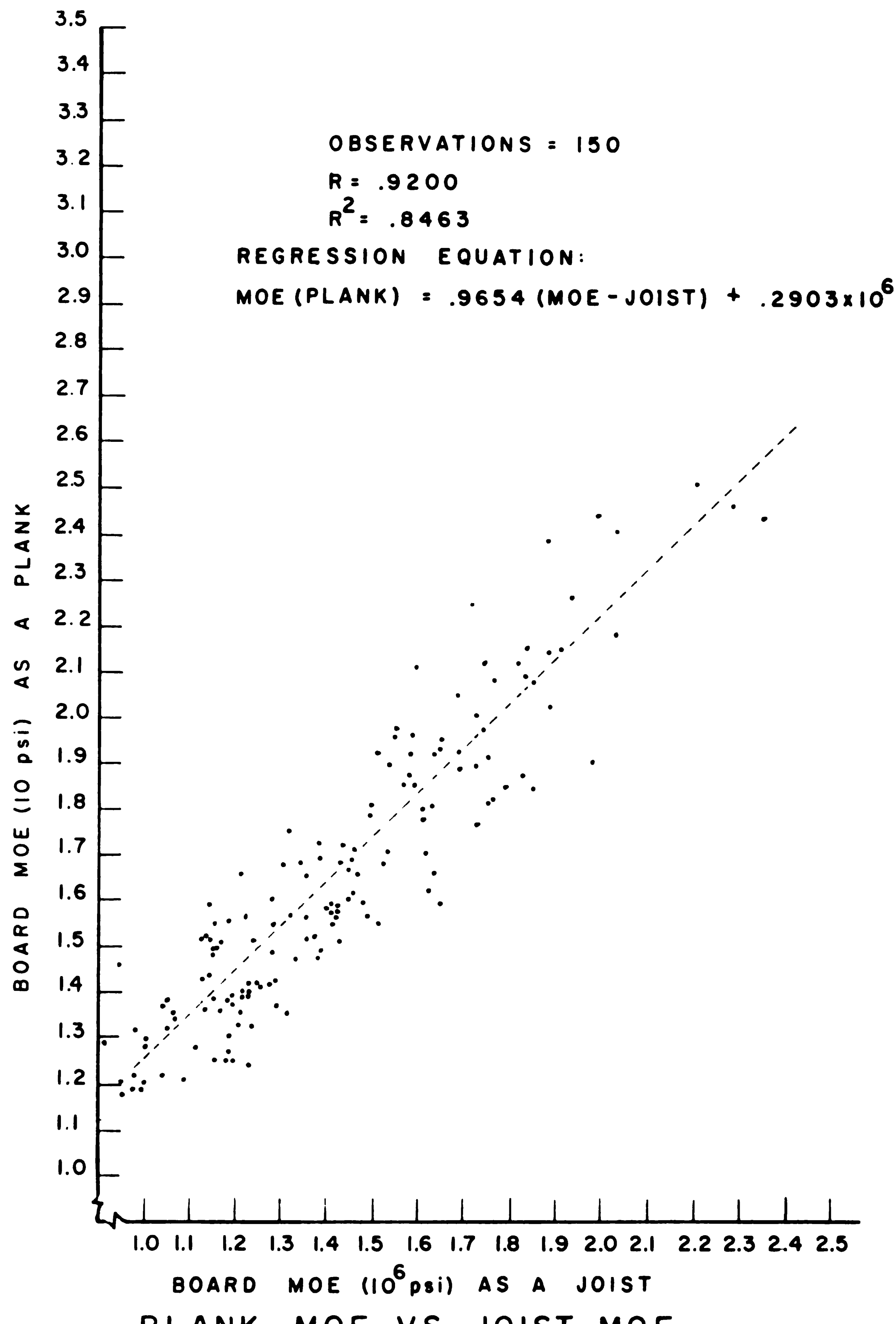
JOIST MOR VS SLOPE OF GRAIN

FIGURE 19



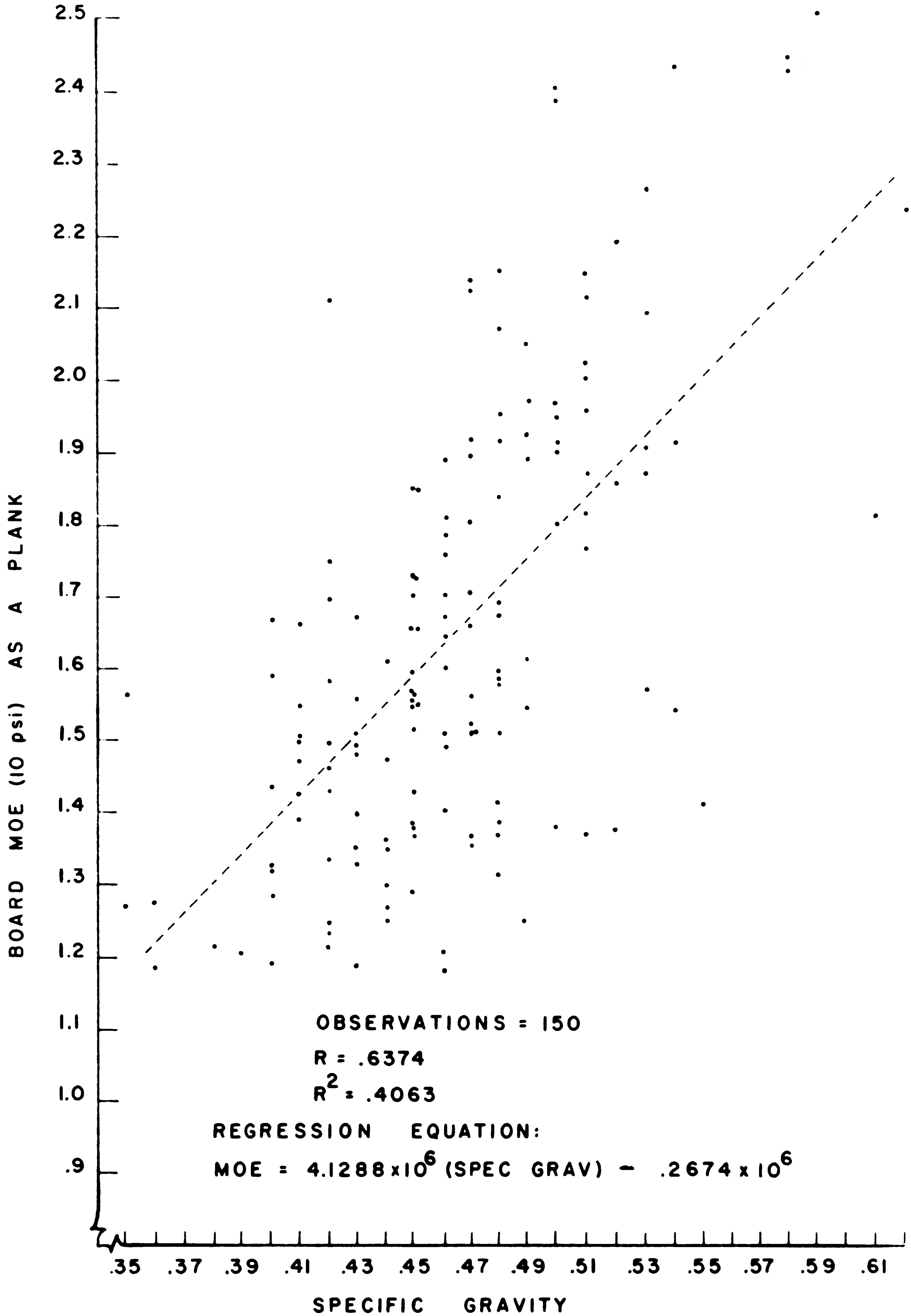
JOIST MOR VS SPECIFIC GRAVITY

FIGURE 20



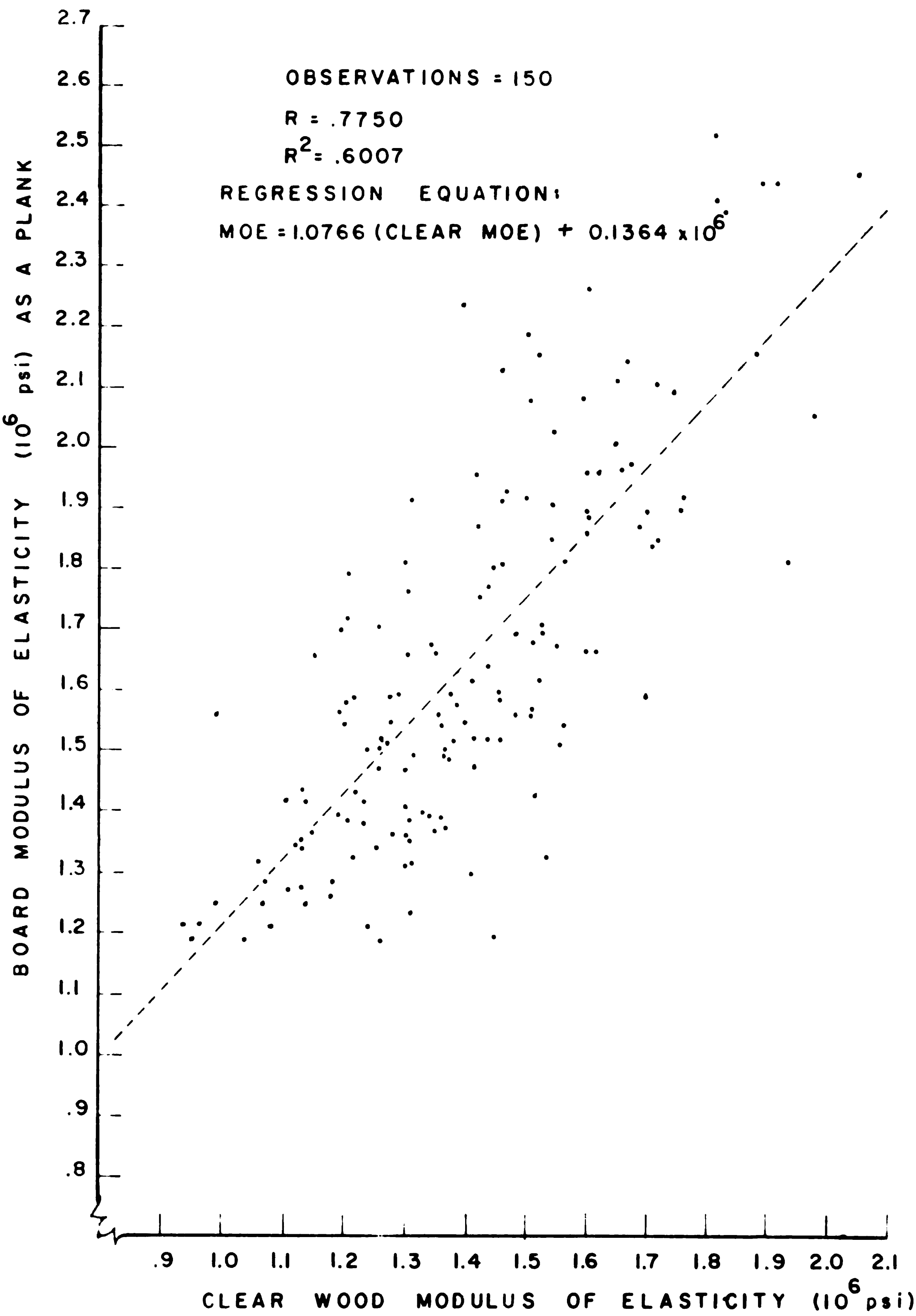
PLANK MOE VS JOIST MOE

FIGURE 21



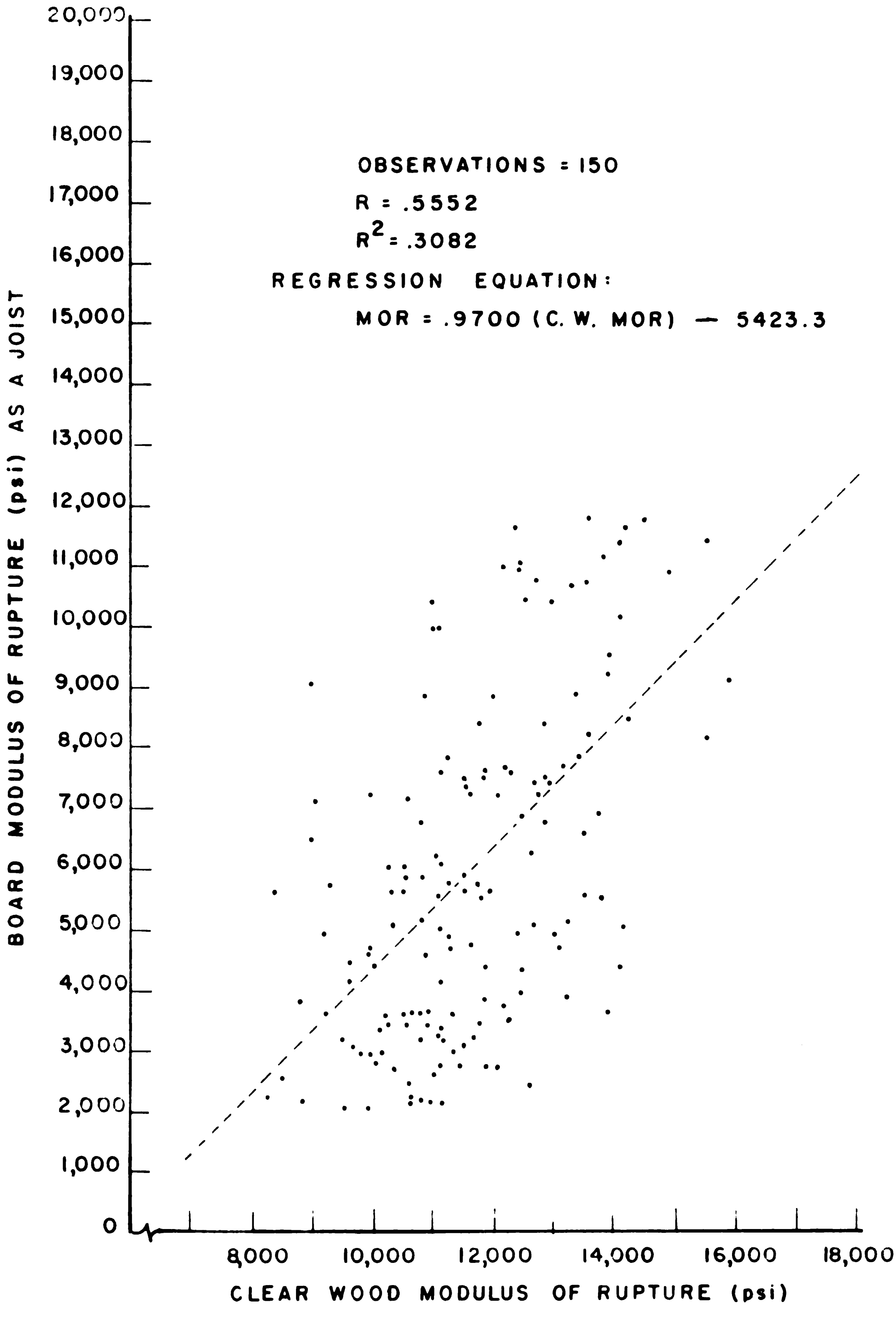
PLANK MOE VS SPECIFIC GRAVITY

FIGURE 22



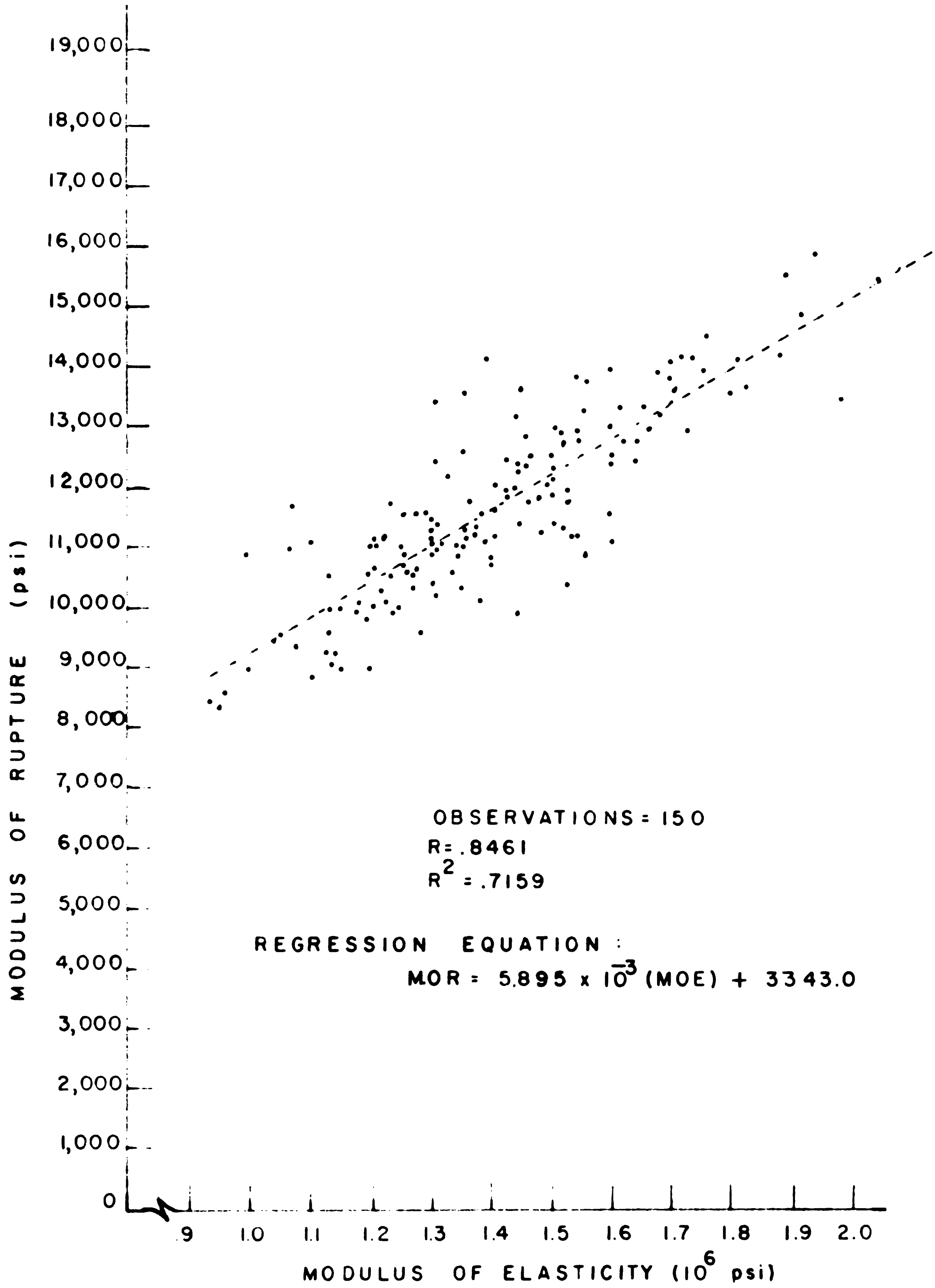
PLANK MOE VS CLEAR WOOD MOE

FIGURE 23



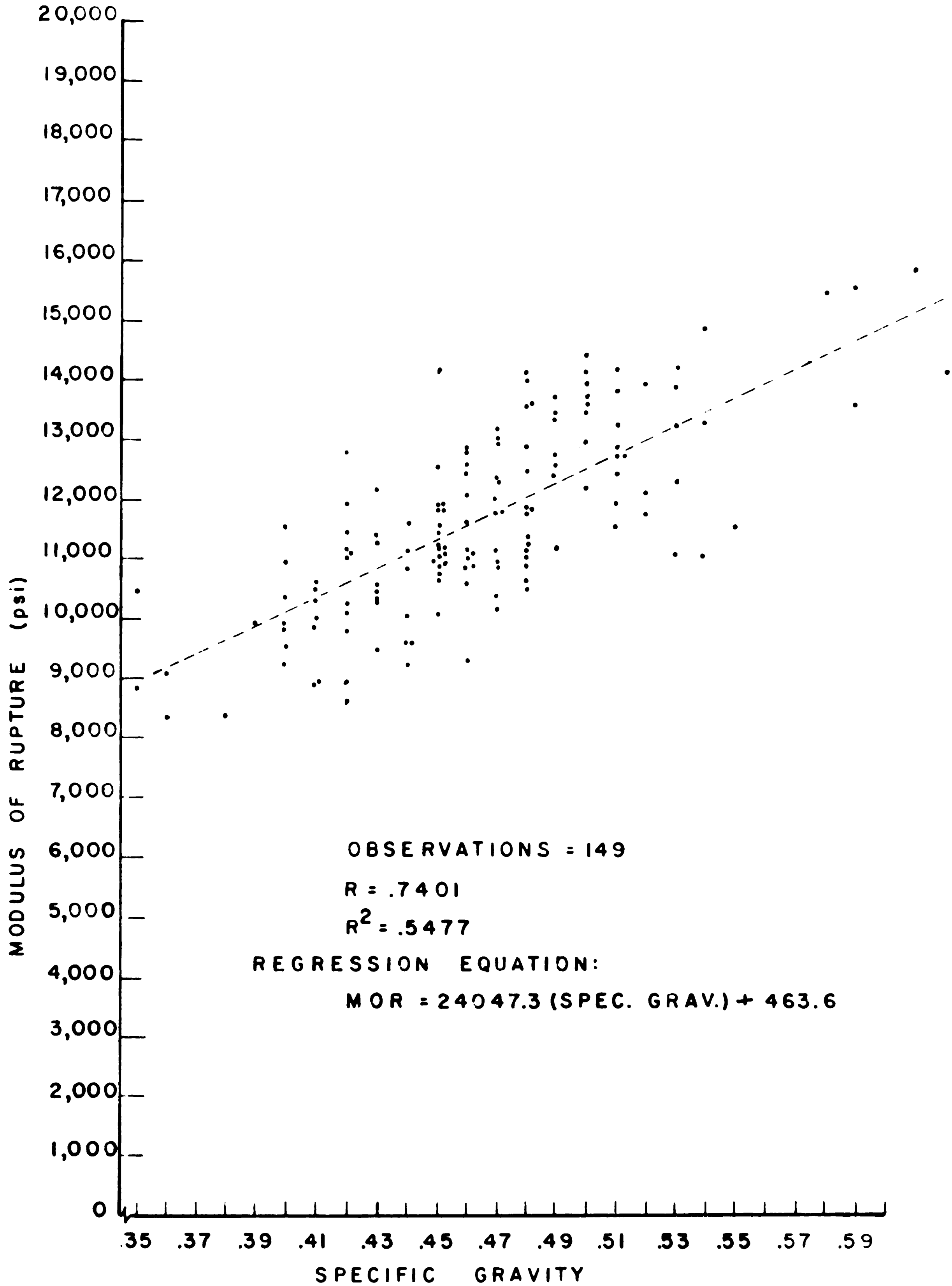
JOIST MOR VS CLEAR WOOD MOR

FIGURE 24



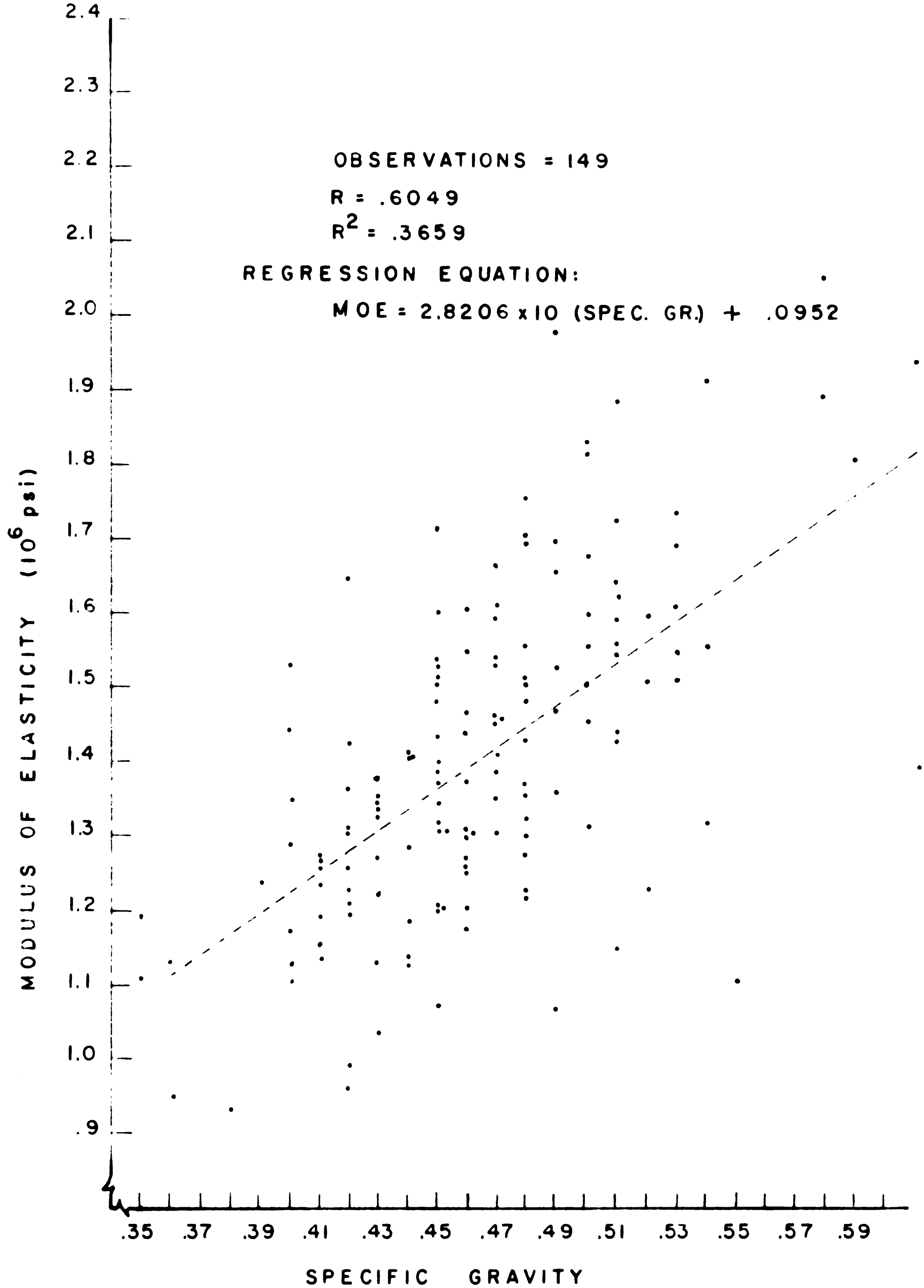
CLEAR WOOD MOR VS CLEAR MOE

FIGURE 25



CLEAR WOOD MOR VS SPECIFIC GRAVITY

FIGURE 26



CLEAR WOOD MOE VS SPECIFIC GRAVITY

FIGURE 27

DISCUSSION OF RESULTS

Statistical analyses were made of the test data for interpretation of the results. Each individual set of data was analyzed by showing its range, average value (or mean), and the standard deviation about the mean. In each graph plotted, one variable is shown as a function of another. Where applicable, a calculated line of regression shows the relationship between two variables and the standard deviation of the points (standard error of estimate) about the line of regression. The correlation coefficient ($R = \sqrt{1 - \frac{\text{stand. error est.}^2}{\text{stand. dev.}^2}}$) was used to compare the goodness of fit of the data to the line of regression from one relationship to that of another relationship. The closer R is to 1.00, the better the fit of the data to the line of regression. If R is squared (to obtain R^2 = correlation of determination) and then multiplied by 100 percent, the resulting percent will indicate the percent variance in values on the Y axis associated with the variance of values on the X axis. For further information see Appendix I.

In Figure 6, the way in which the two grading systems graded the boards is shown by a matrix. It was evident that the two systems did not rate the same boards the same. For instance, of the boards graded 1200f by visual grading rules, 17 boards were rated 1500f, 13 - 2100f, and 13 - 2400f by the CLT-1 machine.

On the other hand, of the 10 boards that were classified 2050f by the visual rules, all were rated 2400f by machine grading. This was most likely due to the fact that the wood was nearly free of defects in this category and both systems would yeild high f-grades.

The accuracy of the EMSR grade and of the visual grade in predicting the ultimate strength of the board was shown in Figures 7 and 8 respectively. It is difficult to say which method predicted the ultimate strength most realistically because neither system was accurate. The machine is designed and set so that, within a 95 percent confidence interval, the boards will have a 2.1 safety factor. The dotted line in Figure 7 indicated the lower threshold limit for 95 percent confidence. It can easily be seen that more than 5 percent failed below these limits. A total of six boards (2 - 2400f and 4 - 2100f) failed below the design stress with no safety limit.

Although none of the visually graded boards in Figure 8 failed below their design stress, more than 5 percent of the boards failed below the threshold limits for a safety factor of 2.4. This is true especially in the 1500f group where about 19 boards out of 70 failed below the design threshold limit.

Since the machine grading for 'f' grade is based upon an assumed correlation between MOR and MOE, these two variables were compared in Figures 9 and 10.

Figure 9 compared the joist MOR with the plank MOR. In determining the 'f' grade, the CLT-1 machine flexes the board as a plank. The scatter diagram shows a rather poor

(0.6951) correlation between joist MOR and plank MOE. Since the correlation between clear wood MOR and clear wood MOE is much better (0.8461), the poor correlation found in the boards must be due to the influence of defects.

The R^2 (coefficient of determination) shows that less than half of the variance in MOR can be attributed to a variance in MOE. Also, the standard error of estimate of 1,967.9 psi indicates another relationship. Within a 95 percent confidence interval for these boards, the average value of MOE (1.649×10^6 psi) could only predict that the MOR would be between 1,919.9 psi and 9,791.5 psi.

The joist MOR was plotted against the calculated joist MOE to determine whether or not a closer correlation would exist since MOR was determined as a joist. Figure 10 illustrates that there was no significant increase in correlation by measuring MOE as a joist.

In Figures 11, 12 and 13, the joist MOR was compared with plank MOE within each of the three machine grades to determine whether or not the correlation was better between the two variables at the higher 'f' rating. These figures indicated that the correlation was not substantially better in any of the grades.

More importantly, these same three figures also illustrate the capability of the machine to separate the boards into MOE groups. As shown in Figure 11, the boards within the 1500f group ranged in MOE from 1.15 to 1.60×10^6 psi. Those in the 2100f group (Figure 12) ranged from approximately 1.35 to 1.80×10^6 psi. Those boards in the 2400f group (Figure 13) had MOE values greater than 1.60×10^6psi with the stiffest board reaching 2.50×10^6psi.

In Figures 14 through 17, the joist MOR was plotted against the plank MOE for each of the four visual grades. These figures show that the visual grades do not predict MOE.

In flexing each board, the machine measured the load necessary to deflect the board a specific amount. The amount of load necessary determined the machine's MOE rating for the board. This was only possible because the sizes of the boards were assumed constant. If a board had been substantially undersized, the stiffness would have been low even though the MOE could have been high. For this reason, the stiffness (EI product) at time of testing was also used to predict MOR in Figure 18.

Because the boards varied in thickness and height along the boards, the I values could not be determined as accurately as the 0.001 inch vernier caliper indicated. However, because an average of three values was used, the dimensions were accurate within $\pm$ 0.010 inches and the oversized and undersized boards were discernable.

The results in Figure 18 show that MOR was not better correlated with stiffness than with plank MOE indicating that the variance in sizes at time of testing did not help or hinder the machine's ability to predict MOR.

The slope of grain was measured and its effect on the joist MOR was shown in Figure 19. In an unpublished paper entitled "Grading Machines Measure the Effect of Grain Slope" by C. Glover, R.J. Hoyle, and D.V. Woodruff, it was stated that the slope of grain definitely affected both the MOE and the MOR of their samples (clear wood). However, because of the overriding influence of other defects, the slope of grain had almost no effect on the ultimate strength of the 2 x 8's in this test. Even boards with slope of grain as high as one inch in eight inches attained MOR values as high as 8,000 psi.

Joist MOR was shown as a function of clear wood specific gravity in Figure 20. The scatter diagram indicates almost no correlation between the two variables.

The strength of clear wood has little to do with the strength of the boards containing defects as shown in Figure 24 where the joist MOR was plotted against the clear wood MOR.

The fact that slope of grain, specific gravity, and clear wood MOR have little effect on board MOR emphasizes the overriding influence of defects on the ultimate strength of the boards.

Figure 23 showed that the MOE of the boards was less dependent on defects than was MOR. In comparing plank MOE with clear wood MOE, the correlation coefficient was found to be 0.7750. Although this is not a good correlation, it does show that board MOE is more dependent upon clear wood MOE than board MOR ($R = 0.5552$) is dependent upon clear wood MOR.

Figure 25 supported the long established fact that clear wood MOR and clear wood MOE are well correlated.

The moisture contents at time of test were found to be between 11.4 percent and 12.8 percent with an average of 11.84

percent. These results indicated that the difference in moisture contents at time of tests were small enough so that they should not have affected the results.

CONCLUSIONS

1. The two stress grading systems used, EMSR and Visual, did not rate the boards the same. An exception to this is in the highest grade where defects are at a minimum and both systems rated the same boards with the highest f grade.
2. Neither method proved more reliable in predicting the ultimate strength of the board.
3. The machine graded boards did not achieve the 2.1 design safety factor. Some of the visual graded boards also failed below their 2.4 design safety factor.
4. The correlation coefficient between joist MOR and plank MOE was found to be about 0.70. This correlation was not improved by measuring MOE as a joist to predict joist MOR.
5. Using stiffness (EI product) to predict MOR did not result in a better correlation than using MOE to predict MOR.
6. Machine grading did separate the boards into MOE groups while MOE seemed independent of visual grade except in the high f grade.
7. With this sample, the slope of grain, clear wood MCR, and density had little affect on the ultimate strength of the 2" x 8" boards.
8. E as a joist correlated very well with E as a plank.
9. E is a better indicator of modulus of rupture than is specific gravity.

APPENDIX I

Statistical Methods Used

In this investigation, statistical analyses were made in order to determine the association between measured and calculated variables for each board. Statistical determination of the relationship between variables, dispersion, and degree of correlation of the experimental data were also made. The relationship between independent and dependent variables was statistically evaluated in simple 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 analysis) programs devised by Michigan State University's computer personnel. 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.

A statistical test of significance was run for each graph using the 'f' statistic. All relationships proved significant at the one percent level.

Simple regressions relate one dependent variable to the independent variable. If two related (associated) series are plotted graphically with one variable placed on the X axis and the other on the Y axis, the result is known as the scatter diagram. If there is a high degree of association, the scatter will be confined to a narrow "path". The less perfect the relationship between the two sets of data, the greater will be the departures from the indicated line of course. The equation for this line is mathematically determined by the least squares technique where the sum of squares of the Y deviations of points about the line is minimized. This regression line always passes through the intersection of the means of X and Y (the centroid of the data). The regression line of Y on X is of the following form:

$$Y = A + B_{yx}X$$

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.

Whether or not a correlation between Y and X exists is indicated by the slope, B_{yx} (called the regression coefficient). If the line of regression is parallel to the X axis ($B_{yx} = 0$), any value of X would predict the general mean of Y and no correlation would exist. Furthermore, if the line is not horizontal, the best estimate of Y would depend upon X and a correlation would exist.

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 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 estimate can be compared with the standard deviation. Whereas the standard deviation is the average (quadratic mean) or the deviations about the arithmetic mean, the standard error of estimate is the average (quadratic mean) of the deviations about the line of regression. Also, the standard error of estimate may be used in the same manner as the standard deviation. Plus or minus one standard deviation about the arithmetic mean includes 68 percent of the cases; and plus or minus one standard error of estimate will include 68 percent of the cases when measured about the line of regression. (It is assumed that there is a normal or approximately normal distribution of the values about the line of regression). (4)

Another measure of the degree of association is the correlation coefficient (R). R is determined by the equation:

$$R = \sqrt{1 - \frac{S_y^2}{\sigma_y^2}}$$

where S_y is the standard error of estimate and σ_y is the standard deviation of the Y values. R is used as a means of comparing the relative correlation of two variables to the correlation of another pair of variables. A perfect correlation results when $R = 1.00$ and no correlation results when $R = 0.00$. A negative R results when an increase in one variable causes a decrease in the other variable.

The coefficient of determination (R^2) multiplied by 100 percent indicates the percent variance in Y associated with the variance in X.

APPENDIX II

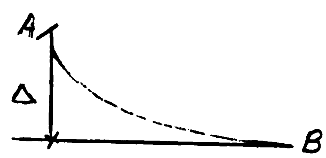
Equations

<u>Major Tests</u>

Because the load applied by the testing apparatus approximated but did not equal a uniform load, it was necessary to derive equations for MOE and MOR using the shear and bending moment diagrams shown in Figure 28.

In determining the equation for MOE, the area moment was used.

Statement of area moment:



If A and B are points on a deflection curve, the vertical distance of B from the tangent drawn to the curve at A is equal to the moment with respect to the vertical through B of the area of the bending moment diagram between A and B, divided by the flexural rigidity EI.

In reference to Figure 28, the sum of the areas of the squares times their centroidal distances from 'A' equals 310,144P. The sum of the triangles times their centroidal distance from 'A' equals 20,768P.

$$\Delta = \frac{310,144P + 20,768P}{EI} \times \frac{W}{13P} = \frac{25,455W}{EI}$$

$$MOE = \frac{25,455W}{\Delta I}$$

In the above equation, W = total load in pounds, Δ = deflection in inches at center, and I = calculated moment of inertia of the board.

In determining the equation for MOR, the flexure formula was used:

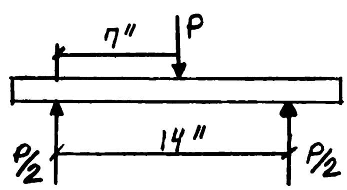
$$\sigma = \frac{MC}{I} = \frac{222W \cdot \frac{h}{2}}{13I}$$

In the above formula, the bending moment was determined by the area under the shear diagram to the left of the maximum or center (222P or $222 \cdot \frac{W}{13}$). The 'C' was the distance to the extreme fibers ($\frac{h}{2}$) and 'I' was the calculated moment of inertia.

Minor Tests

In the minor tests, the clear wood samples were tested using a single point load over a 14 inch span.

Free Body:



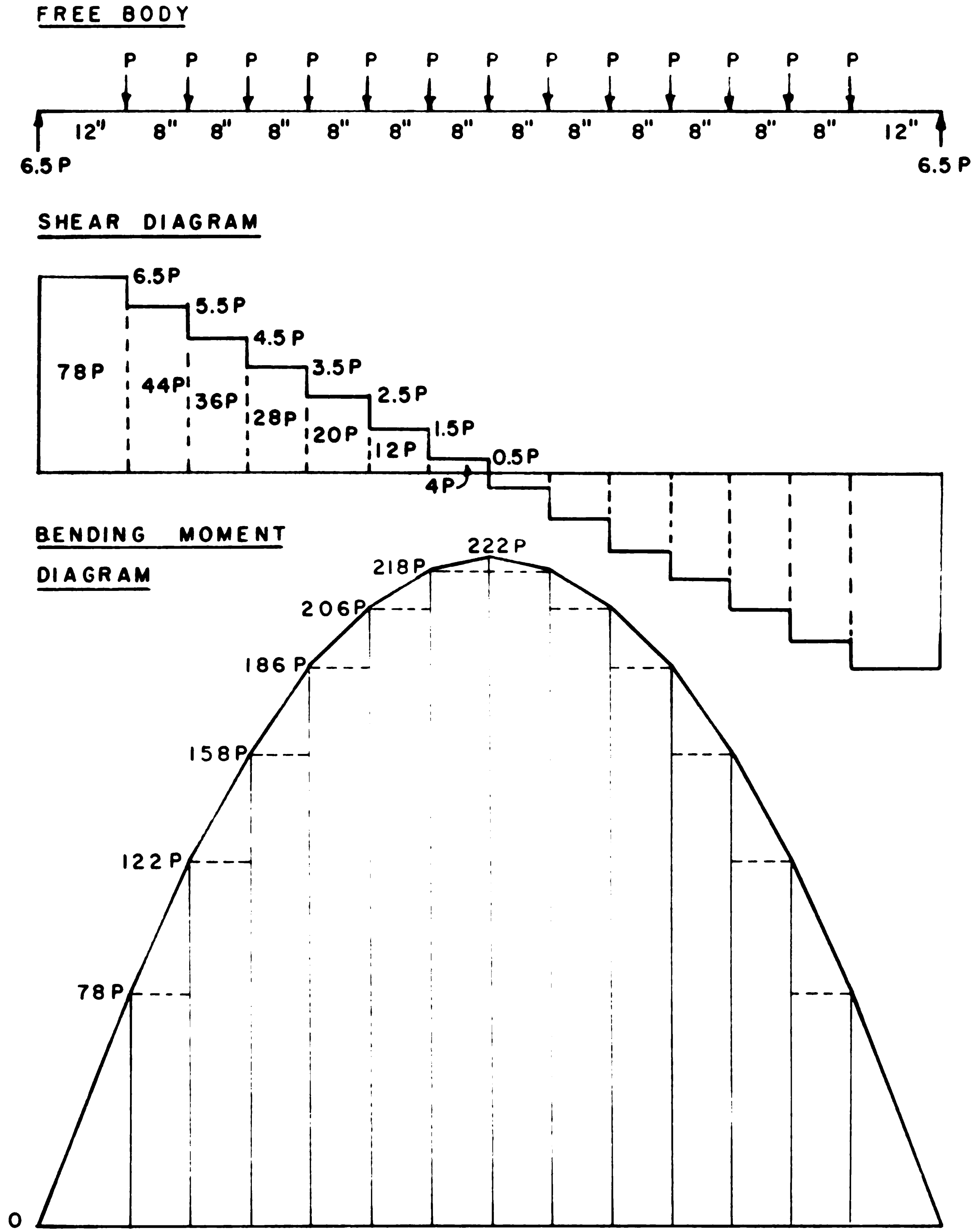
The MOE was calculated using the formula:

$$E = \frac{PL^3}{48\ I} \ ; \quad E = \frac{P \cdot 2744}{4.8(.1)I}$$

where 'P' equals load, 'L' equals span in inches (14"), Δ equals deflection (always 0.1"), and 'I' equals calculated moment of inertia.

The flexure formula was used to determine MOR.

$$S = \frac{MC}{I} \ ; \quad S = \frac{P\ L/4 \cdot h/2}{bh^3/12} \ ; \quad S = \frac{21P}{bh^2}$$



MAJOR TEST SHEAR AND BENDING MOMENT DIAGRAMS

FIGURE 28

In the above formula 'S' is equal to the extreme fiber stress or modulus of rupture, 'M' is the maximum moment (equal to maximum load 'P', times L/4), 'C' is the distance from neutral axis to extreme fiber stress (height, 'h' divided by 2) and 'I' is the calculated moment of inertia for the sample ($\frac{bh^3}{12}$).

Moisture contents were determined using the oven dry method and specific gravity was determined using the oven dry weight and the oven dry volume.

APPENDIX III

Data

Board Number	EMSR Grade	Visual Grade	MAJOR TESTS					MINOR TESTS					Thickness	Height
			Modulus of Elasticity				Mod. of Rupture	Clear MOE		Clear MOR		Sp. Gr.		
			Face	Back	Top	Bottom		1	2	1	2	Average		
1	1500	1500	1.508	1.508	1.140	1.140	5087	1.466	1.077	11936	9198	.43	1.610	7.503
2	1500	1200	1.193	1.302	.994	1.036	4599	1.089	1.197	9558	10157	.40	1.607	7.484
3	1500	1500	1.415	1.428	1.268	1.254	3403	1.223	1.243	10455	10659	.48	1.602	7.459
4	1500	1500	1.189	1.136	.973	.769	2449	.897	1.003	8386	8161	.36	1.615	7.480
5	1500	1500	1.389	1.450	1.214	1.157	2287	1.438	.948	10441	7345	.41	1.609	7.499
6	1500	1900	1.276	1.300	1.114	1.007	7164	1.184	1.085	9346	8725	.36	1.690	7.530
7	1500	1200	1.183	1.286	.954	.954	2151	1.235	1.301	10500	10743	.46	1.640	7.428
8	1500	1500	1.430	1.499	1.130	1.173	2977	1.207	1.241	10078	10186	.42	1.598	7.512
9	1500	1500	1.547	1.547	1.185	1.171	2215	1.307	1.244	11468	9843	.41	1.608	7.470
10	1500	1500	1.557	1.530	1.229	1.361	7800	1.382	1.328	11729	10765	.43	1.610	7.525
11	1500	1200	1.378	1.459	1.229	1.201	3215	1.241	1.224	11371	12097	.52	1.614	7.488
12	1500	1500	1.495	1.441	1.151	1.136	4737	1.237	1.237	9864	9864	.41	1.606	7.485
13	1500	1500	1.236	1.236	1.230	1.201	3543	1.349	1.269	10159	10303	.42	1.598	7.514
14	1500	1500	1.283	1.310	.908	.915	3027	1.208	1.148	10249	9545	.40	1.614	7.497
15	1500	1500	1.522	1.628	1.374	1.366	2702	1.411	1.404	12690	11351	.47	1.590	7.406
16	1500	1500	1.267	1.349	1.183	1.165	2823	1.167	1.198	9556	10520	.44	1.608	7.512
17	1500	UTIL	1.190	1.139	1.000	1.042	3206	1.080	.997	9441	9450	.43	1.635	7.529
18	1500	1200	1.296	1.331	1.179	1.201	2656	1.350	1.472	10603	11766	.44	1.602	7.507
19	1500	1200	1.513	1.531	1.431	1.464	3321	1.226	1.343	9584	10669	.47	1.590	7.449
20	1500	1900	1.470	1.589	1.388	1.163	7232	1.433	1.388	11671	11643	.44	1.610	7.472
21	1500	1500	1.517	1.465	1.126	1.108	2694	1.449	1.419	12771	11014	.45	1.635	7.503
22	1500	1200	1.422	1.509	1.226	1.248	7223	1.165	1.106	9971	9866	.41	1.600	7.414
23	1500	1200	1.274	1.274	1.003	.990	3788	1.111	1.110	9081	8468	.35	1.613	7.487
24	1500	1900	1.380	1.312	1.172	1.194	7730	1.357	1.264	13059	13860	.50	1.605	7.472
25	1500	1200	1.512	1.498	1.132	1.252	3348	1.546	1.534	12357	9979	.47	1.592	7.389
26	1500	1900	1.326	1.339	1.236	1.445	5978	1.275	1.163	9793	10728	.43	1.613	7.419
27	1500	1200	1.508	1.490	1.167	1.189	3632	1.512	1.601	10796	10828	.48	1.595	7.405
28	1500	1500	1.361	1.445	1.131	1.116	4881	1.267	1.343	11060	10995	.45	1.597	7.448
29	1500	1200	1.368	1.423	1.195	1.151	3466	1.358	1.375	11949	11539	.48	1.602	7.490
30	1500	1500	1.336	1.353	1.068	1.090	3625	1.220	1.293	10718	11241	.42	1.603	7.465
31	1500	1200	1.366	1.435	1.039	1.039	4335	1.104	1.189	9179	10807	.51	1.603	7.485
32	1500	1200	1.587	1.583	1.654	1.579	4365	1.624	1.766	13331	14909	.48	1.603	7.418
33	1500	1500	1.251	1.251	1.171	1.251	4079	1.083	1.052	11498	10843	.49	1.600	7.497
34	1500	1900	1.354	1.261	1.308	1.326	3317	1.380	1.221	10948	9937	.47	1.616	7.522
35	1500	1500	1.248	1.265	1.158	1.160	6420	.991	.990	8688	9212	.42	1.596	7.470
36	1500	1500	1.348	1.457	1.062	1.119	3657	1.103	1.162	10394	10636	.43	1.610	7.486
37	1500	1500	1.599	1.617	1.447	1.507	7230	1.415	1.512	12187	11982	.46	1.595	7.470
38	1500	1500	1.789	1.844	1.494	1.540	10424	1.241	1.167	10922	11080	.46	1.602	7.456
39	1500	1500	1.359	1.386	1.160	1.203	4474	1.280	1.285	8911	10347	.44	1.605	7.498
40	1500	1200	1.346	1.375	1.210	1.223	4178	1.065	1.187	9338	9912	.44	1.582	7.429
41	1500	1200	1.462	1.532	.940	.962	2732	1.269	1.334	11265	11706	.42	1.599	7.471
42	1500	1200	1.207	1.207	1.087	BAD	2031	1.192	1.290	9731	10080	.39	1.611	7.508
43	1500	1500	1.325	1.325	1.206	1.192	5022	1.114	1.944	9555	11231	.40	1.601	7.437
44	1500	1500	1.216	1.269	1.040	.957	5592	1.127	.743	10050	6688	.38	1.618	7.525
45	1500	1500	1.207	1.220	.944	.944	3664	1.159	.996	9729	8822	.46	1.612	7.497
46	1500	1500	1.426	1.443	1.291	1.203	3474	1.515	1.517	10594	11913	.45	1.602	7.457
47	1500	1200	1.379	1.391	1.043	1.077	2889	1.202	1.211	10100	10006	.45	1.661	7.536
48	1500	1200	1.216	1.181	.978	1.021	2516	.879	1.043	6335	10809	.42	1.602	7.478
49	1500	1500	1.504	1.367	1.233	1.262	5612	1.249	1.293	10047	10519	.41	1.604	7.468
50	2100	1200	1.385	1.351	1.194	1.216	5582	1.416	1.294	14288	12784	.48	1.603	7.475
51	2100	1200	1.433	1.419	1.139	1.160	5702	1.050	1.212	8421	10060	.40	1.620	7.521
52	2100	1500	1.471	1.420	1.334	1.334	5593	1.254	1.268	10531	10490	.41	1.601	7.503
53	2100	1500	1.801	1.838	1.607	1.630	10719	1.262	1.632	12891	14383	.50	1.568	7.440
54	2100	1500	1.382	1.451	1.151	1.172	2222	1.412	1.274	11584	10051	.45	1.597	7.484
55	2100	1500	1.489	1.575	1.278	1.300	5024	1.406	1.330	11550	10834	.46	1.602	7.484
56	2100	1200	1.313	1.313	.973	1.060	2152	1.282	1.317	10448	11828	.48	1.600	7.440
57	2100	1200	1.547	1.617	1.287	1.309	3276	1.170	1.236	11005	11130	.45	1.598	7.429
58	2100	1500	1.555	1.692	1.360	1.520	7642	1.489	1.477	11814	11848	.45	1.605	7.459
59	2100	1500	1.497	1.480	1.149	1.193	3102	1.517	1.214	13283	8994	.42	1.603	7.431
60	2100	1900	1.804	1.770	1.626	1.535	4937	1.457	1.449	13082	11713	.47	1.602	7.464
61	2100	UTIL	1.562	1.756	1.489	1.442	5997	1.182	1.207	10668	10354	.35	1.598	7.355
62	2100	1500	1.587	1.472	1.141	1.226	6088	1.195	1.358	10869	11253	.48	1.622	7.513
63	2100	1200	1.673	1.656	1.516	1.538	8398	1.561	1.537	12913	12819	.46	1.600	7.461
64	2100	UTIL	1.367	1.477	1.295	1.138	4617	1.409	1.286	11532	10385	.47	1.600	7.523
65	2100	1500	1.541	1.681	1.502	1.502	5116	1.581	1.533	12807	13705	.54	1.595	7.416
66	2100	1200	1.510	1.456	1.360	1.226	5157	1.317	1.198	11039	10614	.46	1.609	7.504
67	2100	NO DATA	1.591	1.538	1.471	1.425	5887	1.283	1.290	11114	12012	.40	1.598	7.385
68	2100	1900	1.570	1.570	1.399	1.631	7515	1.453	1.568	12419	12119	.53	1.690	7.461
69	2100	1500	1.729	1.692	1.383	1.383	5874	1.248	1.373	10902	10826	.45	1.578	7.449
70	2100	1500	1.319	1.353	1.051	1.051	2040	.899	1.214	9295	9765	.40	1.607	7.501
71	2100	1500	1.707	1.690	1.462	1.484	5763	1.545	1.509	11877	11655	.47	1.602	7.434
72	2100	1500	1.644	1.627	1.358	1.403	7207	1.418	1.458	12871	12769	.46	1.598	7.463
73	2100	1500	1.572	1.658	1.421	1.421	3028	1.378	1.391	11837	11269	.45	1.605	7.460
74	2100	1500	1.492	1.302	1.395	1.365	7634	1.417	1.229	12091	12297	.43	1.590	7.464
75	2100	1500	1.611	1.628	1.458	1.480	6748	1.259	1.550	9951	11648	.44	1.602	7.478

Board Number	EMSR Grade	Visual Grade	MAJOR TESTS					MINOR TESTS					Thickness	Height
			Modulus of Elasticity				Mod. of Rupture	Clear MOE		Clear MOR		Sp. Gr.		
			Face	Back	Top	Bottom		1	2	1	2	Average		
76	2100	1900	1.582	1.565	1.418	1.406	5565	1.214	1.223	11734	11907	.48	1.597	7.439
77	2100	1500	1.692	1.727	1.453	1.453	5743	1.481	1.481	11269	11163	.48	1.600	7.452
78	2100	UTIL	1.700	1.718	1.613	1.613	5584	1.382	1.672	11186	12759	.45	1.580	7.466
79	2100	1200	1.676	1.710	1.304	1.248	3651	1.466	1.558	11831	10887	.48	1.609	7.400
80	2100	1200	1.919	1.989	1.504	1.493	3637	1.838	1.480	14353	13521	.48	1.599	7.462
81	2100	1500	1.659	1.659	1.466	1.466	4761	1.609	1.624	13373	12891	.47	1.595	7.438
82	2100	1500	1.250	1.267	1.184	1.206	4959	.990	1.287	8776	9651	.44	1.596	7.461
83	2100	1500	1.771	1.771	1.606	1.572	3817	1.382	1.494	13191	13259	.51	1.599	7.499
84	2100	1500	1.673	1.620	1.343	1.299	2659	1.283	1.408	9975	10679	.43	1.595	7.454
85	2100	1500	1.543	1.525	1.153	1.185	2440	1.413	1.304	12482	12701	.49	1.595	7.406
86	2100	1500	1.560	1.508	1.322	1.278	3406	.966	1.019	10479	11312	.47	1.605	7.436
87	2100	1200	1.560	1.612	1.423	1.401	4307	1.592	1.416	12912	12177	.45	1.603	7.460
88	2100	1900	1.695	1.712	1.383	1.349	2980	1.193	1.195	9726	9831	.42	1.602	7.413
89	2100	UTIL	1.661	1.661	1.444	1.455	9011	1.111	1.197	8776	9206	.41	1.613	7.486
90	2100	1200	1.812	1.794	1.745	1.733	9054	1.988	1.874	16349	15351	.61	1.585	7.453
91	2100	1500	1.849	1.812	1.792	1.877	5066	1.661	1.773	13045	15343	.45	1.570	7.443
92	2100	1500	1.583	1.600	1.413	1.413	2979	1.377	1.530	10866	11845		1.593	7.493
93	2100	1500	1.546	1.599	1.411	1.457	3681	1.436	1.360	11435	9979	.45	1.590	7.461
94	2100	1500	1.750	1.766	1.317	1.359	3804	1.545	1.298	12316	11620	.42	1.640	7.517
95	2100	1900	1.415	1.467	1.239	1.321	7453	1.147	1.057	10981	12131	.55	1.598	7.478
96	2100	1500	1.596	1.544	1.272	1.185	2757	1.392	1.350	10687	11493	.45	1.600	7.498
97	2100	1200	1.480	1.462	1.148	1.235	4717	1.349	1.400	10987	11585	.43	1.592	7.498
98	2100	1200	1.897	1.841	1.534	1.552	4949	1.545	1.653	13663	12290	.47	1.563	7.423
99	2100	1200	1.404	1.404	1.256	1.169	3208	1.338	1.262	11088	10563	.46	1.587	7.507
100	2400	2050	1.813	1.968	1.762	1.985	6916	1.500	1.618	13362	14181	.51	1.603	7.484
101	2400	1900	1.701	1.701	1.528	1.551	4734	1.181	1.331	10826	12495	.46	1.607	7.467
102	2400	1500	2.113	2.113	1.592	1.664	7413	1.701	1.587	13438	11988	.42	1.588	7.338
103	2400	1500	1.670	1.653	1.430	1.496	8728	1.369	1.321	10951	10909	.40	1.620	7.499
104	2400	2050	2.435	2.527	2.352	2.352	10883	2.081	1.746	17041	12617	.54	1.572	7.423
105	2400	2050	2.124	2.089	1.814	1.814	11650	1.446	1.476	11943	12823	.47	1.595	7.407
106	2400	2050	2.186	2.384	2.031	2.031	10923	1.501	1.502	11269	13020	.52	1.590	7.327
107	2400	2050	1.760	1.847	1.725	1.678	10938	1.438	1.171	12782	12168	.46	1.600	7.458
108	2400	1500	1.807	1.775	1.491	1.447	9946	1.303	1.294	10794	11422	.46	1.640	7.477
109	2400	1200	1.658	1.641	1.631	1.595	4321	1.632	1.568	11261	12462	.45	1.597	7.412
110	2400	1500	1.614	1.614	1.626	1.564	6222	1.433	1.612	11737	13671	.49	1.593	7.513
111	2400	MISS.	2.057	2,057	1.683	1.659	8882	2.166	1.788	13196	13658	.49	1.600	7.451
112	2400	1200	1.723	1.706	1.435	1.457	7129	1.193	1.221	10373	10962	.45	1.605	7.475
113	2400	1500	2.152	2.135	1.832	1.786	6745	1.457	1.587	12331	13371	.48	1.608	7.491
114	2400	UTIL	1.952	1.952	1.545	1.639	11062	1.604	1.242	12634	12341	.48	1.590	7.392
115	2400	1200	1.959	1.941	1.591	1.649	5065	1.667	1.577	12731	12733	.51	1.589	7.450
116	2400	1200	2.026	1.957	1.885	1.885	10727	1.693	1.394	13296	12187	.51	1.603	7.460
117	2400	1500	1.891	1.838	1.720	1.838	5464	1.775	1.622	13507	14021	.49	1.588	7.450
118	2400	2050	2.094	2.203	1.834	1.859	11625	1.758	1.720	14487	13929	.53	1.590	7.272
119	2400	1900	1.888	1.888	1.696	1.662	10383	1.606	1.598	12498	12558	.46	1.600	7.500
120	2400	1200	2.116	2.298	1.736	1.711	7468	1.670	1.773	12558	13177	.51	1.582	7.368
121	2400	1500	1.869	1.902	1.572	1.394	8763	1.511	1.343	12255	11690	.51	1.632	7.466
122	2400	1500	2.139	2.104	1.883	1.930	10429	1.679	1.645	12663	13196	.47	1.610	7.452
123	2400	1900	1.916	1.898	1.634	1.704	9550	1.454	1.169	14063	7954	.54	1.595	7.463
124	2400	1200	2.003	2.021	1.727	1.656	3951	1.791	1.491	13583	11325	.51	1.590	7.403
125	2400	1500	1.657	1.759	1.202	1.245	5602	1.452	1.155	12465	10416	.45	1.608	7.496
126	2400	1200	1.915	1.826	1.637	1.660	3746	1.557	1.442	12477	11913	.50	1.590	7.466
127	2400	2050	2.079	2.097	1.765	1.788	7298	1.680	1.508	12148	10930	.51	1.600	7.435
128	2400	1500	1.839	1.804	1.849	1.861	6583	1.701	1.715	13692	13440	.48	1.590	7.417
129	2400	1900	2.264	2.264	1.932	1.957	5499	1.421	1.784	8383	13741	.53	1.593	7.383
130	2400	1500	1.925	1.873	1.691	1.633	6768	1.283	1.649	11749	13164	.49	1.603	7.452
131	2400	1500	2.436	2.400	1.989	1.965	11303	1.947	1.825	15298	15740	.58	1.588	7.472
132	2400	2050	2.237	2.347	1.713	1.725	10149	1.400	1.380	13354	15015	.65	1.580	7.356
133	2400	1500	2.071	1.919	1.845	1.735	7463	1.543	1.469	11544	12068	.48	1.604	7.459
134	2400	1200	2.151	2.134	1.912	1.947	8456	1.870	1.886	13887	14577	.51	1.613	7.486
135	2400	1900	1.849	1.822	1.564	1.629	7528	1.663	1.416	11568	10720	.45	1.610	7.492
136	2400	1900	1.952	1.934	1.645	1.680	7390	1.593	1.601	12708	13122	.50	1.596	7.445
137	2400	1900	2.515	2.551	2.199	2.183	11760	1.776	1.836	13518	13650	.59	1.587	7.409
138	2400	1900	1.869	1.923	1.821	1.774	7664	1.662	1.713	12562	13846	.53	1.590	7.438
139	2400	1900	1.906	1.879	1.752	1.659	11072	1.615	1.475	13916	13730	.53	1.615	7.463
140	2400	1500	1.971	1.971	1.550	1.596	9153	1.800	1.549	14943	12836	.50	1.590	7.458
141	2400	1500	2.453	2.435	2.284	2.284	8165	2.042	2.066	15317	15630	.58	1.592	7.364
142	2400	2050	2.388	2.334	1.873	1.868	8201	MISS.	1.826	MISS.	13609	.50	1.589	7.410
143	2400	1200	1.287	1.252	1.001	MISS.	2176	1.038	1.103	10637	11216	.45	1.558	7.393
144	2400	1200	1.968	2.003	1.744	1.573	10675	1.645	1.664	13259	13346	.49	1.597	7.436
145	2400	1500	1.581	1.606	1.403	1.389	6113	1.176	1.243	11303	10785	.42	1.655	7.531
146	2400	1500	2.408	2.302	2.031	2.114	11436	1.765	1.866	13889	14375	.50	1.597	7.377
147	2400	1200	1.858	1.949	1.595	1.759	9503	1.612	1.580	13955	13885	.52	1.634	7.445
148	2400	1200	1.397	1.397	1.205	1.276	2445	1.309	1.358	10521	10635	.43	1.605	7.440
149	2400	2050	1.900	1.937	1.976	1.989	11770	1.783	1.727	14695	14247	.50	1.575	7.386
150	2400	1200	1.919	1.971	1.380	1.557	8348	1.413	1.503	11364	12123	.47	1.593	7.479

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