FINAL REPORT

PROBLEMS WITH THE PERFORMANCE OF WOODEN NOISE BARRIERS

by

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Graduate Research Assistant

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies)

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ABSTRACT

In September 1984, the Research Council was requested by the Virginia Department of Highways and Transportation to conduct an investigation into the problems experienced with wooden noise barriers. Some of these barriers warped even before construction was completed, and gaps and splits were noted within a short period of time. A questionnaire survey of eleven states that have constructed noise barriers revealed that these problems are widespread. An analysis of the responses to the questionnaire has led to three basic recommendations. The first of these recommends upgrading the overall quality of the material used in the construction of the wooden barriers. This includes raising the grade of wood required and lowering the moisture content, as well as specifying maximum moisture contents for the wood both before and after treatment. Next, it is recommended that simple changes be made in the design of barriers. Technical alterations such as additional braces, fitted joints, overlapping joints, and angled nailing would help preserve their shape. Also, the use of plywood rather than planks would minimize the number of joints. The third recommendation is that specifications be strictly enforced. Wood, with its tendency to warp and shrink, must be handled correctly if it is to provide a noise barrier that will be effective over a long period of time.

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INTRODUCTION

Some of the wooden noise barriers constructed in Virginia began to show deterioration in the form of warping and cracking within a short time of being installed. Noise barriers constructed with various materials were expected to require little maintenance, yet the wooden barriers were found to need substantial repairs after only a few years. It was decided that if these barriers were to compete economically with concrete and steel barriers, the problems had to be defined and solutions identified. It was for that purpose that the work reported here was undertaken.

QUESTIONNAIRE SURVEY AND LITERATURE REVIEW

The first step in the study was to determine how widespread the problems were, and to do this a questionnaire survey was made of the 11 states most active in barrier construction and a literature review was conducted. The information gained through these activities is presented under the following subheads.

General Performance

The responses showed that the problems with wooden noise barriers were the standard rather than the exception among the states surveyed.* Warping and shrinkage were reported to cause gaps between planks and separation of the layers in plywood panels. Also, the use of wet wood was reported to lead to problems with the fasteners as well as with the dimensional stability of the barrier; butt-jointed planks were found to warp and separate and, in some cases, tongue and groove lumber was noted to separate when shrinkage occurred.

*A list of the states participating in the survey is found at the back of the report.

Approximately half of the states surveyed listed maintenance or durability as a factor in their selection of the material to be used in the construction of a barrier. None had performed a life-cycle cost analysis; all had considered only the initial costs and assumed that wooden barriers would have the same low maintenance requirements as those made with steel or concrete. In general, all types of noise barriers are expected to last a few decades, or approximately as long as the road they parallel. California assumes a 50-year service life if proper preservation procedures are followed. Yet, wooden noise barriers have frequently required repairs before construction was completed. Several states reported noticeable warping of the wood prior to installation, some within days of delivery. Almost all the states responding noted that their wooden barriers required much more maintenance than was expected. Oregon has yet to build any wooden noise barriers because of the short service life and high maintenance costs expected for these barriers under the prevailing climatic conditions there.

The performance of a wooden noise barrier relies upon both the quality of the materials and the design. Wood may be dry, well-preserved and of a good grade and still perform poorly in a poor design. The main comments relating to design offered by the respondents to the survey concentrated on such factors as the dimensions of lumber used, the overall design of the barrier, and the location and type of fasteners. These are discussed below.

Dimensions of Lumber

North Carolina cited one of the major problems in writing specifications as determining the thickness of the lumber to be used. An Atlantic Wood Industries report advised the use of 2 in. (5.08 cm) thick planks, and a representative from the Southern Forest Products Association stressed a minimum thickness of 1 in. (2.54 cm).(1) For sound walls, Koppers also recommended the use of 2 in. (5.08 cm) thick lumber.(2) The thickness of the boards should determine their width. A basic rule of thumb is that the width should not exceed eight times the thickness. This helps minimize warping. One state mentioned improving its design by using a reduced number of wide planks. If the width of the board is increased beyond eight times its thickness, there is a trade-off between fewer potential gaps and increased warping.

One way to minimize the number of gaps is to use laminated wood. Since laminated panels up to 4 ft. (1.22 m) wide are available, there will be only a fraction of the joints created with 8-in. (20.32 cm) planks. Plywood panels are designed to be used in large widths without undue warping. The grains of adjoining plies are formed at right angles to give strength in both directions. Thus, while solid wood is weak across the grain, plywood is dimensionally stable both along and across

the grain. Laminated wood members, usually constructed from nominal 1 in. (2.54 cm) and 2-in. (5.08 cm) lumber, are beginning to be used in the construction of noise barriers. While the grains of the layers all run parallel, glue-laminated timbers have proven to be dimensionally stable.

Design Details

Two common means of constructing wooden barriers that will maintain their shape and tight fitness is to use batten boards and tongue and groove lumber. Batten boards have been added to existing barriers in different states after warping began. Batten boards can be used as lateral supports placed at right angles to the planks or they can be placed vertically to lend bracing support or to cover the joints between planks. Connecticut recommends 2 x 4 in. (5.08 cm x 10.16 cm) battens nailed at right angles to the planks. In the design by Koppers, the battens range from 2 x 4 in. (5.08 cm x 10.16 cm) to 2 x 6 in. (5.08 cm x 15.24 cm) and 2 x 8 in. (5.08 cm x 20.32 cm).

The tongue and groove pattern provides maximum tie-in between planks and panels. Both Wisconsin and North Carolina stressed the advantages of using tongue and groove lumber. North Carolina even stated some concern over specifying the depth of the tongue and groove joint required. Connecticut listed the use of a larger than conventional tongue and groove joint. In its specifications, Connecticut mandates a tongue and groove joint resembling that in Figure 1.

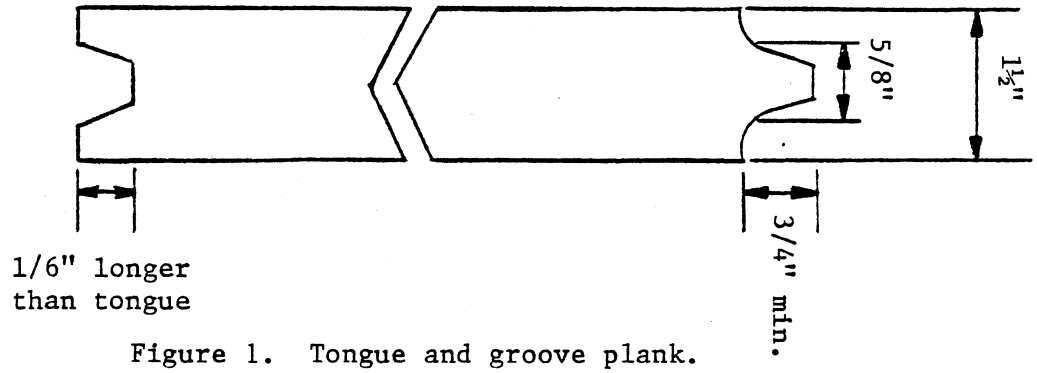

Figure 1. Tongue and groove plank.
Note: 1 in. = 2.54 cm.

Tongue and groove joints have proved to be an improvement over butt-joints but they do not eliminate all problems with shrinkage. They help keep the planks or panels in place, but wood that has not been dried properly will undergo severe shrinkage and the fitted joints will separate. Butt-joints should be used only where vertical braces will provide support.

In a few of the various designs for wooden noise barriers, the sections were overlapped to eliminate the possibility of openings occurring with warping. The joints between planks and panels have proved to be the weakest spot in the barrier. Missouri, in its plan details for a wooden barrier, overlaps the sections the width of the post and uses horizontal tongue and groove planks with the groove down. Connecticut has a design with sections overlapping a total of 2 ft. (0.61 m) on each side of the post. Connecticut uses the basic design shown below for both its timber and plywood barriers.

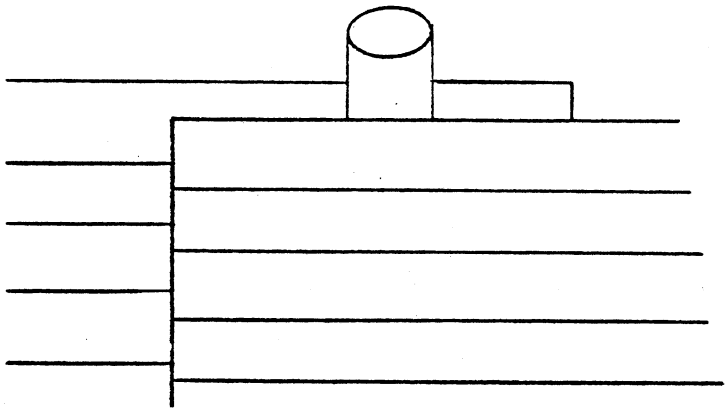

Figure 2. Noise barrier wall which overlaps sections.

The Koppers Company recommends a similar design with the sections overlapped at the posts.

Some states use caulking to seal the cracks between planks and panels, but this practice causes problems when the caulking dries out. Once it has dried out, it shrinks and begins to disintegrate. It has been noted to become unsightly and people living behind one barrier complained of its appearance. The caulking needs to contain silicon to prevent it from drying out. Also, batten boards should be used in conjunction with caulking whenever possible to provide double protection.

Fasteners

The location and type of fasteners used and the method of installing them can all affect the performance of the wooden noise

barrier. Galvanized nails and bolts should always be specified because conventional nails and fasteners can be corroded by the preservative used in the wood, especially when it is a waterborne preservative. The corrosion not only leaves rust stains but can also cause separation of the wood. Popping and pull-away of nails have been common, partly because of changes in the moisture content of the wood. Dry wood retains its dimensional stability and thus puts less pressure on the nails. The withdrawal resistance of nails driven into wood that has undergone changes in moisture content can be as little as one-quarter that of nails tested soon after having been driven.(3)

Nails and fasteners will also perform better if lead holes are drilled for them. If possible, the lead holes should be slightly smaller than the nails used to help increase the withdrawal resistance of the nail and reduce the chance of the wood splitting. Connecticut employs lead holes with the plywood noise barrier. The withdrawal resistance of nails is less with plywood than with equivalent sized solid wood. Plywood holds one advantage for nailing in that nails close to the edge are less likely to cause splitting than with solid wood.(4) Design specifications should require staggered nailing patterns so as to minimize the chances of the wood splitting. Other basic recommendations include nailing perpendicular to the grain of the wood, as cross-grain nailing substantially increases the holding power of the nails. Also, toe-nailing increases the holding power of nails by driving them in at an angle.

Grade

Southern pine and Douglas fir, the two types of lumber used under Virginia specifications, also are the main types used by the majority of the states interviewed. Douglas fir is graded according to the rules published by the Western Wood Products Association and southern pine by the Southern Pine Inspection Bureau. They are graded on the same characteristics that affect strength and stiffness. The grade quality is determined by minimum fiber stress requirements and the frequency of such characteristics as checks, knots (with their maximum size stated), pitch streaks, stain, etc. Most states currently list the minimum grade requirements for their posts and planks in their specifications although a few leave it to the project engineer to determine the grade of lumber required.

There are some variances in the grades required by the different states and the lumber company associations. For instance, Virginia requires kiln dried southern pine no. 1 dense stress rated or Douglas fir with a minimum fiber stress in bending of 1,550 lb./in.^{2} (10,686.87 kilo Pa) for its posts and kiln dried southern pine no. 2 or Douglas fir with a minimum fiber stress in bending of 1,100 lb./in.^{2} (7,584.23 kilo Pa) for its boards. (According to the Southern Pine Inspection Bureau,

the dense classification applies to that southern pine lumber grown predominantly in the southeastern United States, which has experienced a faster growth rate as seen by the number of annual rings per inch and percentage of summerwood compared to springwood).(5) Most states request a higher grade and/or higher F_b reading (fiber stress in bending) for their posts than for their boards. Missouri allows southern pine no. 2 for both its posts and its planks. Texas provided one example of noise barriers built from construction grade materials including no. 1 boards and another where the posts were of no. 2 lumber.

Several states mentioned raising the grade requirements as part of their plan to improve the performance of their wooden noise barriers. In inspecting a wooden noise barrier in Virginia that was experiencing severe warping, a representative of Atlantic Wood Industries criticized the grade of wood used and advised using no. 1 stress rated for posts and no. 1 for the boards.(6) While most posts used are grade no. 1, heeding this advise would entail increasing the grade requirement for the boards. While grade no. 2 is usually recommended for all types of construction, grade no. 1 is even better for noise barriers; because of the strict limitations on knots, it performs well under outdoor conditions.

Plywood is also graded on strength and appearance. It is first divided into five groups depending upon strength, with the strongest group being group I. Appearance grades, describing the front and back veneer, are applicable when the plywood is exposed. California requests sawn texture or C-C group I, exterior grade. The veneer grade C is the lowest grade of veneer permitted for exterior plywood. Veneer grade C allows knotholes of 1 in. and limited splits. C-C implies that the veneer grade C is the minimum allowed for both sides. Virginia requires C-C plugged EXT, the grade recommended for use under severe moisture conditions, with "plugged" referring to the holes being filled. Both of these grades are recommended by the National Forest Products Association in their guidelines for wooden noise barrier specifications.

Moisture Content

Before wood is dried, the amount of moisture present in the wood can equal up to 200% of its oven-dry weight.(7) The moisture content is generally stated as a percentage of the oven-dry weight. Wet wood should not be utilized unless shrinkage and dimensional changes can be tolerated in the structure. Problems with moisture content have also caused fasteners to loosen and gaps to appear. Because these occurrences are extensive, the maximum moisture content allowed has been one of the first requirements reviewed by the states in their attempt to halt these problems. In wooden noise barriers there is an obvious need to minimize shrinkage in order to prevent noise leaks.

The moisture content of wood is usually determined by weighing the wood when wet and then again after it has been dried in an oven at approximately 212°-220°F (100°-104°C). Drying is terminated when the wood stops losing moisture and its weight stabilizes. The oven-dry weight is also referred to as the constant weight. Another important weight is the fiber saturation point. In wood, there is moisture in both the cell cavities (free water) and in the cell walls (bound water). In the drying process, the moisture first leaves the cell cavities, and the fiber saturation point is reached when the cell cavities are empty of moisture and the cell walls remain full. The fiber saturation point occurs at around 30% moisture for almost all woods, and no shrinkage will occur until it is reached.(8) If the moisture content is reduced below 30%, then the cell walls will lose their moisture and the wood will begin to shrink. It will shrink approximately 1/30 in size if the moisture is reduced 1% below the saturation point.(9) Because this shrinkage rate is constant, by the time a 15% moisture content is attained (the moisture content required by the higher grades of wood), approximately 1/2 the possible shrinkage will have occurred.

The traditional method of determining moisture content by oven-drying can be time-consuming and requires that the wood be cut. An alternative to oven-drying is to use moisture meters. Two types of electric moisture meters are available. Resistance meters measure the electrical resistance in direct current between two electrodes driven into the wood. Radio frequency power loss meters gauge the capacitance of the condenser created by the wood acting as the dielectric material. Some concern has been expressed over the precision of moisture meters on wet surfaces and their accuracy being limited to a moisture content of under 30%. Moisture meters are usually relied on to determine pre-saturation moisture contents within 1%. (10) Moisture meters can prove very useful for checking moisture content of wood upon its delivery.

The range of moisture contents for which moisture meters are reliable poses no problems for the wood used in noise barriers because the moisture content is usually specified to be 19%. Current southern pine grading rules allow a maximum moisture content of 19% for lumber 2 in. (5.08 cm) or less in thickness.(11) The vast majority of states which listed a maximum moisture content used 19%. Virginia specifications call for lumber to be kiln-dried to not exceed 19% upon delivery. Kiln-drying involves putting green lumber in a kiln where the humidity is high due to steam and the temperature starts off low. Gradually, the temperature is raised and the humidity lowered. Fans help circulate the air. Nowadays, most lumber is kiln-dried as opposed to air-dried, where it is stacked so as to let the air circulate and is left outside to dry. Some lumber is first air-dried and then kiln-dried to reduce expenses. In this case, the lumber is labeled PAD for partially air-dried. As mentioned earlier, lumber that has been dried to 15% maximum moisture is eligible for a higher design value.

Several states contacted mentioned lowering the maximum moisture content allowed as a solution to the warping of the barriers. States that have used a 19% moisture content have considered switching to a 15% standard. Most states did not specify different standards for plywood or glue-laminates. Connecticut requests a maximum moisture content for plywood and lumber of 16% for gluing in its plans for a plywood noise barrier. The American Institute of Timber Construction, in their Voluntary Product Standard for Structural Glued Laminated Timber, recommend a moisture content of 16% at the time of gluing, save when the laminated timber will experience a higher equilibrium moisture content in use. When such is the case, the pre-gluing moisture content may be increased to 20%.(12) As with its wood plank noise barriers, Virginia requires a 19% moisture content for its plywood that is to be glued.

Just as states need to be careful to state the moisture content requirement prior to gluing, it is important to state when the moisture content is to be taken on wood going into a plank noise barrier. The federal government's specifications acknowledge this factor and call for drying prior to treatment when wood is to be treated with oil-borne preservatives and its use does not allow shrinkage as with noise barriers. When sawn material is preserved with chromated copper arsentate (CCA) or any other chromium-containing preservative, then the wood must be dried to at least 25% moisture prior to treatment. Obviously, the moisture content prior to treatment will have a substantial effect on the success or extent of penetration of the treatment. North Carolina has changed its specifications from initially requiring a kiln-dried 15% standard after treatment to mandating a 19% moisture content before treatment, and if CCA is used (the only waterborne preservative North Carolina permits), it must be re-dried to 15%. Michigan recommends that lumber be kiln-dried to a lower moisture content than usual before being treated with CCA. A moisture content reading both before and after treatment should be required by a state's specification. The need for two tests is especially important as CCA becomes the preservative that is almost always used. Waterborne preservatives, with their ability to inject more moisture into the wood during the treatment, can reduce dimensional stability if the wood is not properly dried.

Pressure Treatment

Because of their outdoor exposure, wooden noise barriers require pressure preservative treatment rather than treatment with dip preservatives. The success of the pressure preservative treatment depends on several factors including the dimensions of the wood, its moisture content, the heating medium used, length of heating period, temperature reached, and the amount of preservative used.

There are two basic groups of preservatives: oil-borne preservatives, including creosote mixtures and pentachlorophenol solutions, and waterborne preservatives such as acid copper chromate (ACC) and the CCA. Both types have their advantages. The oil-borne preservatives do not add any water to the wood during treatment, as mentioned earlier, and thus drying after treatment is not required. Yet the waterborne preservatives are cleaner and safer to work with. Both types have been used by the states in treating their wooden noise barriers.

Among the oil-borne preservatives, pentachlorophenol has become more popular in recent years than creosote. Creosote was the preservative traditionally used by highway departments. It is the oldest commercial wood preservative and has an excellent record. Yet the use of creosote as a preservative has been discontinued because the newer preservatives are cleaner, have no odor, and can be painted. Of the states surveyed, Minnesota was the only one that listed the use of creosote oil as a preservative.

Michigan, Missouri, and Illinois allow only pentachlorophenol to be used. Pentachlorophenol solutions, which repel water and contain chlorinated phenols, can either be transported by heavy petroleum oils or dissolved in liquid petroleum gas (penta LPG). California requires pentachlorophenol to be employed, while Virginia specifies penta LPG as the only permissible pentachlorophenol solution. All the other states that specified which preservatives were permitted used the general name of pentachlorophenol. Missouri specified pentachlorophenol as the preservative to be utilized on planks and posts. Pentachlorophenol in heavy oil is like cresote in that it does not leave a readily paintable surface. Penta LPG is instilled in the wood through liquified petroleum gas, and once it is implanted, the gas evaporates and the pentachlorophenol is left in the wood as a dry, crystalline salt.(13) One big advantage of penta LPG is its ability to be painted. Wood that has been treated with pentachlorophenol in light or volatile solvents can be painted or stained and thus retain its natural color.(14) Paint is also beneficial in that it seals the wood and helps protect against weathering.

Pentachlorophenol in heavy oil will eventually change the wood's color from brown to silver. Creosote results in a color of dark brown to black as exemplified by creosote treated railroad ties and bridges. The waterborne preservative CCA is green but can be painted and is usually required to be painted in a state's specifications. Virginia waives its requirement of the use of a stain on treatment wood when the preservative is pentachlorophenol although as stated earlier, only penta LPG is allowed and it is paintable.

CCA is currently the most commonly used waterborne preservative. Virginia is the only state that mentions two waterborne preservatives, CCA and ACA, in its specifications. CCA's popularity is attributable in

part to its being clean and odorless as well as safe to use. Moreover, it does not leach like the older oil-borne preservatives. Several states listed CCA and pentachlorophenol as the only two permissible preservatives. Minnesota allows CCA, except for when the wood is Douglas fir. For Douglas fir, with its thick sapwood, greater precaution is needed in the preservation treatment. Sapwood is more vulnerable to weathering than the inner heartwood. Many states, as well as the National Forest Products Association, recommend incising Douglas fir to aid the penetration of the preservative.(15)

The National Forest Products Association advises that for ground-contact noise barriers only the waterborne preservatives CCA, ACA, and ACC be used.(16) The exclusion of oil-borne preservatives is most likely due to their association with leaching. Because pentachlorophenol is toxic to fungi and insects there is concern that the leaching of ground-contact barriers treated with this preservative may adversely affect groundwater. However, the federal specifications, as well as those of the states, allow pentachlorophenol to be used with ground- contact noise barriers.

A state can ensure the quality of the pressure treatment by following the standards recommended by the American Wood Preservers Association. These standards address acceptable plant operating standards, including the minimum vacuum, pressure, penetration requirements, maximum steaming and temperature allowances. The Association also has tables which list the retention by assay requirements for the various kinds of preservatives according to the different types of materials and their uses. These standards and tables can provide guidelines for the states and thus save them the bother of writing detailed specifications on the treatment process. Several states, including Minnesota and Illinois, do refer to these standards in their specifications.

SUMMARY

The basic problem with a wooden noise barrier is that it deteriorates under environmental stress. The structure is subject to no unusual load stresses other than the wind stress resulting from the resistance provided by its large sail area. Problems arise because of wood's natural tendency to change size and shape. Problems of dimensional change have been found at joints between adjacent wood members. Two types of wood products, wood planking and laminated wood, present two types of problems and require different solutions. Wood planking has a drawback in its practical limit on the width of the board (again no greater than eight times the thickness). Therefore, a large sound barrier must be constructed from many planks with many joints, each of which potentially represents a problem of separation. This problem can be alleviated by designs that stabilize the adjoining

surfaces, i.e., by the use of overlapping or interlocking joints (tongue and groove) or batten boards, or by the careful placement of structural members to control movement.

Laminated products, such as plywood, seem to have certain inherent advantages over planking. The larger size results in many fewer joints at which separations can occur. In building up the laminations in plywood, the direction of the grain is alternated in successive layers to provide strength. Caution must, however, be exercised to choose the proper material (e.g., the type of glue used), protect the seams to minimize moisture penetration to open wood grain ends, seal off the plywood surface, select the appropriate type and placement of support members and fasteners. Dimensional change can also be minimized by controlling the moisture content. Reducing the moisture content decreases the shrinkage for both planks and laminated panels. Upgrading the quality of the wood is another simple way of minimizing flaws such as cracks, splits, and knots which hasten deterioration.

Basically, if wood is to be successfully used for the construction of noise barriers, good design practices must be followed. Surveys can identify the type and degree of problems encountered and thus reveal partial solutions or corrections. Transportation departments should make visual checks and employ moisture meters to ensure proper adherence to the specifications. They need to dispel the notion that they are lax in enforcing their specifications if the quality of the in-place wooden noise barrier is to match that of the designed barrier. The basic risk profile analysis that follows provides a list of the main considerations that need to be reviewed before the construction of a wooden noise barrier.

Basic Risk Profile Analysis

		Low	High
1.	Design (structural support)	good	poor
2.	Type of material	panels	planks
3.	Type of wood	dimensionally stable	dimensionally unstable
4.	Grade of wood	high	low
5.	Moisture content (pre-and post-treatment	<15%	>19%
6.	Application of preservative	effective	ineffective
7.	Surface sealant	sealed	unsealed
8.	Design of fasteners (location)	effective	ineffective
9.	Fasteners (durability)	galvanized	uncoated
10.	Inspection of material and design quality	strict	lax

RECOMMENDATIONS

The investigation for this report has revealed the following three basic approaches to correcting the dimensional instability that has been noted in wooden noise barriers:

1. Upgrade the quality of material

2. Employ design adjustments

3. Resort to less sensitive barrier types.

The first solution, improving the quality of the wood, has been the most popular one tried by the states so far. Many states recommend reducing the moisture content and increasing the grade requirements as ways to reduce shrinkage and warping. Equally important is the need to require content tests for moisture, both before and after preservative treatment, especially given the widespread use of CCA.

Technical solutions, in the form of adjustments in designs, can lend support to the barrier's form and reduce unwanted movement. A plywood noise barrier, in comparison to a wood plank noise barrier, has fewer joints and thus less potential for noise leaks at the joints. Whether panels or planks are used, tongue and groove joints and batten boards help keep the wood in place and reduce separations. Other minor corrections include the use of overlapping designs, additional braces, appropriate fasteners, and correct nailing patterns.

The last recommendation is offered as an alternative if it appears likely that specifications will not be enforced. If time and effort cannot be allocated to checking the quality of the material and the construction practices, then less sensitive barrier types, such as concrete, that have fewer variables should be considered. Wooden noise barriers have the potential to be aesthetically pleasing and effective noise blocks if adequate precautions are taken in their construction.

Survey Participants

California

Connecticut

Illinois

Michigan

Minnesota

Missouri

North Carolina

Oregon

Texas

Washington

Wisconsin

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