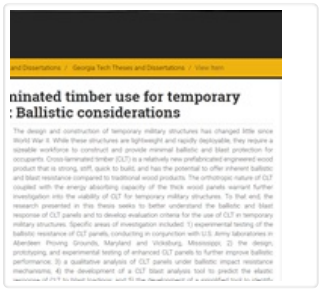

Exploring Cross-Laminated Timber Use for Temporary Military Structures: Ballistic Considerations

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Summary:

The design and construction of temporary military structures has changed little since World War II. While these structures are lightweight and rapidly deployable, they require a sizeable workforce to construct and provide minimal ballistic and blast protection for occupants. Cross-laminated timber (CLT) is a relatively new prefabricated engineered wood product that is strong, stiff, quick to build, and has the potential to offer inherent ballistic and blast resistance compared to traditional wood products. The orthotropic nature of CLT coupled with the energy absorbing capacity of the thick wood panels warrant further investigation into the viability of CLT for temporary military structures. To that end, the research presented in this thesis seeks to better understand the ballistic and blast response of CLT panels and to develop evaluation criteria for the use of CLT in temporary military structures. Specific areas of investigation included: 1) experimental testing of the ballistic resistance of CLT panels, conducting in conjunction with U.S. Army laboratories in Aberdeen Proving Grounds, Maryland and Vicksburg, Mississippi; 2) the design, prototyping, and experimental testing of enhanced CLT panels to further improve ballistic performance; 3) a qualitative analysis of CLT panels under ballistic impact resistance mechanisms; 4) the development of a CLT blast analysis tool to predict the elastic response of CLT to blast loadings; and 5) the development of a simplified tool to identify evaluation criteria for temporary military structure material selection, including conventional materials as well as CLT. Specimens in this research consisted of commercially produced Spruce-Pine-Fir CLT as well as Southern Pine CLT specimens fabricated specifically for this research. Ballistic testing of both types of conventional CLT indicate that the material's inherent penetration resistance is significantly greater than that of dimension lumber and plywood used in current common temporary military structures. The testing shows that current U.S. military design guidelines (UFC 4-023-07), used for determining required wood thickness based on ballistic threat, under predicts the ballistic performance of CLT. From testing and analysis, the thesis develops updated equations for predicting the thickness of CLT required for ballistic protection. A qualitative analysis of ballistic specimens identified local failure modes in the CLT and links the observed damage the anisotropic material properties, grading, and defects in sawn timbers. Enhanced CLT specimens were fabricated using various hardening materials including thin metal plates and gratings, polymer-based armors, and fiber-reinforced epoxy matrix panels. The enhanced CLTs were evaluated based on ease of production, ballistic resistance as compared to conventional CLT, and cost-benefit analysis. The shear analogy method was incorporated into a single-degree-of-freedom blast analysis to predict the response of different types and sizes of CLT panels under blast loads within the elastic regime. The tool was validated using field data from low-level live blast tests and showed good agreement with the field data. Finally, tailored evaluation criteria for comparative assessment of construction materials for use in temporary military structures – considering issues of cost, the logistics of in-theater deployment, energy consumption and force protection were developed and applied through using the AHP decision-making process.

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