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AN INVESTIGATION OF THE SUITABILITY OF LAKE STATES TIMBER SPECIES FOR GUARDRAIL POSTS

Specification for Lake States Guardrail Posts

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16. Abstract

Wood has a number of properties which make it suitable for guardrail posts and blocks, one of the most important being its reaction to dynamic loads such as a guardrail post may experience. The major factor in the use of a certain material for guardrail posts will be economics, or the cost of the post.

In order that the wooden post provide the function that it was intended for, it is necessary to use high quality material and high quality preservative treatment. The specification requires the use of grade stamped posts indicating grade and species requirements have been met, and the use of brands to indicate treating requirements have been met.

The new MDOT specification allows the use of a number of Lake States species at high quality levels, as well as Douglas-fir and southern pine. Because the specifications are quite comprehensive both for the wood and for the preservative treatment it is felt that the new document will do much to improve the quality of guardrail posts in the State of Michigan and increase driver safety. The specification could act as a model for other states.

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Æ CONCEPTS
in wood design
"How'd he like the spec changes?"

NOTICE

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Michigan State Transportation Commission, the Michigan Department of Transportation or the Federal Highway Administration.

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INTRODUCTION

This report has been prepared at the conclusion of Phase I of the project, as required in Agreement No. 82-0410 between Michigan Technological University and Michigan Department of Transportation (MDOT). Phase I involved the preparation of a recommended specification for wooden guardrail posts, with the stated objective being:

> 'To develop a specification for new guardrail posts and sign supports, including the suitability of Lake States wood species for these products, and to develop associated inspection procedures to use with the proposed specification'.

The proposed specification can be found as an appendix to this report which provides background information concerning several aspects of the specification.

Wood is used extensively for guardrail posts and highway sign posts in the United States. In the Midwest area more than 60 percent of new guardrail installations are supported by wood (32). Some of the reasons for using wood in highway structures are aesthetics, economics, durability, and ease of installation and maintenance (16). A report, reviewing current practice in 1967, also notes that wooden posts exhibit desirable strength properties, in that they appear more resilient under dynamic loading and are less dependent on direction of loading than steel H-section posts (21). Currently, a wood system has the advantage, compared to other materials, of being relatively low cost. However, this may be dependent on the use of local species, because transportation costs for West Coast species or species from the South add significantly to the cost of a guardrail post.

The intent of the specification is to provide guardrail posts with suitable initial strength properties and to provide means to maintain those properties against attack by wood destroying organisms. The former can be accomplished by species selection and quality control by grading. In developing this specification, the Institute of Wood Research (IWR) was given the major constraint that posts should meet the Federal requirement of 1200 psi allowable stress in bending (F_b). The recommended MDOT specification details species which meet this requirement and we specify the use of approved grade stamps to provide quality assurance.

The second part of the intent can be achieved by suitable preservative treatment. Pressure treatment of timber is a specialized science and premature deterioration of material can occur if treatment procedures are improperly designed or carried out. Much of the sections on preservative treatment are based upon accepted procedures developed by the American Wood-Preservers' Association (AWPA), and the American Society for Testing and Materials (ASTM). The specification requires that the treating plant provide certification that guardrail posts and blocks meet the specification.

Impact Strength of Wood

It was not the purpose of this project to question the requirement of F_b = 1200 psi, however, some discussion is justified. Wood has the property of being able to withstand substantially greater loads for short durations compared to long durations. For impact loading, design values can be increased by a factor of two (27). This factor was based on tests of small clear specimens done at the Forest Products Laboratory (35) and has been verified for green Douglas-fir specimens (24). It is not known if this factor was taken into account when specifying an allowable bending stress of 1200 psi but it should be.

Some work has been done on the impact properties of wooden guardrail posts (22,25). Michie *et al* (25) tested one hundred posts of Douglas-fir, southern pine, red oak and red pine, as well as some steel members, to determine the performance when subjected to dynamic horizontal forces. The test specimens were various sizes and were secured in a rigid base to provide comparisons. The variations in strength within a species were attributed to strength-reducing factors such as knots, checks and grain deviation. They surmised that the effects of moisture content and preservative treatment are small. Specimen shape, round or rectangular, did not appear to be critical; one can expect equal performance from equal moments of inertia. Concerning species, Michie *et al* noted that red oak exhibited the highest dynamic properties, followed by Douglas-fir and southern pine and then red pine. This is the same ranking as for static bending properties.

Some further work was done by Gatchell and Michie (22), who specifically compared wood posts with steel ones and looked at red oak and southern pine of several

sizes. They noted that the grade of post was not a true indicator of post performance and that grain distortion around knots in the tension face was more significant. However, they did not look at different grades of material and it would appear that they meant quality rather than grade. In addition, grain distortion is addressed and limited by grading rules and therefore grading can be important. Grading rules are discussed in more detail later but one point Gatchell and Michie make is significant. Under the current grading rules,posts are graded for the full length; but there appears to be justification for placing the limiting restrictions for guardrail posts, such as knots and cross grain, only on the middle third of the length, because this is the area of maximum stress. Gatchell and Michie indicate that knots in the outer thirds of length have no effect on impact strength and can be ignored.

Grading Rules

Individual pieces of wood represent a wide range in quality and strength, dependent on knots, cross grain, shakes and other characteristics. An obvious requirement for the orderly marketing of lumber is the establishment of grades that permit the procurement of the required quality of material. Grading rules (28,29,30,33,36,37), which are written by various agencies, specify limiting characteristics for each grade. Grades may be appearance grades, where, as the name suggests, pieces are graded for aesthetics, or they may be structural or stress grades where pieces are specified to have a certain allowable stress, e.g., F_b = 1200 psi.

A guardrail post is in the category 'Posts and Timbers', which are at least 5-by-5 inches in cross-section with no more than 2 inches difference between width and thickness. This category has two stress grades, Select Structural and No. 1. These grades designate near-minimum strength properties on which to base design. The development of allowable stresses is based upon extensive research covering tests of small specimens and full sized structural members (17). In the case of bending, the limiting strength-reducing characteristics are slope of grain and knot size and location. Other features, such as wane, splits and checks which reduce the effective cross-section are also listed for each grade.

In summary then, visual stress grading is an attempt to control the number and location of strength-reducing characteristics, so that an allowable design stress can be specified for a piece of lumber. The National Forest Products Association has gathered together all the allowable stresses for various species, grades and grading rules and published them as 'Design Values for Wood Construction, a Supplement to the National Design Specifications' (26).

Allowable Stresses

In discussing species and grades, a review of the methods used in grading rules to determine allowable stresses should help to clarify some points. The visual grading system for lumber is based upon two ASTM Standards:

i) ASTM D 2555-81 'Standard Methods for Establishing Clear Wood Strength Values'

ii) ASTM D 245-81 'Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber'

Average strength properties and variability (standard deviation) for small clear, unseasoned specimens are listed in ASTM D 2555 (19). The Standard also gives methods to obtain these properties for species groups, which are based on the relative standing timber volumes of species in the group. Allowable design properties are obtained from the basic clear mechanical property statistic using adjustments for design derived using ASTM D 245 (17).

The first step is to obtain the five percent exclusion limit for the strength property. This is defined as the level of strength below which five percent of the strength values are expected to fall and corresponds to a selected probability point from the frequency distribution of strength values (19). For guardrail posts the strength property is bending strength or modulus of rupture and the exclusion limit (EL) is obtained using:

$$EL = \bar{X} - 1.645s$$

where

$\bar{X}$ = average bending strength

s = standard deviation

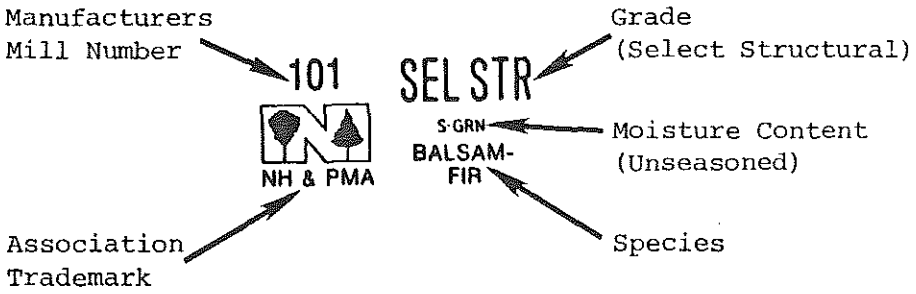
Then, the allowable bending stress for clear, straight grained material is obtained by using adjustment factors and modifications for seasoning and density. The adjustment factor includes a factor for duration of load and a factor of safety; in the case of bending this is 0.476 (1/2.1) for softwood species and 0.435 (1/2.3) for hardwoods. The density and seasoning modification do not apply in the case of guardrail posts. The resulting values are allowable unit stresses for wood free from knots or other strength-reducing characteristics.

In order to obtain the allowable or design bending stress for a particular grade, a strength ratio and a depth factor are applied. The strength ratio is the ratio of the strength of a piece with strength-reducing characteristics to its expected clear, straight-grained strength. Only the characteristic which give the lowest strength ratio, i.e., the limiting characteristic, is used to derive the allowable stress (35). The depth factor is used because the initial strength properties are obtained from small specimens, whereas the posts are considerably larger. Anytime a piece of lumber is greater than 2 inches deep in bending, the depth factor is used because the unit stresses in a large member are lower than those in a small specimen. The strength ratios and depth factors are combined into strength ratio factors, which are 0.57 for Select Structural and 0.46 for No. 1 graded material. The values obtained in this way can be found in the 'Design Values for Wood Construction' (26).

As an example consider balsam fir as a post. From ASTM D 2555 we find that the average bending strength is 5517 psi and the standard deviation 552. Using the formula above, the five percent exclusion limit is 4607 psi. This is divided by 2.1, the adjustment factor for duration of load and safety, giving 2195 psi. Then, multiplying by the strength ratio factors given above for Select Structural and No. 1 grades and rounding the values as specified in ASTM D 245, we obtain 1250 and 1000 psi, respectively. These are the values given in 'Design Values for Wood Construction'.

SPECIES AND GRADES

We have seen that grading rules put limits on strength-reducing characteristics for a particular grade. Material inspected under such rules is grade stamped, with a typical stamp for the Northern Hardwood and Pine Manufacturers Association (NHPMA) shown below:



This provides assurance that the material is of a certain quality and that the design stresses can be used with confidence. The use of grade stamped material should correct existing problems in guardrail post procurement. The stamp will also assure that the species is from among the approved list. The use of grade stamps from an approved agency will put the onus of quality assurance on the supplier, rather than on the treating plant or MDOT personnel.

Before selecting species, specifications from about twenty states were reviewed. It was obvious from this review that the current MDOT specification is one of the least restrictive, both in terms of allowable species and in the determination of whether material meets the required standard. Some states are very restrictive, for example, Hawaii does not allow the use of wood for guardrail posts and California only allows the use of Douglas-fir. Most states allow the use of suitable grades of Douglas-fir and southern pine and several states the use of red oak. New York was the only state reviewed which allowed hardwoods other than oak. In writing the new MDOT specification IWR attempted to restrict species compared to the old specification, while allowing the use of some Lake States species.

The initial species considered for inclusion in the new specification were those listed in the 'Design Values for Wood Construction' (26) that met the F_b = 1200 psi requirement in one of the 'Post and Timber' grades. When this was done, few Lake States Species were included even for Select Structural material. Those that were consisted of the softwoods, balsam fir and eastern hemlock. In addition to these, the following species or combinations met the requirement:

Coastal Douglas-fir
Douglas-fir/larch
Douglas-fir south
Hem/fir
Mountain hemlock
Southern pine
Western hemlock

Of these, coastal Douglas-fir or the Douglas-fir/larch species combination and southern pine were included in the specification because they are major structural species, they are available in quantity and they can be adequately treated to provide decay resistance. A number of timber species are often grown, harvested and marketed together and have similar properties. This is the case for the Douglas-fir/larch combination. Where it is practical to separate individual species, they may be grade stamped as such (37).

Western hemlock and the hem/fir combination, which consists of western hemlock, California red fir, grand fir, white fir, noble fir and pacific silver fir, also treat well and could be included in the specification if MDOT desired. They were excluded because they are not often seen in local markets. Douglas-fir from other regions and mountain hemlock were excluded because they are more difficult to treat with preservatives.

Jack pine and red pine can be included in the 6-by-8 inch size providing they are graded for Select Structural in the 'Beams and Stringers' classification. The NHPMA grading rules (30) allow this to be done as they state that Posts and Timbers grades

> 'are designed to provide high compression values. If the higher fiber stress in bending values applicable to Beams and Stringers are desired, the Select Structural and No. 1 grades may be graded under rules for Beams and Stringers, if all faces of square pieces are considered as narrow faces'.

Eastern white pine should not be included as its strength properties are substantially lower. We recognize that this may pose sorting problems but if quality is to be maintained white pine should be excluded. Also aspen has insufficient strength to meet the requirements of a 6-by-8 inch post. An alternative, which was suggested in the draft specification but which we have eliminated in the final copy, is to use a larger cross-section. White pine or aspen of Select Structural grade could be included in the specification in an 8-by-8 inch size. Jack pine and red pine, graded as Select Structural Posts and Timbers, rather than Beams and Stringers, could be included at 7-by-8 inches. This would increase material costs approximately 35 and 18 percent, respectively.

In addition, as indicated earlier, if weak post systems or breakaway provisions are supplied by reducing the cross-sectional area of a post, then these lower strength species such as aspen and eastern white pine could be included. The quality level of posts from other species could be reduced,providing post integrity is not jeopardized.

It should be noted that the allowable design values are based on unseasoned clear wood strength and its variability, as listed in tables in ASTM D 2555. These tables present the most reliable basic information developed over many years of testing and experience and they are regularly updated. The data do not always correspond with that in the Wood Handbook (35). For example, if we compare balsam fir and white pine the Wood Handbook gives unseasoned bending strengths of 4900 psi for both species, while ASTM D 2555 lists values of 5517 psi for balsam fir and 4930 psi for white pine. Part of the difference may be due to geographic location, as ASTM D 2555 lists a bending strength of 5290 psi for balsam fir grown in Canada. The Standard recognizes the limitations of data collected from material sampled from forests extending over large regions and suggests practical approaches to the determination of strength data for a particular region.

While considering species and grades to be included, the following grading rules were reviewed:

Northern Hardwood and Pine Manufacturers Association
Northeastern Lumber Manufacturers Association
Western Wood Products Association

West Coast Lumber Inspection Bureau

Southern Pine Inspection Bureau

National Hardwood Lumber Association

It was apparent from looking at these grading rules that most hardwood species are not stress graded at the present time. The few that are, such as aspen, cannot be considered for the new specification because of their low strength. The ASTM standards, previously discussed, apply equally well to hardwood species and softwood species (20), therefore there is no reason why the hardwoods cannot be stress graded. Calculations of allowable stresses showed that the following Lake States hardwoods (red oak, hard maple, white ash, beech, elm) can meet the desired allowable stress, assuming they are graded to the Select Structural requirements.

The limiting characteristics for Select Structural material as specified in Section 3.32 of the NHPMA grading rules (30) are:

Stained sapwood

Splits 3/4 the thickness

Seasoning checks - single or opposite each other with a sum total equal to 1/2 the thickness of the piece

Heavy torn grain

Slope of grain - 1 in 12

Pitch streaks

Occasional skips 1/16" deep, 2' in length

Medium pitch pockets

Wane 1/8 of any face

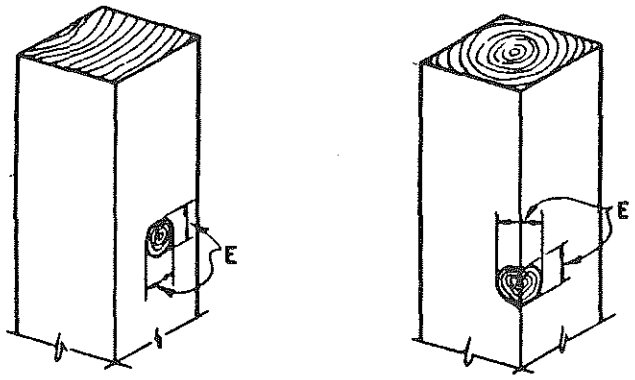
Shake 1/3 the thickness on one end

Knots must be sound, tight and well-spaced. Knots equal to the size permitted on the widest face are allowed on all faces. Knot size limitations are as follows:

Face Width	Knot Size
6"	1-1/4"
8"	1-5/8"

Examples of knot measurement, shake, split and check measurement and slope of grain are given on the following page taken from the NHPMA grading rules.

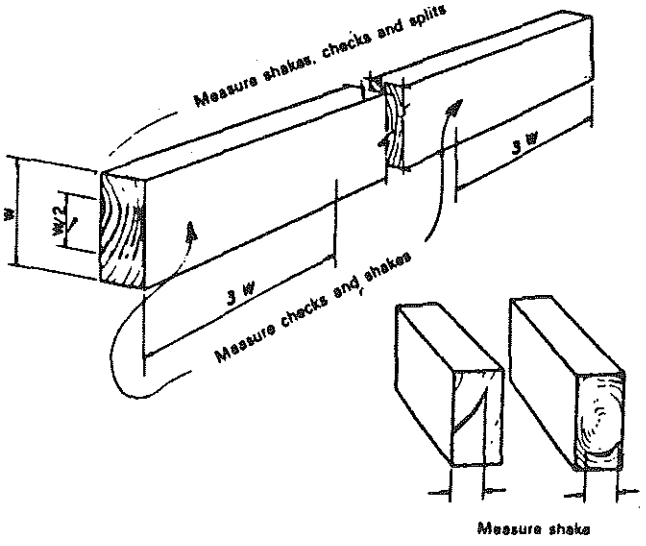
POST and TIMBER KNOTS
5" x 5" and Larger Lumber
Width Not More Than 2" Greater Than Thickness



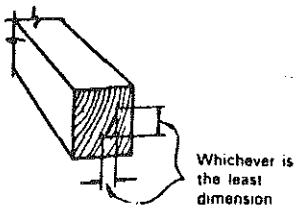
E-Measure average dimension.

●8.20 SHAKES, CHECKS and SPLITS

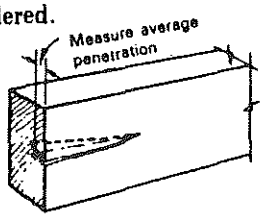
In all grades of framing, except Posts and Timbers, these characteristics are measured only in the middle half of the width. Restrictions on checks apply for a distance from the ends equal to three times the width of the wide face. Shake is measured at the end between lines enclosing the shake and parallel to the wide face. Illustrations of how these characteristics are measured follow:



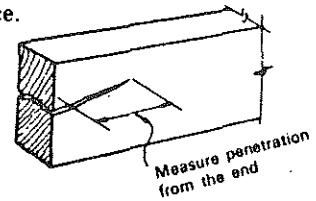
SHAKES in Posts and Timbers are measured at the ends of pieces between lines parallel with the two faces that give the least dimension.



CHECKS are measured as an average of the penetration perpendicular to the wide face. Where two or more checks appear on the same face, only the deepest one is measured. Where two checks are directly opposite each other, the sum of their depths is considered.



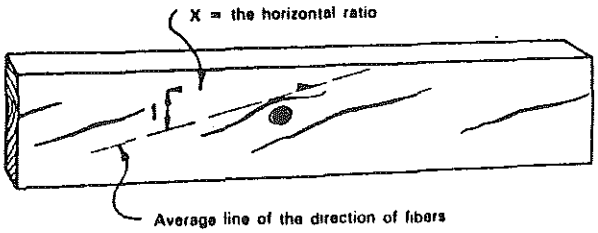
SPLITS are measured as the penetration of a split from the end of the piece and parallel to the edges of the piece.



●8.30 SLOPE OF GRAIN

Slope of grain is the deviation of the wood fiber from a line parallel to the edges of a piece. The deviation is expressed as a ratio such as a slope of grain of 1 in 8, etc.

Generally, slope of grain shall be measured over sufficient length and area to be representative of the general slope of the fibers, disregarding local variations. However, local variations shall be measured in lumber less than 4" wide, except around visible knots.



Because Lake States hardwoods are not currently stress graded, we recommend that MDOT, or IWR as a representative of MDOT, approach NHPMA or another appropriate agency to allow the use of its grading stamp to certify that the Lake States hardwoods meet the requirements for 'Select Structural' grades of guardrail posts which currently apply to softwoods.

INCISING

Some wood species are more difficult to treat than others and it is generally recognized that for refractory woods,incising is an important aid in preservative treatment (31,35). Incising consists of making shallow slits in the wood surface to allow deeper and more uniform penetration of preservative. In order to achieve the consistent retentions and penetrations required in guardrail posts, IWR followed AWPA Standard C14 (11) and recommends incising for all softwood species except southern yellow pine. In addition, incising is recommended for all the Lake States hardwood species. This will add about one percent to the cost of the guardrail post. The strength of large sawn products, such as guardrail posts is not significantly affected by incising (31), while on the other hand there is some evidence that seasoning checks are reduced in incised hardwood material (34).

BRANDING

IWR recommends that guardrail posts and blocks be branded by the treating plant in accordance with AWPA Standard M6 (15). Branding will correct a number of the problems now occurring in guardrail post procurement and use. The brand will establish the particular treating plant supplying the post, the type and level of preservative treatment and the date of treatment. If a problem arises the specific treating records should be obtainable for up to five years to help determine where the problem arose. The specification requires branding on a wide face close to the top of the post, which will allow easy observation of the brand.

CERTIFICATION AND INSPECTION

Quality assurance for the treated material is indicated by conformance with a results-type specification, such as that prepared. An accurate measure of penetration and retention is thus required to indicate proper treatment of the wood.

This is done by taking measurements from sample borings of the treated material. The requirements in the specification are based upon AWPA Standard M2 (13), which details sampling methods, boring techniques, number of borings, and general methods. Appropriate sections of this standard which are specifically referenced in the specification are reproduced on the following three pages.

Similar to the recommendations for grading, where responsibility for quality assurance is placed with the supplier, each treating plant supplying guardrail posts/blocks must certify that the preservative treatment conformed with the MDOT specification. The certificate must warrant that the material supplied has been conditioned, treated, inspected, branded and handled in accordance with the specification.

If this is done, guardrail posts and blocks used in the Lake States on state controlled highways will not lose their identity and certain recurring historical problems will be corrected. Should problems arise it will be easier to determine the responsible party and take corrective action. The quality of highway barriers will be increased and motoring safety should increase.

PRESERVATIVE TREATMENT

Although the heartwood of some woods has good natural durability (35), none of these species are suitable for guardrail posts in the Lake States. Therefore, we recommend that all guardrail posts and blocks be preservative treated to provide protection against decay or other wood destroying organisms. Much of the material in Section B of the specification is based upon appropriate AWPA Standards which are listed in the references, and ASTM Standard D 1760 (18). The chemical and physical properties of various preservative solutions are specified in AWPA Standards P1 through P5, P8 and P9.

Conditioning

Reduction of the moisture content of guardrail posts and blocks before preservative treatment is essential to aid the penetration and distribution of preservative. Conditioning also reduces the risk of checking which might expose untreated wood.

5.51 With timber species or individual pieces not having a sharp demarcation in color between the heartwood and sapwood the sapwood thickness shall be checked with indicators described in the following paragraphs.

5.511 Pines—The sapwood-heartwood indicator for the pines shall be made by mixing together equal volumes of the following two solutions:

Solution A—O-anisidine Hydrochloride
Weigh out 8.5g concentrated hydrochloric acid (37%).
Dilute with water to make 495g of solution.
Add 5g O-anisidine and stir until completely dissolved.

Solution B—10 percent Sodium Nitrite
Dissolve 50g sodium nitrite in 450g water.

The mix of the two solutions may be applied by brush or atomizer. After several minutes, the heartwood will develop a bright reddish-orange color, while the sapwood remains a pale yellow-orange. Smooth surfaces give better results than rough surfaces. (Wettability of the indicator can be improved by adding a few drops of Kodak Photo-Flo to each 100 ml. of indicator mix).

For maximum shelf life, both Solutions A and B should be stored in a refrigerator or other cool, dark location. Under such conditions the storage life exceeds one month. The mix of the two solutions can be used over a period of several days, but filtering before use is necessary.

5.512 Test for Douglas Fir—The heartwood and sapwood of Douglas fir can usually be differentiated with a 0.1 percent solution of Methyl Orange in water or a 0.75 percent solution alizarine-sulfonate solution in water. The latter stains the heartwood and one or two adjacent annual rings in the sapwood yellow and the sapwood pink, or some other shade of red. In the former, the heartwood is reddish and the sapwood yellowish. The indicator works on both dry and green wood, and the colors are comparatively permanent. The test works best on a freshly exposed surface. A little alcohol added to the solution will make wet wood dry more rapidly.

5.95 A sharp increment borer which extracts a core 0.2 in. (nominal) in diameter shall be used. When sampling for assay purposes, the core diameter shall be within a tolerance of plus or minus 0.02 in. The borer shall be calibrated at least once a month, and after each sharpening. Either of two methods shall be used:

Method 1

Calibrating the Increment Borer Bit

This method shall be used on new or unworn bits. A Starrett Taper Gage (Cat. No. 269A), or equivalent, shall be used, reading to the nearest 0.001 in. The bit diameter shall be considered as the average of two readings made at the maximum and minimum diameter.

Method 2

Calibrating the Increment Cores

At least 20 borings shall be measured. Preferably this shall be done immediately after extracting each core from the cooled wood. If this is not done, the cores shall be placed in a small, clean, tightly stoppered bottle, and they shall be measured immediately on return to the laboratory. Only well-cut cores shall be used and care should be taken to measure at a point within the assay sampling zone, free from knots and resin accumulations. The diameter of each core shall be measured once with the grain and once across the grain using either a machinist's micrometer or a Starrett Dial Test Indicator reading to the nearest 0.001 in., or equivalent. The two diameters shall be averaged, and the calibrated diameter of the borer shall be considered as the total of these diameters divided by the number of cores.

5.96 Core Sampling—The following procedure shall be used in securing increment borer cores for assay purposes, moisture determinations and bit calibrations:

a. Tare weighing bottle and screen thimble.
b. Mark spot with lumber crayon where boring is to be taken. The spot serves to insure that the outer zone is not lost. For Boulton dried fir or case-hardened surfaces, a punch with a 0.25 inch stop is used to facilitate boring.
c. Extract core sample from material, taking care that the increment borer is perpendicular to the surface being bored.
d. Measure sapwood depth and when applicable, the depth of penetration.
e. Record data.
f. After sectioning in jig (section 5.98) remove separated zone with forceps; drop in weighing bottle and immediately replace stopper.
g. Upon completion of sampling, reweigh bottle, thimble and sample.
h. Proceed as directed in AWPA Standards A6 or M2.

7.2 Each inspection shall be covered by an Inspector's Report which should include all of the following applicable information, plus any other information requested by the inspector's supervisor or by the client.

- Name of treating company
- Location of treating plant
- Applicable product specification or standard
- Charge number
- Date of treatment
- Contents of charge
  - Type of material
  - Number of pieces by size
  - Species
  - Degree of seasoning
  - Manufacturing (incised, unincised, rough surfaces, etc.)
  - Number of cubic feet
- Preservative
- Process used in treatment
- Steam conditioning
  - Time required to reach maximum temperature
  - Time steamed at maximum temperature
  - Maximum temperature
  - Initial vacuum period
  - Maximum vacuum
- Heating in oil
  - Heating period
  - Maximum vacuum
  - Maximum temperature
  - Total condensation
  - Total absorption of preservative
- Treatment
  - Initial air pressure
  - Initial air period
  - Pressure period
  - Maximum pressure
  - Maximum temperature
  - Average temperature
  - Maximum final vacuum
- Final vacuum period
  - Time and temperature of final steam bath (if any)
  - Time and temperature of expansion bath (if any)
  - Working tank readings with temperature
  - Injection under pressure
  - Final retention
  - Total time of treatment
- Penetration
  - Number of borings taken
  - Percent conforming

Even though good penetration of preservative may be possible at high moisture contents it is often followed by serious checking when the wood dries in service (23). Besides air drying, which can take extended periods of time and kiln drying, other methods of conditioning are available when pressure treatment is used.

Steaming of wood reduces water content in green stock and renders it more permeable to preservatives. It is routinely applied to conifers, particularly southern pine (34). Oak is susceptible to damage from this process and the AWPA standard does not allow steaming for oak (10). Because there are indications that other hardwoods could react in a similar manner, we prohibited steaming in the specification. Because the conditioning of maple could cause degrade we recommend that only air drying be allowed.

Other conditioning methods involve heating the material in the preservative solution with or without a vacuum applied. The former, boiling under vacuum, is known as the Boulton process and uses lower temperatures. This is a considerable advantage in treating woods because degrade is reduced.

Treatment

Creosote solutions and pentachlorophenol dissolved in petroleum oils are practically inert to wood and have no chemical influence that would affect its strength. In addition, CCA and ACA in the concentrations commonly used have limited effect on the strength of wood (23). Although there is evidence that high retentions of salt-type preservative may reduce the shock resistant properties of wood (34), the retentions were much higher than those listed in the proposed specification. There is no evidence in the literature to suggest that combinations such as CCA and Douglas-fir produce treated material with reduced properties.

Although the preservatives are not harmful in themselves, the treating process, if not adequately controlled, can produce material with significant loss of strength (23,35). Most important of these are the severity and duration of the heating conditions used. For example, the use of an expansion bath is restricted

to softwood species. The expansion bath removes part of the entrapped air and surplus preservative to reduce the tendency to exude preservative. It involves raising the temperature of the preservative after impregnation of an oil treatment is completed. The treating cylinder is then quickly emptied and a vacuum applied. This technique can cause degrade in hardwood timbers and is, therefore, restricted. The maximum pressure during the treating cycle is also limited depending on species. Therefore, as indicated in the National Design Specification (27) design values are unaffected by preservative treatment provided the process and preservative are AWPA or ASTM approved.

Retention and Penetration Requirements

The retention requirements are taken from AWPA Standard C14 (11). Because the product is of critical importance the retentions and penetration requirements are relatively high. Although a guardrail post may never be required to perform its function, it must be able to resist impact forces when required, throughout its lifetime. Therefore, high levels of preservative treatment are required to prevent attack by decay or other wood destroying organisms which would reduce the strength and thus the effectiveness of the guardrail post.

Field Treatment

Whenever practical, the guardrail posts and blocks should be manufactured in final form before treatment. This eliminates the necessity for subsequent cutting of the treated material. For example, the preboring of holes used to attach the guardrail assures protection of the material around the bolt hole. If it is not possible to do this, then the machined areas must be field treated with the appropriate preservative according to the specification. In addition, major cuts or damage should be field treated.

REFERENCES

American Wood-Preservers' Association. Washington, D.C. The following Standards were referenced:

(1) P1-78 Creosote. 1 p.

(2) P2-68 Creosote and Creosote Solutions. 1 p.

(3) P3-67 Creosote-Petroleum Oil Solution. 1 p.

(4) P4-70 Petroleum Oil for Blending with Creosote. 1 p.

(5) P5-78 Water-Borne Preservatives. 3 p.

(6) P7-72 Creosote for Brush or Spray Treatment for Field Cuts. 1 p.

(7) P8-77 Oil-Borne Preservatives. 1 p.

(8) P9-77 Standard for Solvents for Organic Preservative Systems. 2 p.

(9) C1-82 All Timber Products, Pressure Treatment (General Requirements). 4 p.

(10) C2-82 Lumber, Timbers, Bridge Ties and Mine Ties, Pressure Treatment. 9 p.

(11) C14-79 Wood for Highway Construction, Pressure Treatment. 2 p.

(12) M1-76 The Purchase of Treated Wood Products. 3 p.

(13) M2-81 Inspection of Treated Timber Products. 6 p.

(14) M4-79 Care of Pressure-Treated Wood Products. 2 p.

(15) M6-75 Brands used on Forest Products. 8 p.

Other references:

(16) American Wood Preservers' Institute. 1969. Guardrail Systems: Safety With Treated Wood. AWPI Technical Guidelines H2. 4 p.

(17) American Society for Testing and Materials. 1982. Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber, D 245-81. Annual Book of ASTM Standards. Part 22. Wood; Adhesives, pp. 147-170.

(18) American Society for Testing and Materials. 1982. Standard Specification for Pressure Treatment of Timber Products, D 1760-81. Annual Book of ASTM Standards. Part 22. Wood; Adhesives, pp. 532-556.

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(23) Hunt, G. M. and G. A. Garratt. 1967. Wood Preservation. McGraw-Hill Book Company. 433 p.

(24) Keeton, J. R. 1968. Dynamic Properties of Small, Clear Specimens of Structural-Grade Timber. Technical Report R573. Naval Civil Engineering Laboratory, Port Huenene, California. 50 p.

(25) Michie, J. D., C. J. Gatchell and T. J. Duke. 1971. Dynamic Evaluation of Timber Posts for Highway Guardrails. Highway Research Record No. 343, Highway Research Board, Washington, D. C., pp. 19-33.

(26) National Forest Products Association. 1980. Design Values for Wood Construction. A Supplement to the 1977 Edition of National Design Specification for Wood Construction. Washington, D.C. 28 p.

(27) National Forest Products Association. 1977. National Design Specification for Wood Construction. Washington, D.C. 78 p.

(28) National Hardwood Lumber Association. 1982. Rules for the Measurement and Inspection of Hardwood and Cypress. Memphis, Tennessee. 115 p.

(29) Northeastern Lumber Manufacturers Association. 1980. Grading Rules for Northeastern Lumber, Falmouth, Maine. 114 p.

(30) Northern Hardwood and Pine Manufacturers Association. 1982. Standard Grading Rules. Green Bay, Wisconsin. 125 p.

(31) Perrin, P. W. 1978. Review of Incising and its Effects on Strength and Preservative Treatment of Wood. Forest Products Journal 28(9):27-33.

(32) Reid, W. H. and D. B. McKeever. 1978. Wood Products and Other Materials used in Constructing Highways in the United States. USDA Forest Service, Resource Bulletin FPL 5. 19 p.

(33) Southern Pine Inspection Bureau. 1977. Grading Rules. Pensacola, Florida. 214 p. With supplements to 1982.

(34) Thompson, W. S. and P. Koch. 1981. Preservative Treatment of Hardwoods: A Review. USDA Forest Service, Southern Forest Experiment Station General Technical Report SO-35. 47 p.

(35) United States Department of Agriculture. 1974. Wood Handbook: Wood as an Engineering Material. USDA Forest Service, Agriculture Handbook No. 72. 366 p.

(36) West Coast Lumber Inspection Bureau. 1981. Standard Grading and Dressing Rules. Portland, Oregon. 223 p.

(37) Western Wood Products Association. 1981. Standard Grading Rules for Western Lumber. Portland, Oregon. 216 p.

APPENDIX

A SPECIFICATION

FOR

LAKE STATES GUARDRAIL POSTS

A SPECIFICATION FOR LAKE STATES GUARDRAIL POSTS

Prepared by

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November 1982

A. SAWED TIMBER POSTS AND BLOCKS FOR BEAM GUARDRAIL

A.1. Species and Grades

Posts with a 6-inch by 8-inch cross-section shall have a minimum stress grade rating of 1200 psi in bending, before preservative treatment.

Posts shall be graded in accordance with current grading rules developed according to the principles of ASTM D 245. Permitted species and grades, in the Posts and Timbers classification, required to meet the minimum stress grade rating are as follows:

SPECIES	POSTS AND TIMBERS GRADE	GRADING RULES AGENCY
Lake States Hardwoods (Red Oak, Hard Maple, White Ash, Elm, White Heartwood Beech)	Select Structural	Northern Hardwood and Pine Manufacturers Assoc. (NHPMA)
Balsam Fir Eastern Hemlock	Select Structural	Northeastern Lumber Manufacturers Assoc. (NELMA) or NHPMA
Jack Pine Red Pine	Select Structural in Beams and Stringers classification	NHPMA
Pacific Coast Douglas-fir or Douglas-fir/Larch	No. 1 or better	Western Wood Products Association (WWPA) or West Coast Lumber Inspection Bureau (WCLIB)
Southern Yellow Pine	No. 2 dense SR or better	Southern Pine Inspection Bureau (SPIB)

For any species, blocks may be one grade lower than the posts provided they meet the requirements for allowable degrade listed in Section A.3.4.

All material must show the approved grading agency stamp indicating the origin, species and grade of the material.

A.2. General Requirements

A.2.1. Dimensional Tolerances - Posts shall be sawed square to within ± 1/2 inch of the specified full end dimensions. A tolerance of minus 2 inches will be permitted on the specified length of the post.

A.2.2. Decay - Posts and blocks shall be free from decay before treatment.

A.2.3. Crook - Posts with crook exceeding one inch between top and bottom will not be accepted.

A.3. Preservative Treatment

All posts and blocks shall be treated in accordance with the provisions of Section B, with additional specifications as follows:

A.3.1. Incising - All species except southern yellow pine shall be incised before treatment.

A.3.2. Sorting and spacing - The material in any charge shall consist of the same species or consist of species within any one group shown below. The material shall have similar moisture content and be of similar form and size. Blocks and posts can be treated in the same charge. Pieces in the charge shall be separated by horizontal stickers so that preservative and steam (if used) will contact all horizontal surfaces.

SPECIES GROUPINGS FOR TREATMENT IN SAME CHARGE

GROUP	SPECIES
A	Southern Yellow Pine
B	Douglas-fir, Hemlocks, Hem-Fir and Balsam Fir
C	Jack Pine and Red Pine
D	Lake States Hardwoods

A.3.3. Machining - The material to be treated should be manufactured in its final form before treating to eliminate any necessity for subsequent cutting of treated wood. If subsequent cutting becomes necessary, field treatment shall be conducted in accordance with the appropriate parts of AWPA Standard M4 'Care of Pressure-Treated Wood Products', which are reproduced in Section B.6.

A.3.4. Degrade after treatment - Guardrail posts or blocks developing the following degrade prior to installation shall be rejected regardless of any prior approvals:

> Single checks greater than 3 inches deep, 1/4 inch wide or extending more than 1/3 of length, or checks opposite each other totalling more than 3 inches deep,
>
> Splits greater than 3 inches long which are in the plane of the bolt hole,
>
> Crook as specified in Section A.2.3.,
>
> Combinations of checks, splits or shake which otherwise meet specifications but which could cause the post or block to separate into several pieces.

A.4. Branding

All posts shall be branded clearly and permanently on one of the wide faces within 12 inches of the top of the post; blocks shall be branded on one of the wide faces. The brand shall identify supplier, plant designation, species, treatment retentions and year of treatment coded in accordance with AWPA Standard M6 'Brands Used on Forest Products'.

A.5. Certification and Inspection

A.5.1. Certification - The treating plant supplying the material shall be responsible for, and shall be required to supply a certificate of conformance to the minimum treatment requirements established in this specification. The certificate shall indicate the species treated, preservative type and level of treatment. It shall also indicate that the material was treated in conformance with conditions specified in Section B.3. and that the material was inspected as specified in Section A.5.4. below and meets the requirements of Sections B.4. and B.5.

A.5.2. Inspection before treatment - The treater shall be responsible for insuring that the material has the required approved grading agency stamp before treatment is commenced.

Material that has been air dried or kiln dried shall be inspected for moisture content as specified below according to AWPA Standard M2. Tests of representative pieces shall be conducted. The minimum number of tests shall be the lesser of 5 percent or 50 pieces out of a charge.

The test shall be made with an electrical resistance type moisture meter with insulated needles of 1.5 inches in length. The readings shall be corrected for species and temperature readings as per meter instructions, and shall be taken on one surface at mid-length. The lot shall be considered acceptable when the average moisture content does not exceed 19 percent. Any individual pieces exceeding 23 percent moisture content shall be rejected and removed from the lot.

A.5.3. Inspection during treatment - The treater shall determine that the preservatives used conform to the requirements of Section B.2. The minimum frequency of the preservative analyses shall be each charge for the occasional single charge inspected and in the case of consecutive treatments from the same working tank, the first and at least one of every five additional charges, selected at random.

Preservative samples shall be taken directly from the treating cylinder. A valve for sampling should be located near mid-height and mid-length of the cylinder. Samples from the treating cylinder shall be taken immediately after filling, and at least one gallon of preservative shall be allowed to flow through the valve before the sample is taken.

A.5.4. Inspection after treatment - Following treatment the charge shall be examined for cleanliness, mechanical damage to individual pieces, treatment damage such as severe checking, splitting or honeycombing and

for any untreated areas resulting from air pockets, floating material, or insufficient height of preservative. Any such material shall be removed from the remaining acceptable material before shipment.

Borings for penetration and or assay shall be taken midway between the ends. A sharp increment borer which extracts a 0.2-in. (nominal) diameter core shall be used. When sampling for assay purposes, the core diameter shall be within a tolerance of plus or minus 0.02 in. The borer shall be calibrated at least once a month, as described in Section 5.95 of AWPA Standard M2-79 'Inspection of Treated Timber Products'. Boring shall be done with an increment borer kept free from rust, pitch or preservative.

Borings to comprise a retention sample shall be taken from pieces which represent as nearly as practical an equal proportion of the different size pieces in the charge. Representative pieces to be bored shall be further selected on the basis of other significant factors such as seasoning and location in the charge. For example, the number of seasoned pieces selected shall be proportional to the total number of seasoned pieces in the charge. When material is retreated in a charge with untreated material, borings from the retreated material shall not be included in the assay samples.

The number of borings per charge for retention samples shall be

Creosote solutions - 48
Pentachlorophenol - 20
CCA and ACA - 20

The sampling zone shall be from 0.0 to 0.6 inches from the surface.

When there is an insufficient quantity of material in the charge to obtain, with one coring from each piece, the required size sample for the assay, an equal number of additional borings shall be taken from each of the pieces already bored. The procedure listed in Section 5.96 of AWPA Standard M2-79, shall be used in securing increment borer cores for assay purposes, and bit calibrations.

Care must be used to avoid checks and knots when boring. If the core contains a resinated portion, if the boring intercepts a check or other irregularity within the zone to be assayed, if the outer end of the core is considerably slanted, or if the core is broken or dropped, it shall be replaced with a new boring taken from the same piece close to the original boring and in the same line of grain. Cores should not be touched by the fingers in the section to be assayed.

In order to determine penetration of material, representative pieces shall be selected from different locations in the charge, with consideration to variation in size, seasoning and timber characteristics. For charges of sawn material which require minimum heartwood penetration in addition to percent of sapwood, borings shall be taken from heartwood faces and sapwood faces in the approximate proportion of heartwood and sapwood faces in the entire charge.

In sawn material, borings to determine preservative penetration of sapwood should be directed toward the center from the side with the most sapwood. The maximum penetration required on any piece of sawn material shall be no greater than half the width of the piece if the boring is taken from the edge, or half the thickness if the boring is taken from the face of the piece.

The number of cores sampled for penetration in each charge shall be 20, if 80 percent of these meet minimum requirements the charge shall be satisfactory.

If the borer passes through an internal knot, check or shake, or if the core is crushed, broken or smeared with treating solution, so that the depth of penetration and sapwood thickness cannot be readily determined, the core shall be discarded. A second boring shall be taken in order to obtain a core physically suitable for accurate measurement.

When the first core taken is physically satisfactory but the preservative penetration is insufficient, the piece being tested shall be rejected without any further boring of the piece.

Except as modified below, the depth of penetration shall be the distance from the outer end of the core to the first untreated annual ring and shall include only that portion of the innermost ring plainly showing preservative. An annual ring shall be considered penetrated if any portion of that ring is penetrated. The measurement shall be made to the nearest one-tenth inch. Cores should be split lengthwise from the inside to outside face and penetration measured on the cut face. The penetration measurements shall be made promptly after the removal of the core.

The depth of penetration in material treated with colorless solution shall be determined in accordance with AWPA Standard A3.

In red oak, the number of annual growth rings in the core and the number of rings containing preservation shall be counted. The latter divided by the former times 100 will give the percentage of rings penetrated, and preservative in any pore or vessel of an annual ring shall class that ring as penetrated. In case of doubt, the core shall be split or cut crosswise through the springwood. The percentage of rings penetrated in any charge of red oak shall be determined by totaling the individual percentages and dividing their sum by the number of measurements.

The thickness of the sapwood shall be measured on all cores where a percent of sapwood to be penetrated is stipulated. Sapwood measurement shall be to the nearest one-tenth inch. With timber species or individual pieces not having a sharp demarcation in color between the heartwood and sapwood the sapwood thickness shall be checked with indicators as described in Section 5.51 of AWPA Standard M2-79.

All increment holes shall be promptly plugged with treated, tightfitting wooden plugs. Care should be used in selecting the proper diameter plugs, and in driving to avoid breaking the plug or splitting the piece. Plugs need not be driven to the bottom of the bore holes.

A.5.5. Records - Copies of treating records, analysis records and other records that may be necessary to determine conformance with this specification shall be made available to Department of Transportation personnel or their designated representatives upon their request. Required information shall be that listed in Part 7.2 of AWPA Standard M2-79. These records shall be retained by the plant for five years from date of material shipment.

A.5.6. Independent inspections - The Department of Transportation may inspect the material or call for a non-departmental inspection to verify that it meets these specifications.

B. PRESERVATIVE TREATMENT OF WOOD PRODUCTS

B.1. Scope

This specification covers the wood preservatives and treatment methods by pressure processes of wood guardrail posts and blocks.

B.2. Preservatives

The materials shall conform to the appropriate current AWPA standard(s) as listed below:

MATERIAL	STANDARDS
Creosote and Creosote Solutions	P1, P2, P3, P4
Pentachlorophenol	P8, P9
Chromated Copper Arsenate (CCA) and Ammonical Copper Arsenate (ACA)	P5

B.3. Treatment Methods

Wood for guardrail posts and blocks shall be treated to conform with current AWPA Standards C1 'All Timber Products - Preservative Treatment by Pressure Processes', and C2 'Lumber, Timbers, Bridge Ties and Mine Ties - Preservative Treatment by Pressure Processes' and ASTM Standard D 1760 'Pressure Treatment of Timber Products', including the following requirements:

B.3.1. Conditioning - Material may be conditioned by air seasoning, kiln drying, Boulton drying, steaming and heating in preservative except as limited below.

Material that is air seasoned or kiln dried shall have an average moisture content not exceeding 19 percent before treatment.

For Douglas-fir steaming shall only be permitted for CCA and ACA treatments. When using CCA, steaming of southern pine, red pine and jack pine shall only be permitted to thaw frozen or ice coated material. In addition when using CCA, material must be removed from the cylinder and allowed to cool to 120^{O}F

or below after steaming and before preservative is applied. When steam conditioning, the maximum temperature indicated in the Table below shall not be reached in less than one hour. If a vacuum is applied after steaming, it shall be a minimum of 22 inches of mercury at sea level.

When conditioning by heating in preservative, the solution shall cover the material. Maximum temperatures allowed are given in the Table below. Conditioning by heating in water-borne preservatives (CCA, ACA) shall not be permitted.

SPECIES	CONDITIONING METHODS ALLOWED	STEAMING		HEATING IN PRESERVATIVE	
		MAX. TEMP. (^{O}F)	MAX. DURATION (hours)	MAX. TEMP. (^{O}F)	MAX. DURATION (hours)
Hard Maple	Only air drying permitted				
Other Hardwoods[+]	No steaming			220	No limit
Southern Pine	All	245	17	220	No limit
Other Softwoods[x]	All	240	6	210	6[*]

[+]Red oak, white ash, white heartwood beech, elm

[x]Red pine, jack pine, balsam fir, Douglas-fir, hemlocks

[*]If seasoned material used, otherwise no limit.

B.3.2. Treatment - Material shall be treated by such processes and under such conditions as to achieve the retentions specified in Section B.4. and the penetrations in Section B.5.

Pressure shall be increased to at least the minimum but not higher than the maximum levels given in the Table below, and shall be maintained until the desired volume of preservative has entered the wood.

The temperature of the preservative during the entire pressure period shall not exceed the following maximum temperatures:

Creosote and Pentachlorophenol	210°F
Ammoniacal Copper Arsenate	150°F
Chromated Copper Arsenate	120°F

If permitted as shown in the Table below an expansion bath or a final steaming may be applied after completion of the pressure phase, when treating with creosote or pentachlorophenol.

SPECIES	PRESSURE		EXPANSION BATH	FINAL STEAMING*	
	MIN (psi)	MAX (psi)	MAX. TEMP (°F)	MAX. TEMP. (°F)	MAX. DURATION (hours)
Red Oak	125	250	Not permitted	240	1
Other Lake States Hardwoods	125	200	Not permitted	240	1
Jack Pine Red Pine	75	175	220	240	2
Southern Pine	75	200	220	240	2
Douglas-fir Hemlocks	50	150	220	240	2

*If seasoned material is used post steaming at 225°F for a maximum period of 15 hours shall be permitted.

B.4. Retentions

The minimum retentions in pcf for guardrail posts and blocks are listed below. Retentions shall be determined by chemical assay with samples taken according to Section A.5.4.

PRESERVATIVE	RETENTION
Creosote Solutions	12.0
Pentachlorophenol	0.60
CCA or ACA	0.60

If blocks are treated along with posts, retention of the charge shall be determined by assay of borings from posts.

B.5. Penetration

The minimum penetration requirements for heartwood and sapwood are listed below. Samples shall be taken according to Section A.5.4.

SPECIES	MINIMUM PENETRATION	
	IN INCHES OF HEARTWOOD	IN PERCENT OF SAPWOOD
All Species*	0.5	90

*For red oak, 65 percent of the total annual rings shall be penetrated, however, if this is not possible, properly conditioned wood may be treated to refusal.

B.6. Field Treatment

The preservative used for field treatment shall be the same as that originally used in treating the material.

B.6.1. Creosote and creosote mixtures - Creosote for field treatment of material originally treated with creosote or any creosote solution shall meet the requirements of Standard P1. Creosote should be between 150°F and 200°F when applied. Where particularly heavy coatings are required, a suitable plastic compound can be prepared by mixing 10 to 20 percent of creosote and 90 to 80 percent of pitch.

B.6.2. Oil-borne preservatives - Pentachlorophenol used for field treatment shall be in a solution prepared with solvent conforming to AWPA Standard P9. The pentachlorophenol concentration shall be 5 percent, or more, of the solution weight. Preparations for field treatments, made by manufacturers of these preservatives, can be specified.

B.6.3. Waterborne preservatives - Concentration of water-borne preservatives shall be a minimum 3 percent in solution.

B.6.4. Method of application - All cuts, holes and injuries of the surface of treated material shall be field-treated by brushing, spraying, dipping, soaking or coating.

Care should be taken to ensure that all injuries, such as abrasions, nail and spike holes, are thoroughly saturated with the field-treating solution. Holes bored in pressure-treated material shall be poured full of preservative. Horizontal holes may be filled by pouring the preservative into them with a bent funnel.