MACHINE STRESS
RATING PANEL
PRODUCTS

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Abstract *

The variability of stiffness and strength in visually graded structural wood panels, intended for use in construction, puts panels at a substantial disadvantage relative to competetive building materials like steel, asbestos cement and glass reinforced plastics. Machine Stress Rating (MSR) of panel products, developed along the same lines as that for lumber, has the potential of introducing new structural wood panel grades with less variation in mechanical properties.

Alberta Research Council, in co-operation with Porter Engineering Ltd. has developed a MSR prototype in which full-sized panel stiffness can be measured at a rate of approximately five seconds per panel. The non-destructive stiffness data obtained with the panel MSR prototype correlates very well with destructive stiffness and strength tests done with the well-known Post Flexure testing machine.

Various pricing scenarios for MSR graded panels, according to stiffness and strength, are mentioned to illustrate points of interest that may enhance discussions on the economics of MSR grading of panels.

A universal MSR panel grade requirement-and-designation scheme will allow the development of better panel utilization systems.

It appears timely to develop a North American MSR panel grading system mutually acceptable to manufacturers, consumers and building authorities related to residential construction and engineered design with panels.

* This paper was presented September 9, 1985 at the 5th Symposium on Non-Destructive Testing of Wood at Washington State University

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1. INTRODUCTION

In structural applications with wood panel products, the designer needs good estimates of stiffness and strength characteristics to make safe and economical designs. In the past, grading rules established by the manufacturer have allowed visual assessment of panel quality. Building authorities have subsequently recognized these visual grades as indicative of some minimum level of panel quality and performance. Building code officials and others have further established rules for the permitted use of various grades and thicknesses of panel products in residential construction. With regard to engineering design with structural wood panels, "Allowable Unit Stresses" have been published for some visually graded plywood constructions.

Variation places wood panels at a considerable disadvantage relative to other building materials. As a result, assigned design values have traditionally been very low and most panels produced have not been used to their real potential.

The emergence of new structural panel products has led to the "APA Performance Standards" that favor panel products produced with little variation in stiffness and strength. To fully benefit from these standards, the manufacturer needs techniques for grouping the panels into new grades with smaller variations in stiffness and strength than in the present grades.

Machine stress/stiffness rating (MSR) of panel products is a method of rating panel performance based on non-destructive testing of each individual panel. The accuracy of the estimates of both panel stiffness and panel strength are much higher by this mechanical method than can be obtained by visual stress rating (VSR).

In 1982 a project on Machine Stiffness Rating (MSR) of structural panel products was initiated by the Alberta Research Council and the Alberta government departments of Energy and Natural Resources and Economic Development.

The first phase of the project was devoted to development, construction and laboratory testing of an MSR prototype machine (Figure 1) for fast evaluation of panel stiffness. This work was conducted in co-operation with Porter Engineering Ltd. on a contract basis.

The second phase was devoted to mill trial testing of the prototype in co-operation with Alberta companies producing structural wood panel products. More than 8000 full-size panels were tested.

The third phase of the project now in progress is the design and construction of an In-Line Machine Stress Rating System suitable for installation in a mill.

2. POTENTIAL BENEFITS FROM PANEL MSR

The present Visual Stress Rating (VSR) system for panels underrates structural panel stiffness and strength, but it is convenient.

Unpublished field studies done by the Alberta Research Council (and others) on visually graded panels show considerable variation in stiffness and strength. Variations around mean values of stiffness are commonly ± 40%. Large variability indicates business opportunities for manufacturers that can reduce variations with new, and better defined, panel grades. Low cost, non-destructive MSR techniques for panels appear to be of interest to manufacturers, consumers and building authorities.

An MSR system definitely has the potential to more accurately determine stiffness and strength of panel products, but it requires capital investment.

The benefits from MSR stiffness rating of a mill's production of structural panels can be realized in various ways. For example:

(a) as an on-line quality control of the stiffness and strength of the panel products produced

(b) as a tool for grouping of the panels produced into new and more accurately assessed stiffness and strength grades that give special marketing advantages in terms of price or product characteristics

(c) designers appreciate accurate information on the materials they use in their designs. Figure 2 clearly illustrates this point.

3. PANEL MSR EQUIPMENT DEVELOPMENT

Machine Stress Rating of panels (as for lumber) is based on non-destructive measurement of a "predictor" that correlates well with the "property/properties" that determine the "rating" or commercial grouping referred to as a "grade".

Machine Stiffness Rating equipment for panels, as for lumber, can be based on various concepts such as "vibration" and "static" loading.

In 1982 Alberta Research Council and Porter Engineering Ltd. started co-operative development of a prototype industrial MSR panel grader, as we had found none available in North America. The information available on Australian and Norwegian panel grading equipment did not appear to be suitable either.

The "predictor" suggested is the bending stiffness value (EI) obtained non-destructively and quickly in an MSR panel tester on full-sized panels. The "properties" used for correlation are "stiffness" and "maximum moment" measured by slow destructive methods.

In our opinion, it was desirable to establish high-speed techniques for non-destructive determination of the stiffness of panels.

In laboratory testing we had already found that the stiffness of panels correlates well with panel strength obtained from the slow but generally accepted post flexure testing machine (ASTM D3043-76 Method C).

We formulated the following criteria for the proposed static MSR loading machine:

- it must accommodate large panels (4' x 8');
- it must distribute the deflecting load substantially uniformly and linearly across the full width of the panel, in spite of warp;
- it must cope with the fact that the load vs deflection curve for a wood panel is not, typically, linear in the proximity of the zero point; and
- it must be relatively fast in operation and capable of being upgraded to production line speeds.

The prototype machine that was finally constructed is a first step towards fulfillment of the criteria above. In Figure 3 a schematic drawing is shown and Figure 4 shows the standard formulae used by the machine for automatic computation of stiffness and strength.

The prototype stiffness machine in the operation mode first applies a linear load to one major surface of a panel while supporting it on the opposite side with two linear supports which bracket the loading member. The load is applied with a loading member which can pivot in a plane perpendicular to the main surface of the panel, to permit the loading member to conform to a warped or sagging surface of the panel.

The load which is applied is selected so as to fall on the substantially linear portion of the load deflection curve for the panel. Once the panel has been deflected in this manner, the loading is then increased incrementally, causing further deflection. The two loadings and the incremental deflection are measured and recorded. These measurements are used to compute "E"/"EI" and to estimate "MOR/M_{max}" from derived correlations. A typical loading cycle plus data processing is completed in approximately five seconds. The manual infeed and outfeed of the panel to the MSR machine takes considerably longer but can easily be improved.

In summary, the MSR prototype works as follows:

(1) the panel is deflected to a limited extent by applying a load of pre-determined magnitude;

(2) the panel is then further deflected through a known distance and the magnitude of the incremental load required to achieve this is measured;

(3) from the values for the incremental load, the deflection arising from the incremental load and the known span and width of the panel, the stiffness of the panel is calculated by the processor which also controls the loading sequence.

The prototype MSR machine panel stiffness correlates well with the stiffness determined by the post flexure testing machine on the same panels. In Figure 5 we have shown this correlation for full-sized panels. The correlation is:

[Equation 1] $EI_{PF} = 0.06 + 1.03 \cdot EI_{MSR}$

Where EI = stiffness in million N mm^2/mm

R^2 = correlation coefficient squared = 0.980

S_e = standard error of estimate = 0.21×10^6 N mm^2/mm

N = number of observations = 300

Figure 6 shows a typical plot of the relationship between the "Max. Moment" and the "Stiffness" of various thicknesses of the same type of structural panels. The plot shows that "stiffness" can be used as a non-destructive measured predictor of "max. moment" that otherwise can be measured only by destructive techniques. The correlation is:

[Equation 2] $M_{max} = 399 + 360 \cdot EI$

Where M_{max} = bending moment at rupture in N mm/mm

EI = stiffness in million N mm^2/mm

R^2 = correlation coefficient squared = 0.843

S_e = standard error of estimate = 227 N mm/mm

N = number of observations = 300

In Figure 7 the same data are shown for "modulus of rupture" (MOR) and "modulus of elasticity" (E); the correlation is not quite as good as for "max. moment" versus "stiffness". The correlation is:

[Equation 3] $MOR = 4.10 \cdot E$

Where MOR = modulus of rupture in MPa

E = modulus of elasticity in 1000 MPa

R^2 = correlation coefficient squared = 0.627

S_e = standard error of estimate = 6.2 MPa

N = number of observations = 300

With data as above, we feel confident when measuring the stiffness of panels with our MSR prototype. In Figure 8 we have, for illustrative purposes, shown the stiffness distribution measured on 3600 "no name" panels of four thicknesses. Distribution curves of this nature are most valuable in estimating the potential of MSR rating of panels, as they give a clear picture of just how large the stiffness variation is. Quantitative estimates of volume yield of MSR grades (defined in terms of minimum stiffness requirements) can further be readily made on the data in the format presented. Numerous scenarios exist for the grade requirements in terms of all the mechanical properties that correlate with stiffness.

The MSR prototype (as presently developed), when equipped with an automatic "In-and-out-feed" system, can be used industrially in "off-line" panel grading applications as shown in Figure 9.

Further development is now to be oriented towards second generation prototypes for "in-line" operations as shown in Figure 10. Developments similar to those done by Metriguard Inc. for the well-known Continuous Lumber Tester would appear one way to proceed.

4. MSR PANEL GRADE REQUIREMENTS AND DESIGNATIONS

The MSR panel requirements suggested here differ little from the NLGA MSR rating of lumber. In "NLGA SPS-2-82" the mechanical grade requirements are formulated in terms of "modulus of elasticity" and "modulus of rupture". A good relationship between "E" and "MOR" does exist for some structural panels (Figure 7) but we find the MSR grade requirements in terms of "stiffness" (EI) and "moment" (M) preferable (Figure 6). We suggest this approach as most panel consumers generally are more interested in panel performance than thickness as such. This approach is also in line with Canada's new Limit States Design Standard (CAN3-O86.1-M84) "Codes for Engineering Design in Wood" and the American Plywood Association's "Performance Standards and Policies for Structural-Use-Panels" in the United States.

The principal differences between MSR lumber and panel grading requirements are:

(a) The grade requirements for panels be in terms of "stiffness" (EI) rather than "modulus of elasticity" (E), and "specified bending strength capacity" (M_p) rather than "modulus of rupture" (MOR).

(b) No specific panel thickness be required. (This, however, does not preclude that the actual thickness of the panel be indicated in the grade designation).

As we are not aware of any MSR grade designations and requirements for panels, we suggest that such be decided on by manufacturers and consumers. Sample "Minimum Requirements" have been shown in Table 1 for illustrative purposes only.

TABLE 1

MSR PANEL GRADE DESIGNATIONS AND REQUIREMENTS

SUGGESTED MINIMUM REQUIREMENTS			
GRADE DESIGNATION*	LOWER 5% "M_p" N mm/mm	LOWER 5% EXCLUSION "EI" 10^6 N mm^2/mm	AVERAGE "EI" N mm^2/mm
150M-0.50EI-x	150	.50	No requirement (Individual mills may, however, want to stamp actual mean values for the MSR grade in consultation with a MSR-grading agency)
250M-0.75EI-x	250	.75	
350M-1.00EI-x	350	1.00	
450M-1.25EI-x	450	1.25	
550M-1.50EI-x	550	1.50	
700M-2.00EI-x	700	2.00	
900M-2.50EI-x	900	2.50	
1100M-3.00EI-x	1100	3.00	
1300M-2.50EI-x	1300	3.50	
1500M-4.00EI-x	1500	4.00	

* x indicates panel thickness in mm

As a prerequisite for MSR grading (in conformity with minimum requirements, as in Table 1), we suggest:

1. All panels be non-destructively stiffness rated by a machine capable of measuring bending stiffness reproducible within 1.0%.
2. All panels, after moisture correction, be bending strength rated based on:
    - Established "stiffness-maximum moment" correlations or
    - Proof loading
3. All panels be stamped by an approved grading agency guaranteeing compliance with a written products standard for machine stress rated panels.

5. PRICING OF MSR PANELS

Supply and demand will eventually determine sales prices for any new panel grade in the marketplace. However, it may be of some value for business decisions regarding machine stress rating of construction panels to assume that the customer is willing to pay for "stiffness" or "strength" performance rather than for "thickness" and "generic panel type" (as he appears to do today).

Below are listed various pricing scenarios for estimating the sales price of various machine stress rated (MSR) panel grades based on known sales prices of visual stress rated (VSR) panels.

Scenario I The sales prices for all panel types are related to the "specified bending stiffness" ($EI_{5\%}$) as defined by a lower exclusion 5% for the designated grade. The functional relation between "price" and "EI" can be derived from known sales prices and estimates of "$EI_{5\%}$" for structural panel products presently marketed.

Scenario II The sales price for all panel types is directly related to the "specified bending strength capacity" (M_p) as defined by the lower 5% exclusion limit for the designated grade. The functional relationship between "price" and "M_p" can be derived from "known sales prices" and the published allowable engineering design property "Mp" for structural panel products presently marketed.

Scenario III The sales price for all panel types is directly related to the "specified bending stiffness" (EI) - as defined by average values (50% exlusion limit) for the designated grade. The functional relationship between "price" and "EI" can be derived from known sales prices and the published allowable engineering design property "EI" for a structural panel products presently marketed.

Scenario IV The sales price for all panel types is determined by a combination of the Scenarios I, II and III.

For illustrative purposes, we have listed data references that can be used to calculate the sales prices associated with the yields of various MSR grades from 12.5 mm "no name" panels, for example:

a) Table 1 in which the MSR panel grade designations and requirements are shown.

b) Figure 11 in which the bending stiffness distribution for 900 "no name" structural panels of 12.5 mm thickness is shown, together with the MSR grade requirements to stiffness and the corresponding MSR grade yields.

c) Figure 5 showing the correlation between "maximum bending moment" and "bending stiffness" for 300 "no name" structural panels. (The position of the 5% exclusion line indicates that the grade requirements in this case are not governed by the bending strength).

d) Figures 12 a, b, c show the 1985 Edmonton sales price for unsanded Douglas fir plywood (CSA 121) versus the "thickness", "EI" and "M_p" mentioned in CAN3-086.1-M84. The curves showing sales prices versus engineering properties are of particular interest.

Evaluation of the price scenarios mentioned suggests that MSR grading of panels appears attractive when sales price setting is related to minimum strength and/or stiffness performance of each grade (Scenario I and II). An average stiffness performance does not encourage MSR grading of panels (Scenario III).

Today's allowable design stresses of VSR grades of structural panels are related to the lower 5% exclusion limit for bending strength and to the average (50% exclusion limit) for bending stiffness. MSR grading does not appear profitable if the sales price setting is influenced to any large extent by an "average bending stiffness" of the panels in each particular grade class.

Today's MSR graded panels may not command sales prices above VSR grades, but they would appear attractive to designers who do not like to see their designs exceed deflection limits set by the building codes. However, the future likely holds a move towards design with wood that rewards information of a guaranteed minimum stiffness or strength of individual panels used.

In residential construction where visual performance rated structural panels presently are used, MSR panel rating also would appear to have merit.

Whatever the sales prices of MSR rated panels may be, business decisions regarding installation of MSR equipment in a manufacturing plant also require estimates of capital, labour and other costs in order to calculate return on investment.

6. POTENTIAL USES FOR MSR PANELS

The users of MSR panels are expected to be engineers, builders and architects interested in guaranteed strength and stiffness performance.

The uses for structural MSR panels are expected to be:

-- engineered use in structural components

-- floor and roof sheathing (residential and light industrial)

-- concrete formwork

-- preserved wood foundations

The availability of MSR panel grades to the user hinges around general acceptance by building authorities of "Guaranteed Performance of Individual Panels" in terms of minimum stiffness and strength; - without reference to generic panel type or panel thickness.

7. CONCLUSIONS

It appears timely to move ahead and develop a machine stress rating system mutually acceptable to manufacturers, consumers and building authorities.

Acknowledgements

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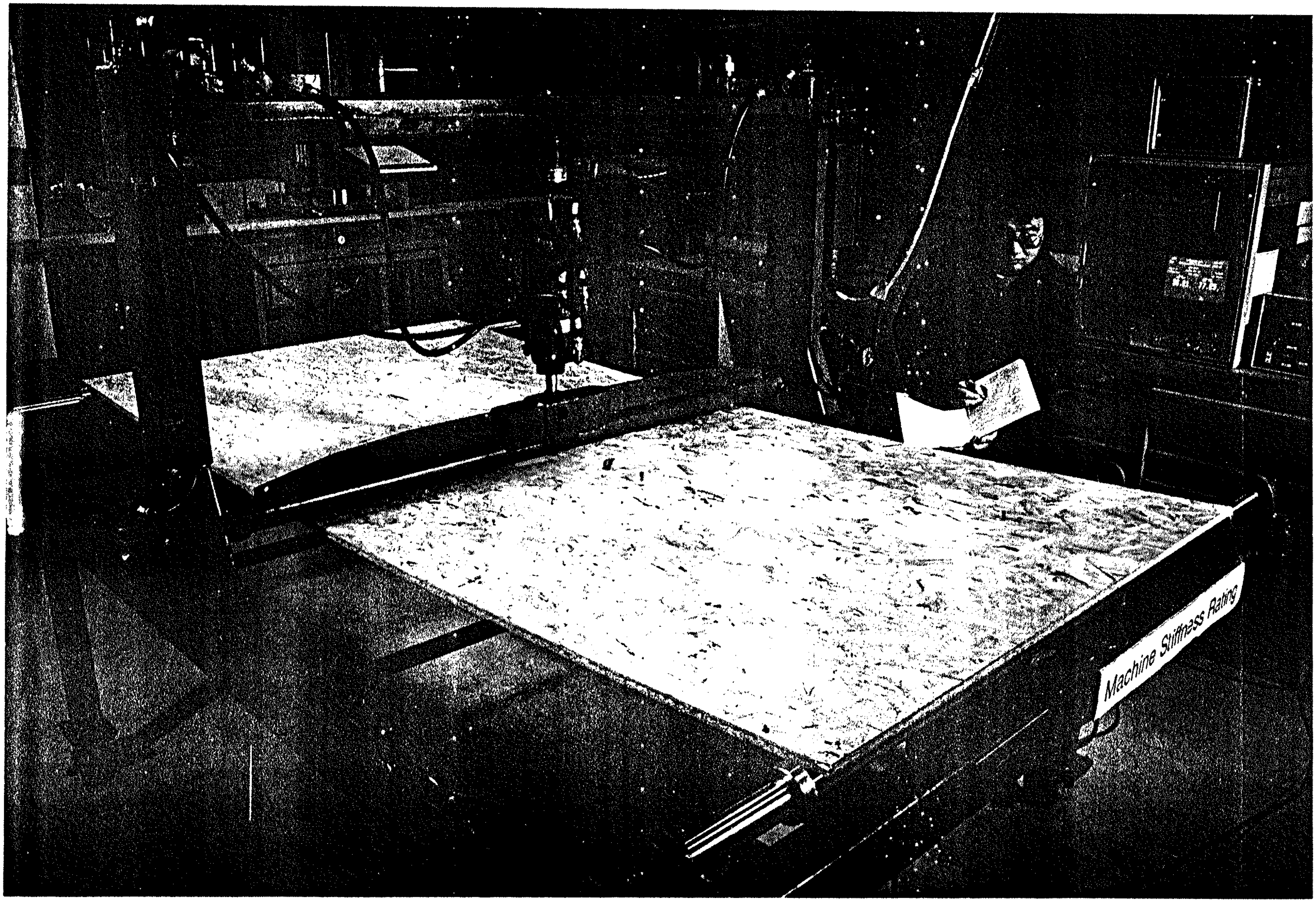

Figure 1. Photo of the prototype panel stiffness tester developed by the Alberta Research Council and Porter Engineering Ltd. for machine stress rating of structural panels

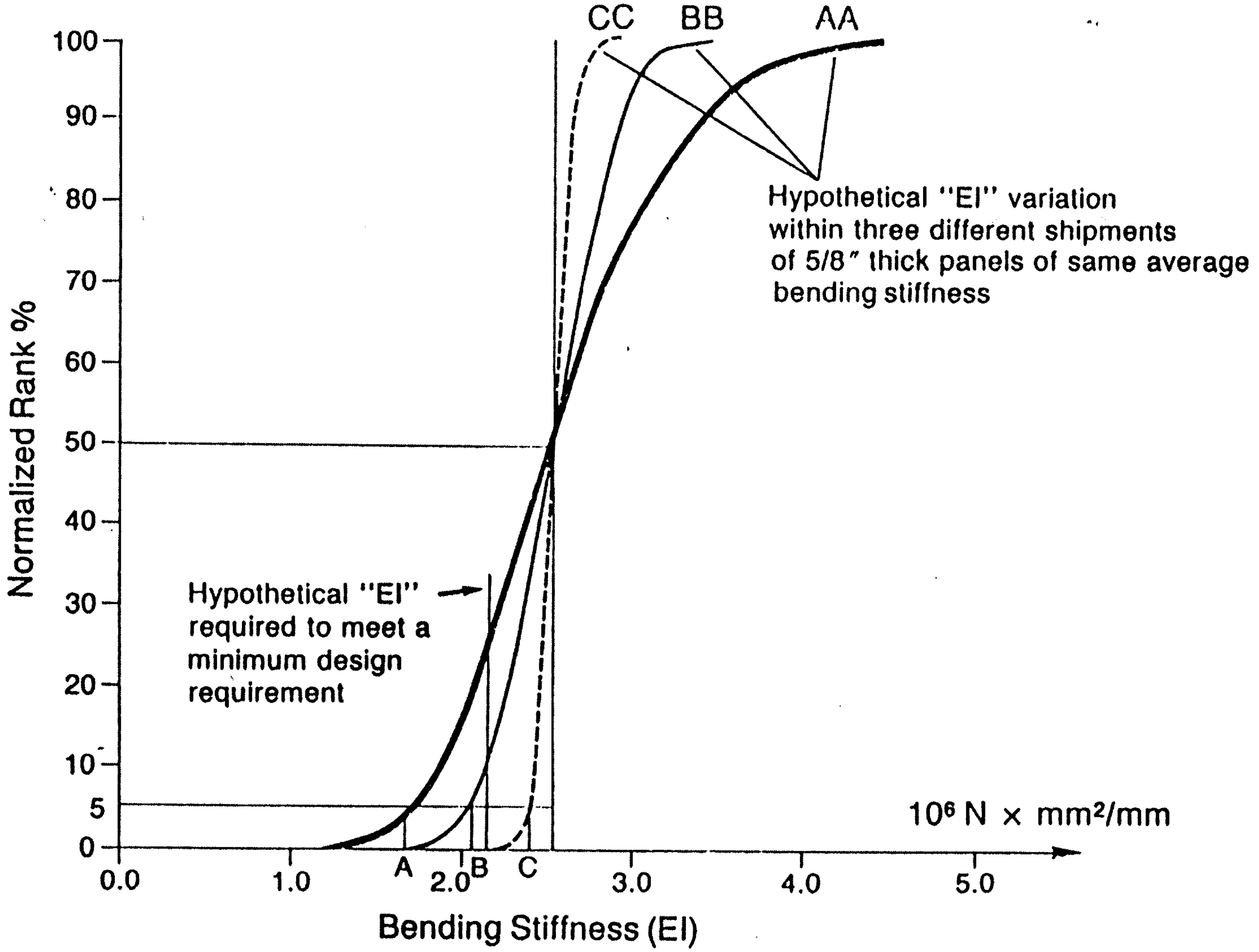

Figure 2. Average panel stiffness and engineering design of deflections

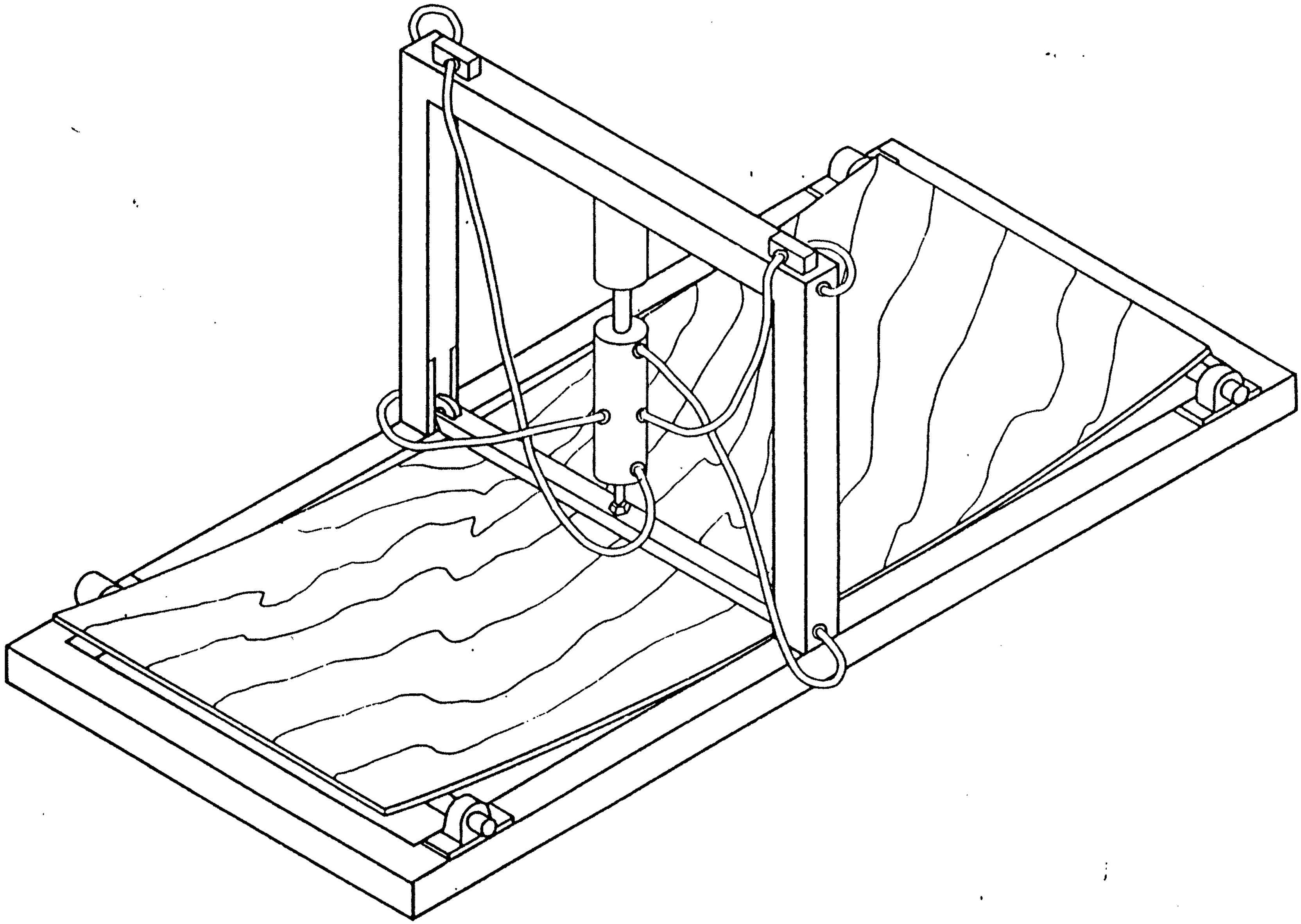

Figure 3. Schematic drawing of prototype for machine stiffness rating of panel products

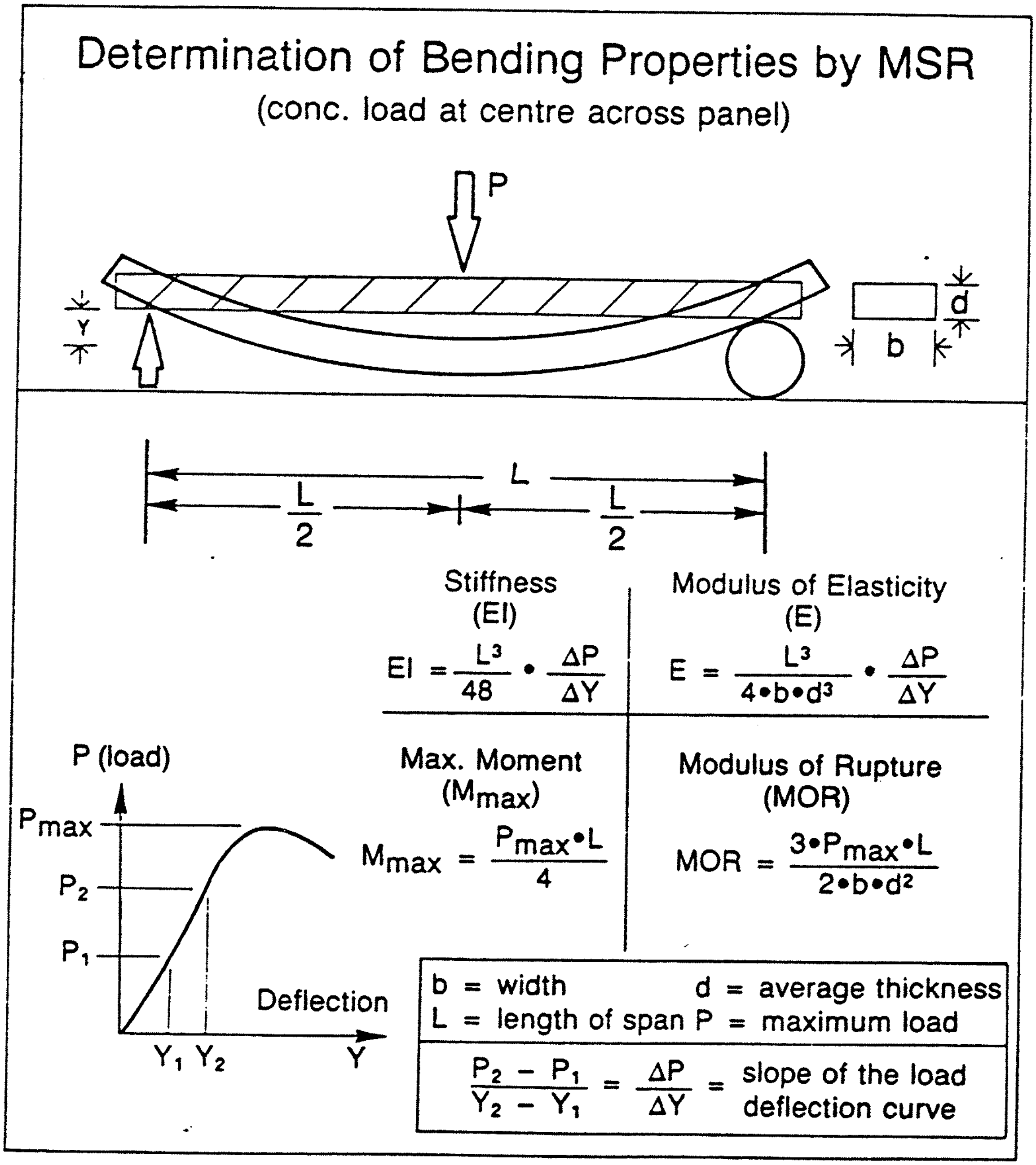

Figure 4, Formulae used for determination of bending properties by MSR

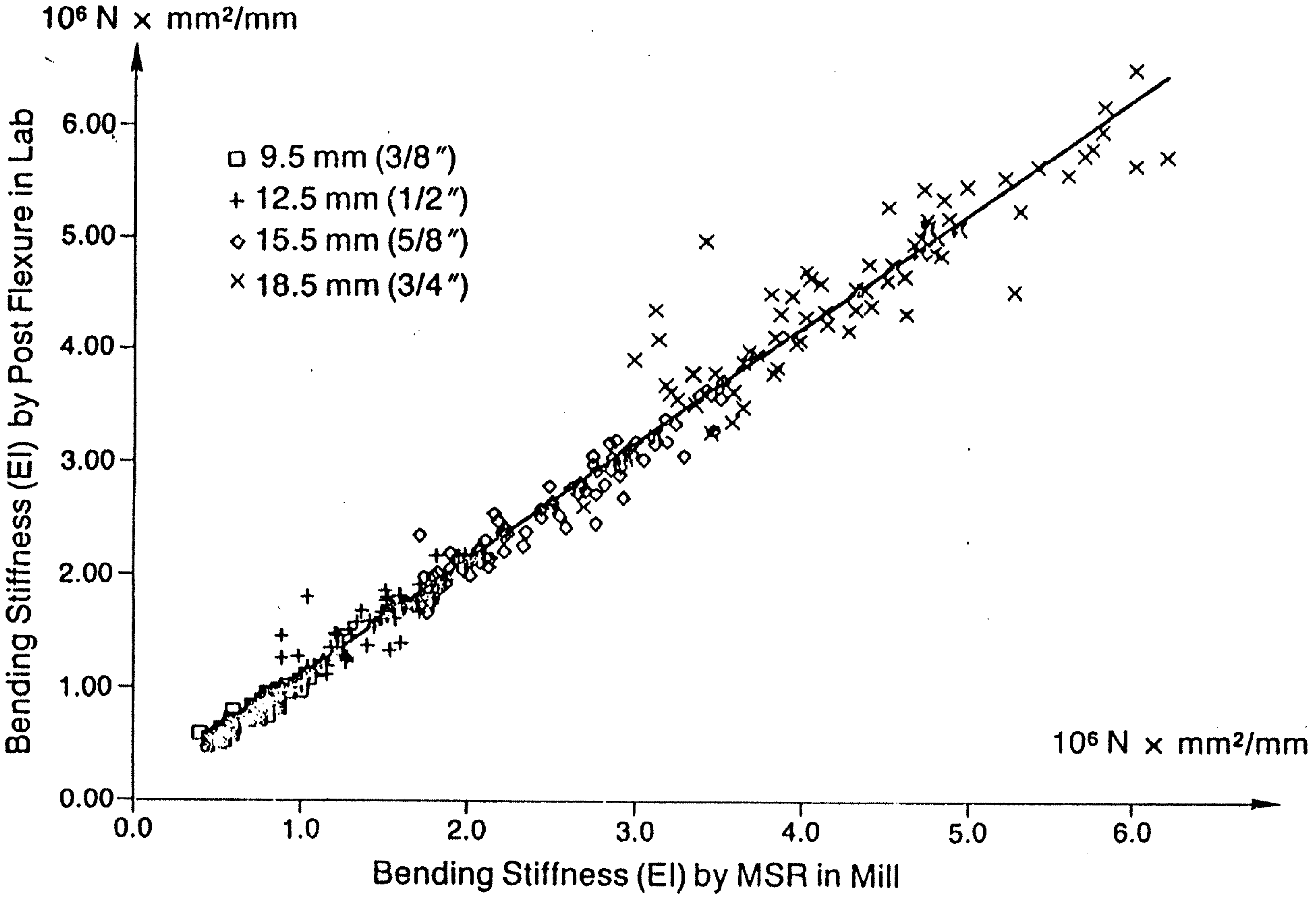

Figure 5. Comparison of the bending stiffness measure on the same panels by the fast nonstandard MSR technique and by the slow standard post flexure method (ASTM D3043-76 Method C)

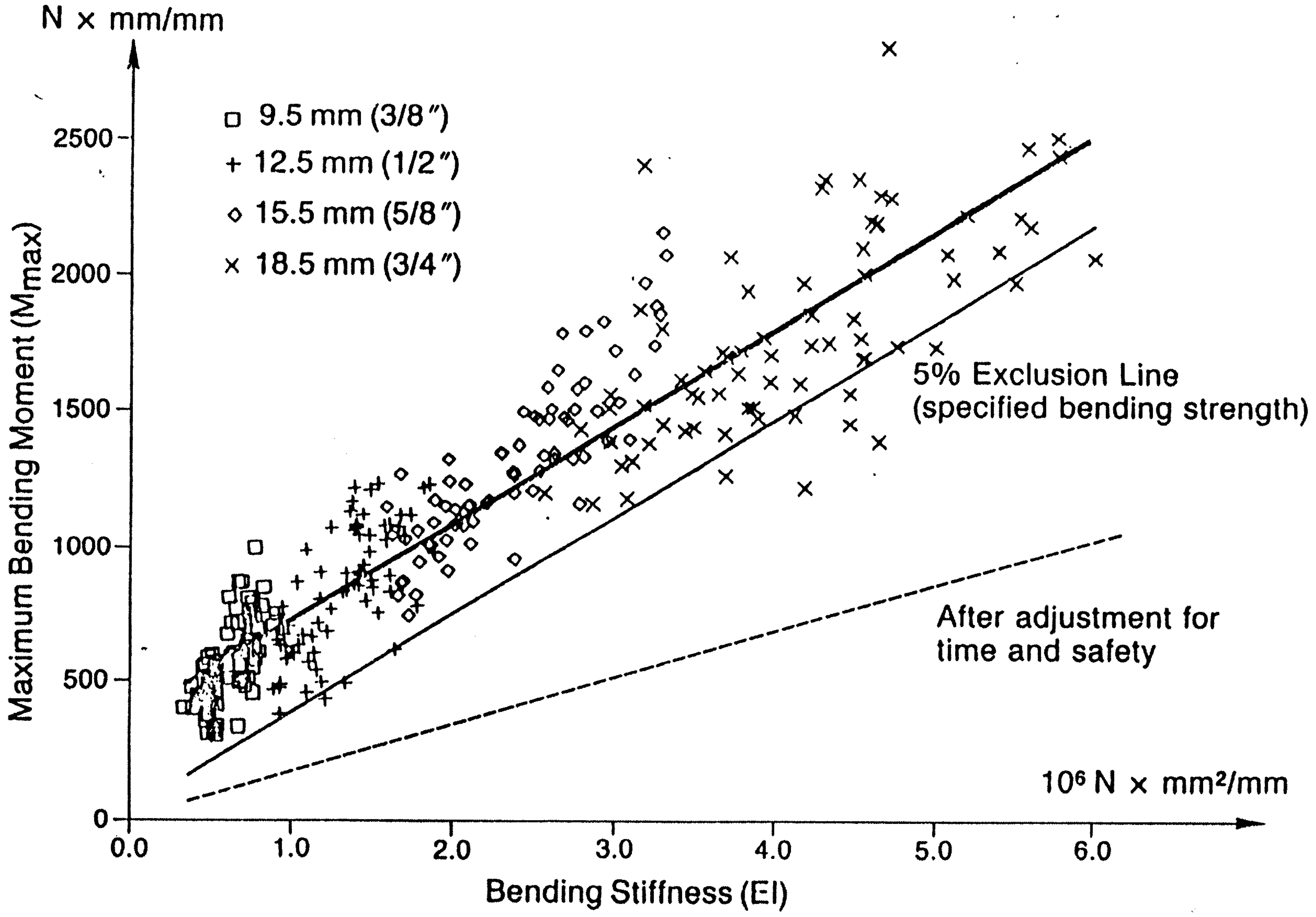

Figure 6. Maximum bending moments of full sized "no name" structural panels of four panel thicknesses versus the bending stiffness measured nondestructively by the MSR technique

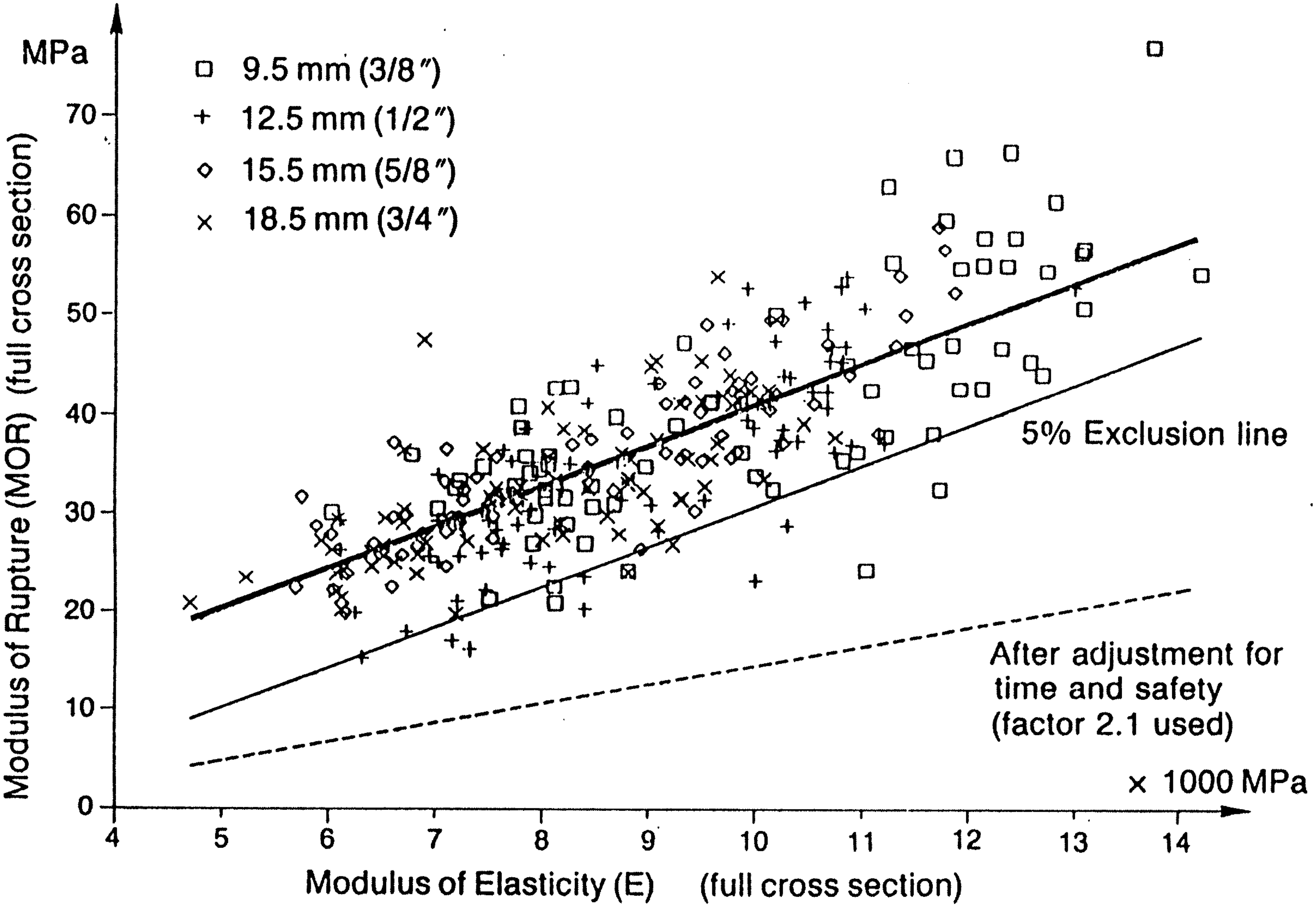

Figure 7. Modulus of rupture versus modulus of elasticity for a "no name" structural panel product

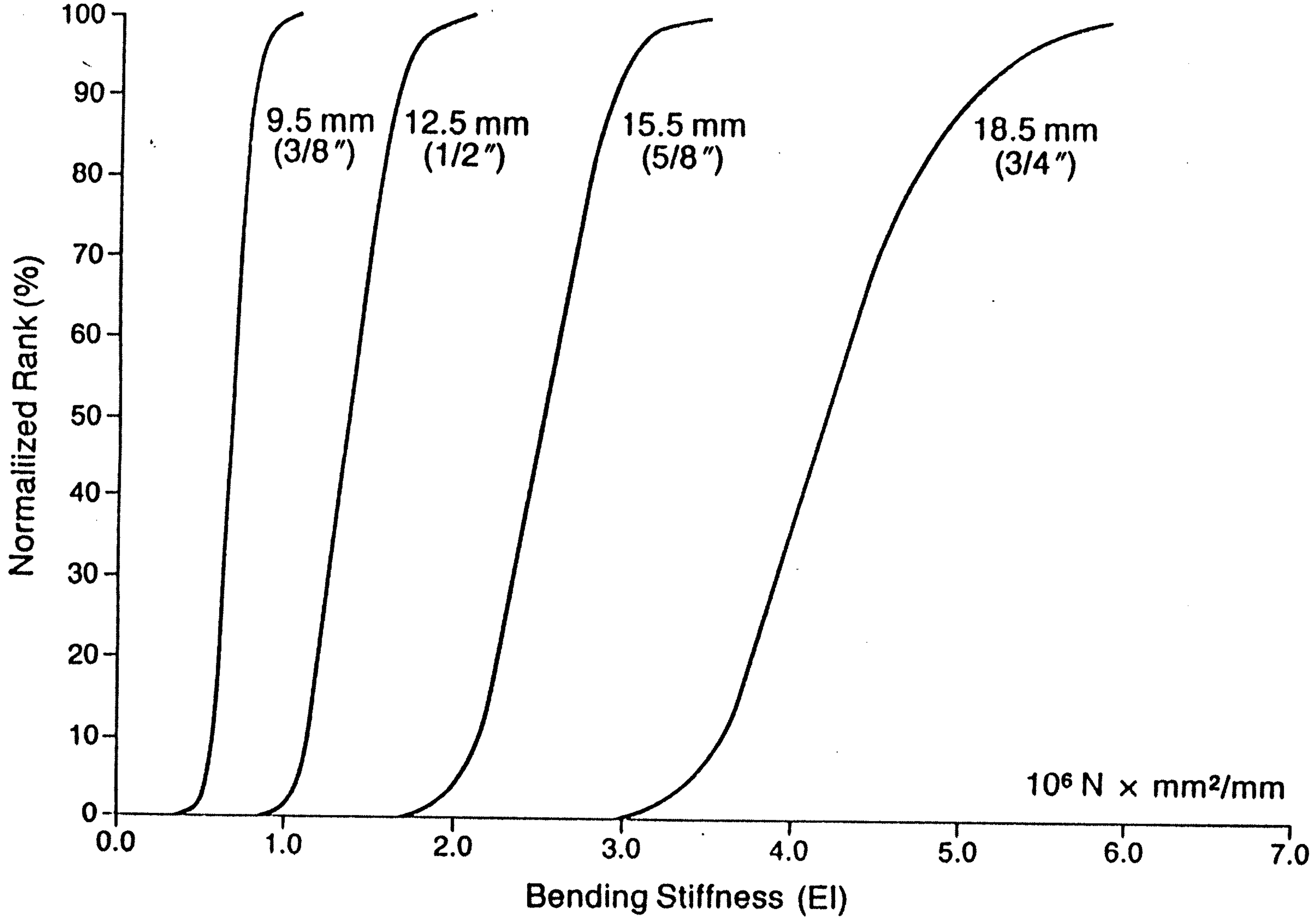

Figure 8. Stiffness variation in four (4) thicknesses of a "no name" structural panel product

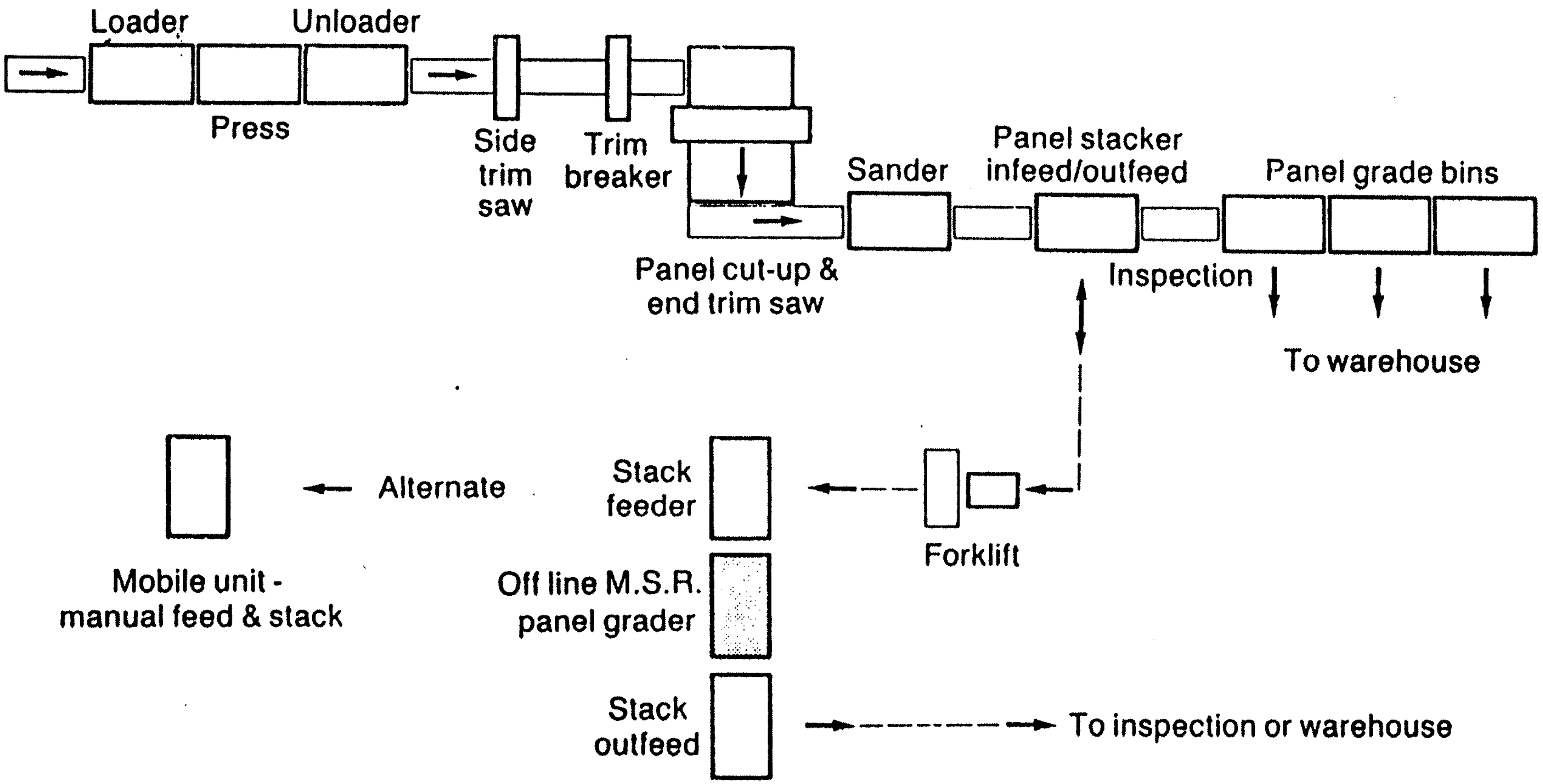

Figure 9. Location of MSR equipment for off-line panel grading at a manufacturing plant

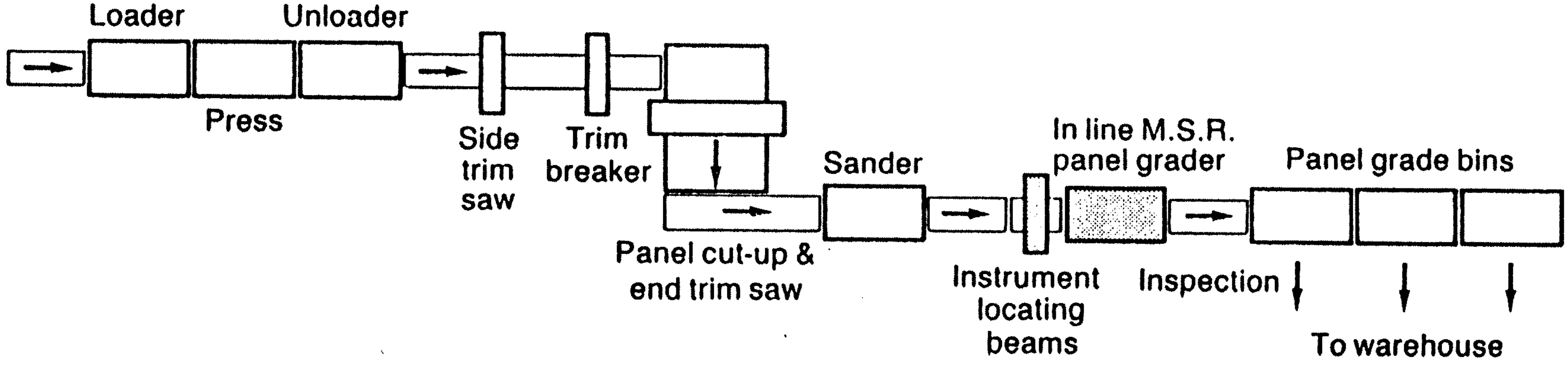

Figure 10. Location of MSR equipment for in-line panel grading at a manufacturing plant

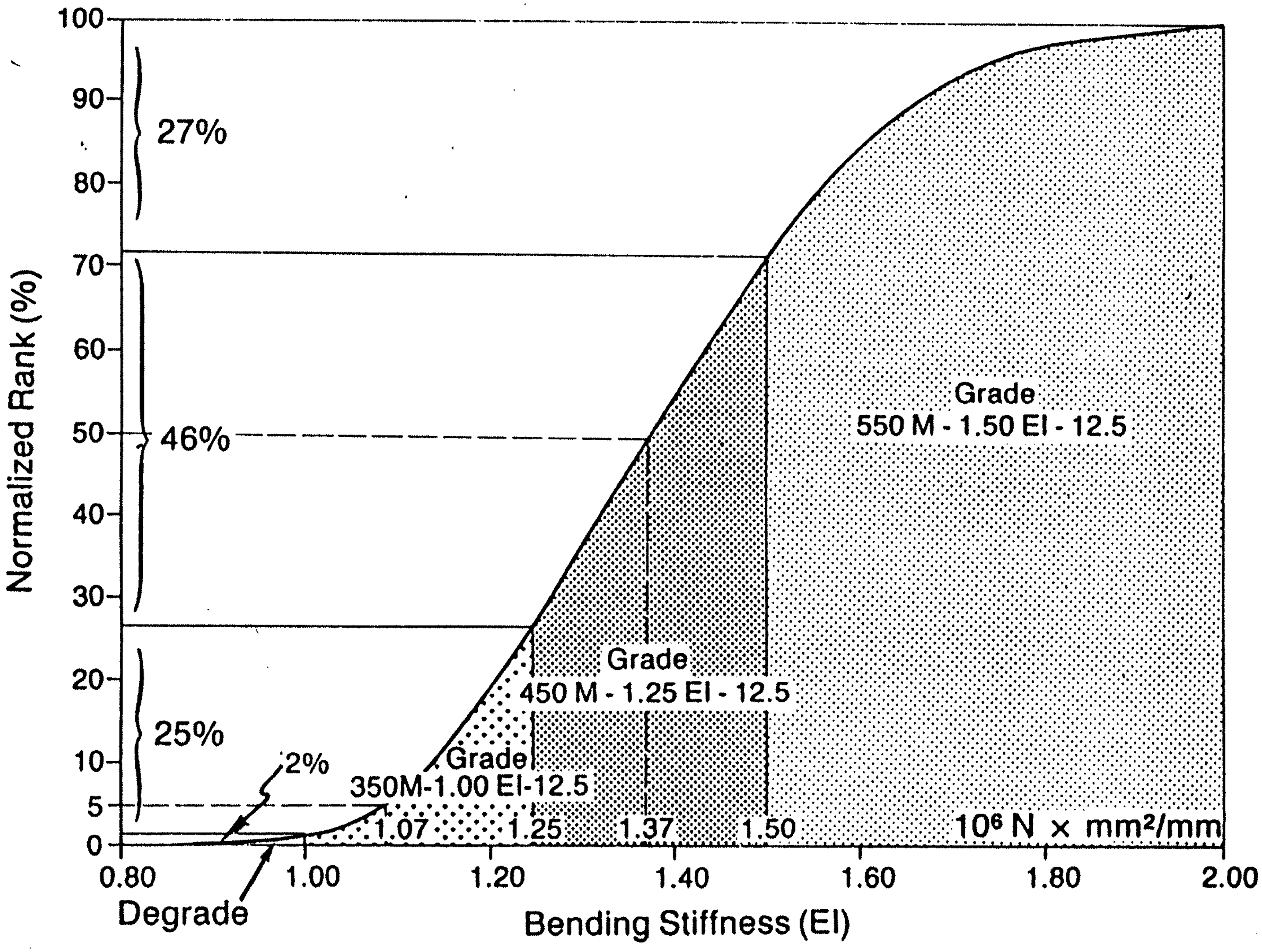

Figure 11. Stiffness variation of a "no name" 12.5 mm (1/2") structural panel. The shaded areas show the yield of three (3) MSR grades for which the minimum requirement for stiffness is known

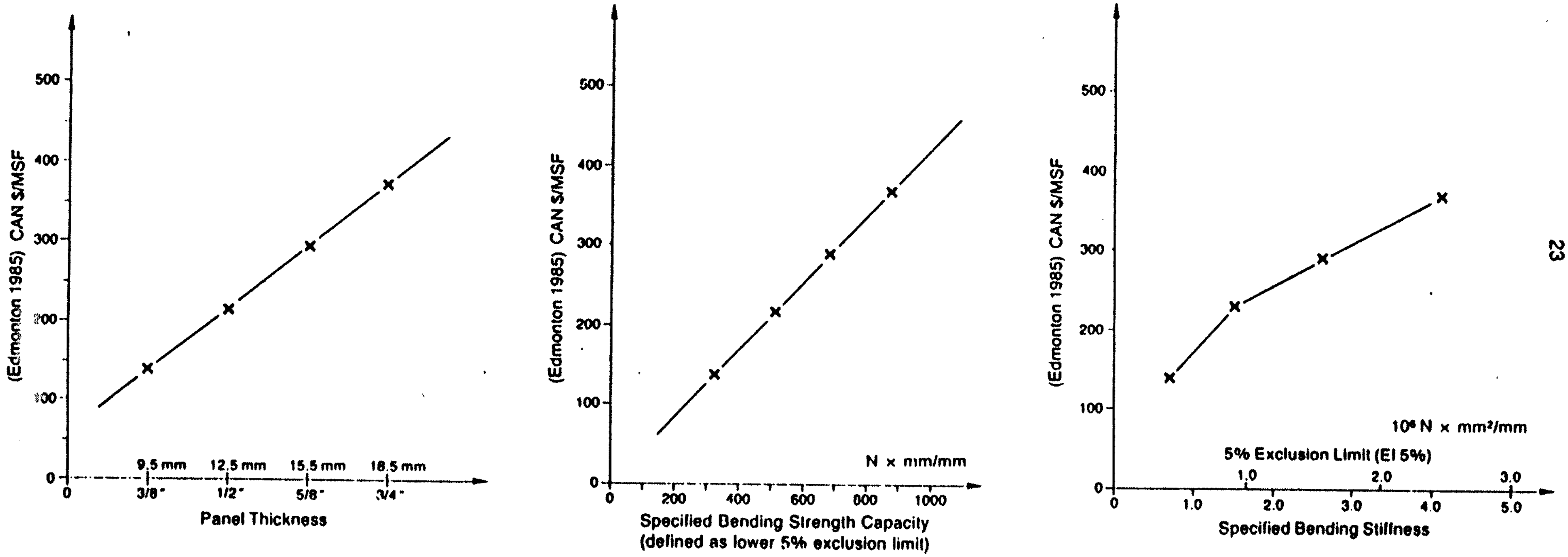

Figure 12. Plots showing the relationship between the 1985 Edmonton sales prices of unsanded Douglas fir plywood versus thickness, specified bending strength and specified bending stiffness as published in the Canadian Standards for Engineering Design in Wood