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EXPLORING THE STRUCTURAL DESIGN, COST AND DURABILITY OF MASS TIMBER NOISE BARRIER FOR HIGHWAY APPLICATIONS

Weichiang Pang[1], Michael Stoner[2], Harsh Bothra[3], Laura Redmond[4], Patricia Layton[5]

ABSTRACT: The sound generated from vehicular traffics on highways cause noise pollution. To deal with the traffic noise coming from these highways, noise barriers have been erected across major highways. Currently, the primary material used for highway noise barrier is concrete. This paper explores the use of mass timber as highway noise barrier from a structural design, cost, and durability perspective. The structural design of mass timber noise barrier to resist wind and earthquake loadings will be discussed. Cost comparisons between noise barriers constructed using pre-cast concrete panels and cross-laminated timber panels indicate that mass timber noise barrier is cost competitive. As part of this study, a prototype noise barrier was constructed for evaluating the constructability of the proposed design and for monitoring the moisture performance in an exposed weather environment.

KEYWORDS: Cross-Laminated Timber, Noise Barrier, Highway

1 INTRODUCTION

Highways are some of the biggest causes of noise pollution in the United States of America. To deal with the traffic noise coming from these highways, noise barriers have been erected across major highways. Several materials are used for sound barriers, including steel, wood, concrete, composites as well as insulating wool. These materials help to abate noise via reflecting, diffusing or absorbing sound waves. Concrete and steel are the most common materials for highway noise barriers. However, wood products are known to be more environmentally friendly than concrete or steel. Additionally, the use of wood products is also considered to be more aesthetically appealing to most motorists. Wood products also have the benefit of being lighter and thus easier to transport and erect compared to concrete and steel.

The design of a highway noise barrier is typically based on the structural design, sound efficiency, long-term durability, and material and construction cost associated with implementation [1]. A comparative study on the performance of wood highway sound barriers revealed that wood barriers (solid sawn or glue-laminated timber) which were properly installed, designed, and detailed could be designed to achieve similar acoustic performance to precast concrete panels [2]. Given that most mass timber elements are thicker than those measured in this study, it was assumed that a sufficient acoustic performance could be achieved by utilizing mass timber elements.

In this study, wood products, specifically Cross-Laminated Timber (CLT) and Mass plywood Panel (MPP) are considered as potential materials for noise barriers. A representative noise barrier design is presented and compared to typical concrete construction with respect to cost and carbon footprint. Additionally, a prototype sound barrier was constructed and instrumented for long-term moisture monitoring.

2 DESIGN OF MASS TIMBER NOISE BARRIER

Cross-laminated timber (CLT) is made from lumber boards that have been glued to each other forming layers. Structurally, mass timber exhibits high bending strength and has lower weight than a concrete or steel system. A CLT noise barrier was designed considering the wind load and seismic loads across the US following the design procedure of AASHTO (American Association of State Highway and Transportation Officials) [2] and FHWA (Federal Highway Administration) [3]. The panel span width was limited to 6m (20 ft) based on an attempt to maximize the efficiencies of current CLT fabrication facilities and to produce the easiest construction sequence. The analysis results showed that 3-ply CLT panels could withstand winds of up to 80.5 m/s (180 mph), however larger steel posts were required. Seismic analysis was

[1]Weichiang Pang, Professor, Clemson University, USA, wpang@clemson.edu
[2]Michael Stoner, Research Assistant Professor, Clemson University, USA, mwstone@clemson.edu
[3]Harsh Bothra, Project Engineer, Reackon Concrete Pvt Ltd, USA, hbothra@reackon.com
[4]Laura Redmond, Assistant Professor, Clemson University, USA, lmredmo@clemson.edu
[5]Pat Layton, Direction, Clemson University Wood Utilization + Design Institute, USA, platyon@clemson.edu

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carried out and a smaller W10x33 steel post was shown to be sufficient for the very high seismic region with an S_s value of 2.25g. Table 1 shows the design criteria for the CLT noise barrier.

***Table 1**: Design Criteria of CLT highway noise barrier*

Design Criteria	*Value*
Design Wind Speed	80.5 m/s (180 mph)
Wind Pressures	2.9 kPa (60 psf)
Spectral Response Acceleration @ 0.2s (S_s)	2.25 g
Peak Ground Acceleration	0.9 g
Steel Post Design	W10 x 33
CLT Panel Design	3-ply V3: 105 mm (4.13 in)

Figure 1 shows the top and isometric views of the noise barrier with two 3-ply CLT panels of 6.1m x 2.4m (20-ft. x 8-ft.) stacked vertically along the long edge and W10x33 structural steel posts. The installation of the noise barrier begins with typically installed foundations concrete foundations. Structural steel posts are installed with four cast-in-place anchor bolts. Figure 2 shows the details of connections used to fasten the CLT panels to the steel posts. After the steel posts are bolted the foundation, shim angles and seating angles are fastened to the post using bolt connections, the CLT panel is then slid into the post from the top (Figure 3). In this example, a second panel is added on top of the first and jointed using a lap joint connection with wood screws.

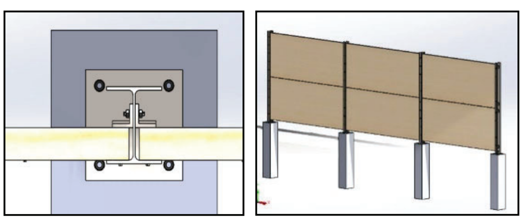

***Figure 1**: Top View of 3-D Model (left), Isometric View of 3-D Model (right)*

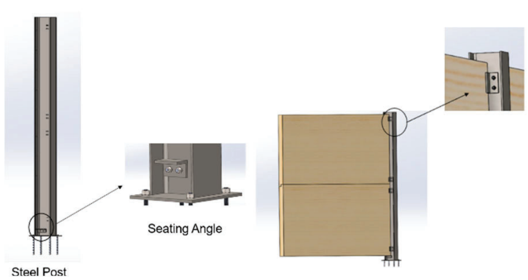

***Figure 2**: Seating Angle (left), Shim Angle (right)*

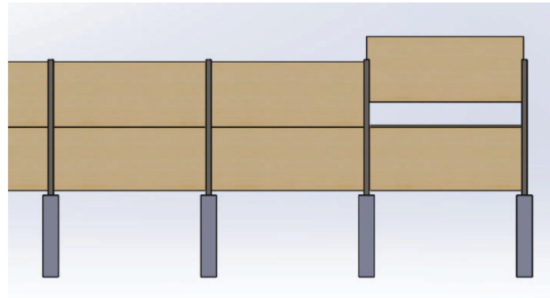

***Figure 3**: Installation of CLT Noise Barrier.*

Additional improvements in the structural design to further increase the structural efficiency, reduce the amount of non-wood components, reduce the number of concrete foundations, and reduce the time for construction of the highway noise barrier system using CLT.

3 COST COMPARISON AND ENVIRONEMNTAL IMPACTS

Factors such as the environmental impacts, costs, waste management, and aesthetics play a role in the selection of what construction materials will be used in a construction project. The use of wood and its different forms and products has substantially reduced environmental pollution and greenhouse gas emissions within the building sector [3]. A carbon emission study on a 6m x 4.9m x 10.4cm (20' x 16' x 4.125") timber panel used as the primary structural component in a highway noise barrier and an equivalent size concrete panel was carried out during this research. It was found that 740 kg (1630 lbs) of CO2e is emitted during the construction process of the concrete panel whereas 2040 kg (4500 lbs) of CO2e will be stored if a CLT panel is used. Therefore, adoption of mass timber noise panels will result in a reduction of up to 2780 kg (6130 lbs) of CO2e for every 6m (20 ft) of noise barrier. These environmental calculations did not include the environmental impacts of the foundations, steel posts, or transportation of such elements.

***Table 2**: Cost Analysis Summary of 800m Case Study*

	CLT	Precast Concrete
Panel Dimensions	6 m x 2.4 m	3 m × 2.4 m
Distance From Project Site	400 km	160 km
Material Cost	\$185.67/m^2 including posts and treatment	\$123.79/m^2 including posts
Total Material Cost	\$ 644,554	\$ 485,760
Transportation & Installation cost	\$ 91.49/m^2	\$145.31/m^2
Total Project Cost	\$1,003,594	\$1,056,000

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A cost study for a project in 2020 in Florida was conducted for a representative CLT noise barrier compared to a concrete noise barrier using construction cost data collected for typical concrete noise barriers. The cost study was performed on for an 800m (1/2 mile) length of noise barrier. The factors considered in the cost study include the material cost, transportation cost, and installation cost described in detail in Table 3.

***Table 3**: Detailed Cost Breakdown of Case Study*

	CLT		Precast	
	per m^2	total	per m^2	total
Material	$1.60	$728,640	$1.07	$485,760
Transport	$0.03	$13,563	$0.06	$25,575
Install	$0.76	$345,477	$1.20	$544,665
Total	$2.39	$1.00 mil	$2.32	$1.06 mil

Reductions in the transportation cost for the CLT noise barrier were due to the reduction in weight per panel resulting in 14 truckloads versus 66 truckloads for the precast panels. Additionally, reduction in the installation cost was due to the reduction in foundations and lifting equipment required for the CLT noise barrier. Additional cost was included for the treatment of the CLT panels, though the maintenance cost was not included as the extent of such costs was unknown at the time of the study.

It was determined for the 800m (½ mile) case study length, a cost reduction of around 5.2% was achieved. The saving mainly comes from transportation and installation costs as wood is about 1/5 of the weight of concrete.

4 MOCK-UP CONSTRUCTION AND MOISTURE MONITORING

A 2.4m x 2.4m (8 ft x 8 ft) prototype CLT noise barrier was built and installed at the Clemson University Built Environment Laboratory located in Pendleton, South Carolina. Two different Sansin coatings applied on the CLT panel to protect the panels from UV and moisture (Figure 4). Each coating was applied in two coats per the manufacturer recommendation with sanding of the surface between each coat. The total thickness of the coating after both layers were applied was 0.3 mm (11-12 mils).

***Figure 4:** Application of UV and moisture protection*

The prototype noise barrier was constructed in accordance with the design procedures mentioned (Figure 5). The panel was instrumented with temperature and moisture sensors to measure the moisture fluctuation in the panels. SMT Research sensors were used to instrument the prototype noise barrier and obtain moisture, temperature, and rainfall data. In total, 18 moisture sensors, 2 rain gauges and 2 temperature sensors were installed in the panel and data is being collected remotely. The sensors were installed at depths of 2.5 cm (1 in.), 5.1 cm (2 in.), and 7.6 cm (3 in.) at three locations on each of the two coatings. Figure 6 and Figure 7 represent the location and depths of the moisture sensors installed in the prototype panel.

***Figure 5:** Front view of prototype noise barrier (left), Rear view of prototype noise barrier (right).*

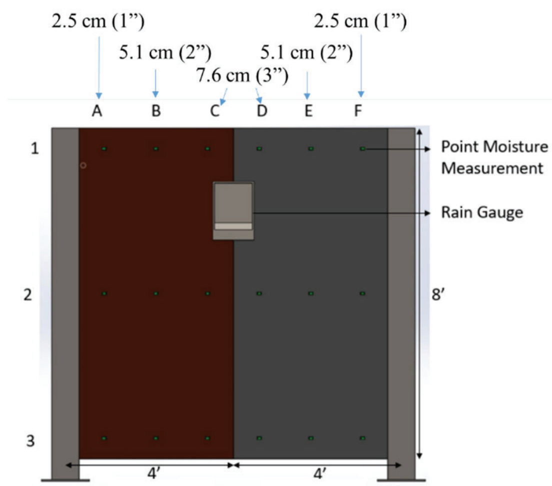

***Figure 6:** Schematic view of sensors installed in the prototype noise barrier.*

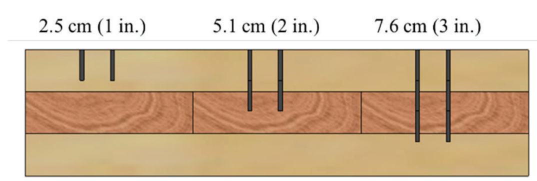

***Figure 7**: Depth of moisture sensors in prototype noise barrier*

The intent of the sensors was to determine the moisture content fluctuations in the CLT panel due to rainfall events. Information such as the peak moisture content after a rainfall event, the variation in moisture in each layer, and the rate at which the moisture content returned to pre-rainfall event levels were all of interest. The amount of rainfall in each rainfall event was captured by rain gauges located on either side of the prototype panel. These rainfall events are summarized in Figure 8. Gaps in the data between October 2022 and January 2023 exist due to battery outages in the sensors. In total 105 measurable rainfall events were recorded by the system over the time of the measurement.

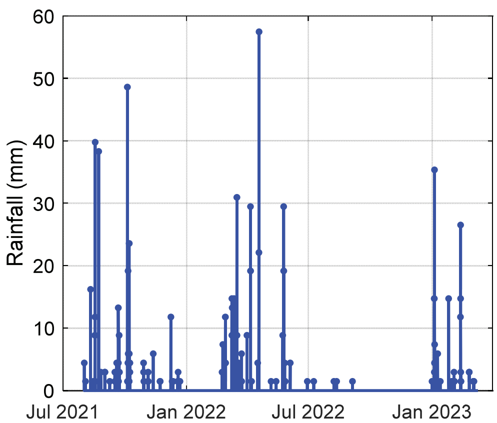

***Figure 8**: Rainfall events July 2021-Mar 2023*

The moisture content in the CLT panels were quantified in terms of the peak moisture content after the rainfall event. In data presented in Figure 9 shows the distribution of the peak moisture content after each event as an average of the three sensors placed at identical depths in each of the two coatings. After rainfall events, the moisture content increases to between 15% to approaching the fiber saturation point of wood. Though differences in the moisture content by layer were evident, no trend was found consistent between the two coatings. The average peak moisture content measured between 20% and 23.5%, which is just above the point at which the effects of increased can begin to occur, usually around 20% [5].

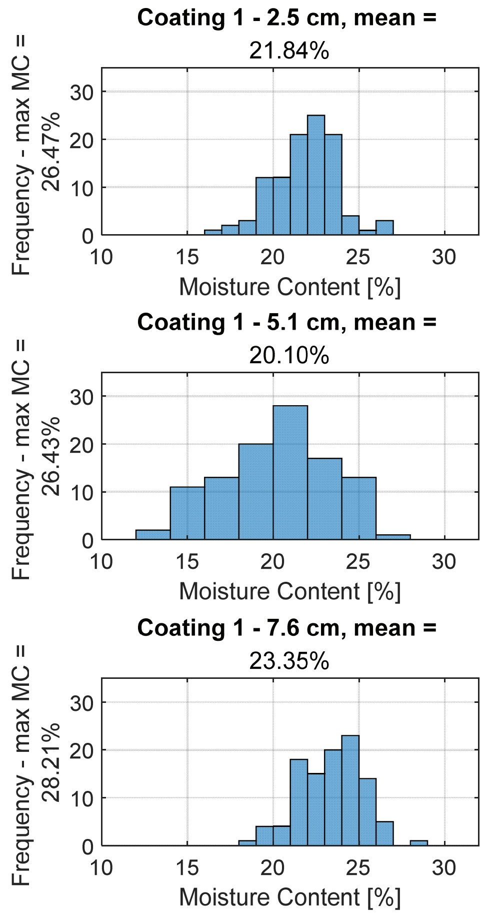

***Figure 9:** Distribution of peak moisture content readings after rainfall event for Coating 1*

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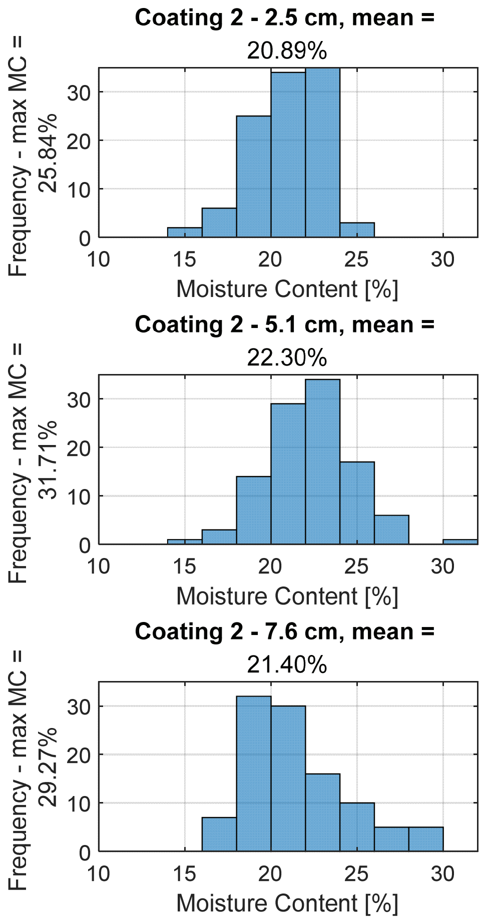

Figure 10: *Distribution of peak moisture content readings after rainfall event for Coating 2*

In addition to the peak average moisture content, the return of moisture content to pre-event levels was tracked by the sensors. As the moisture content exceeded the point at which decay to the wood fibers, it became important to track the amount of time to return to a moisture content below 20% and below 16%, the recommended moisture content for dry service conditions specified in the National Design Specification [6]. Figure 10 represents the average moisture content after a peak rainfall event and the subsequent 24 hours following the event. It shows that within the first two hours after the peak moisture content was measured, the moisture content in the wood drops below the 20% threshold. After approximately 5-7 hours, the moisture content returns to at or below 16% indicating that the wood fibers do not experience elevated moisture content for very long.

The qualitative degradation of the noise barrier over time was measured through periodic inspections of the panel. Discoloration of the noise barrier over the 20+ months of exposure was minimal, indicating the coatings were performing as intended. Delamination of a single piece of the outer layer of the CLT barrier at the top of the wall was observed, likely due to the repetitive moisture cycling (Figure 12). For future installations of the panel, it is recommended that a steel cap be placed on top of the noise barrier to prevent such delamination from occurring and to prevent moisture intake on the panel end-grain. An additional CLT noise barrier with no coating will be installed and monitored in the same way to compare the moisture and degradation performance.

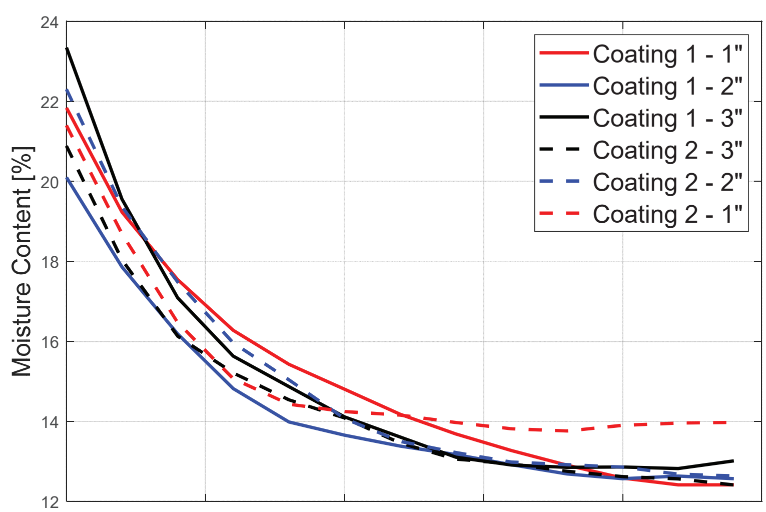

Figure 11*: Moisture content after rainfall event*

Figure 12: *Delamination of top of CLT noise barrier*

5 SUMMARY AND CONCLUSIONS

Cross-laminated timber has the potential to serve as the primary structural material for highway noise barriers in an effort to reduce environmental impact and sequester carbon from the atmosphere. Based on the structural design and cost estimates presented, such a noise barrier is comparable to a similarly designed barrier made of precast concrete with substantial carbon advantages. A prototype noise barrier was installed and instrumented ot determine the long-term moisture performance and degradation of the panels. The data from the prototype noise barrier has been monitored since mid-August 2021 and will be continually monitored as part of a long-term study. For the initial monitoring period from August 2021 to November 2021, the moisture content in the CLT goes up to 28% during heavy rain and drops down to 10% within 24 hours under dry conditions. Using durable and high-quality breathable coating appears to be a viable solution that addresses the effect of moisture retention in CLT panels.

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