Blast Testing of Loaded Mass Timber Structures
Project Report

UFC 4-010-01 requires that inhabited Department of Defense (DoD) buildings constructed of mass timber structural systems be analyzed for airblast loads. As of the summer of 2015, there was a lack of test data documenting mass timber system response under the strain rates imposed by airblast loads. Thus, the primary objective of this effort was to perform testing that would demonstrate the capability of mass timber systems to resist airblast loads and therefore, allow these systems to be designed into military construction. To achieve this primary objective, the following project objectives were defined:

- To develop analytical methodologies to analyze mass timber panels for blast loads.
- To conduct static and dynamic testing on mass timber systems as a means to validate and/or improve these developed analytical methodologies.
- To document the developed analytical methodologies and obtained test data in a form that could serve as a reference for structural engineers interested in designing mass timber structural systems to resist blast loads.

Two mass timber systems were investigated as part of this effort: cross-laminated timber (CLT) and nail-laminated timber (NLT). Grades V1, E1, and V4 CLT as well as 2x4 and 2x6 Spruce-Pine-Fir NLT were tested. The general process followed for each entailed the following steps:

- Develop a preliminary resistance function for use in a single-degree-of-freedom analysis model.
- Perform testing to investigate the post-peak response of an individual mass timber panel to a quasi-static, uniformly-applied, out-of-plane load.
- Compare the results of the quasi-static testing with the preliminary resistance function to refine the preliminary resistance function.
- Use this refined resistance function to design test articles for blast demonstration tests.
- Perform blast demonstration tests and document the results of this testing.
- Create and deliver slide presentations for educating designers on outcomes of testing

The quasi-static panel testing was performed at the University of Maine in Orono for both CLT and NLT panels. The NLT blast demonstration testing was performed at BakerRisk's shock tube facility in La Vernia, Texas, and the CLT blast demonstration testing was performed at Tyndall Air Force Base in Panama City, Florida.

All phases of this project are complete and the final technical report has been compiled. Based on the results of the testing in this project, the following general conclusions are made:

- Mass timber structural systems can effectively resist blast loads in the elastic range with little noticeable damage. Due to the relatively high strength and low stiffness of mass timber panels, significant blast loads can be resisted by mass timber panels in the elastic response range.
- The post-peak response of mass timber panels is relatively brittle. However, for CLT systems, the presence of multiple plies allows for measurable residual strength following initial panel rupture. Additionally, the two-way action inherent in CLT provides a means for load distribution across the panel, thus limiting the damage at the location of peak applied load. NLT systems do not have this advantage of cross lamination and thus do not exhibit these post-peak response benefits.

- Provided fastener penetration is of sufficient depth, significant blast loads can be resisted and transferred through CLT connections that are both simple and quick to install. An added benefit is that dowel-type connection limit states associated with CLT construction are often ductile in nature due to the propensity for wood to crush and/or steel to yield when loaded in shear beyond their respective elastic limits.

- The results of the blast demonstration testing indicated that SDOF dynamic analysis can be used to approximate peak displacements of 3-ply CLT panels without openings within the elastic range. As such, based on CLT characteristic design values and SDOF dynamic analysis calculations, conventional construction standoff distances (CCSDs) for primary gathering / billeting facilities constructed with of CLT can be generated. These CCSDs are shown in the tables below assuming two different claddings and compared with other relevant CCSDs currently defined in UFC 4-010-01.

Conventional Construction Standoff Distances for 3-Ply CLT with EIFS Cladding.

Wall Type	Sections	Span	Min. Static Material Strength	EWI Standoff Distance	EWII Standoff Distance
Reinforced Concrete	≥ 6”	12’ – 20’	3,000 psi	66	16
Reinforced Masonry	8” – 12”	10’ – 14’	1,500 psi	86	30
CLT – EIFS	3-ply	10’ – 12’	Grade E1	120	50
CLT – EIFS	3-ply	10’ – 12’	Grade V4	250	95
CLT – EIFS	3-ply	10’ – 12’	Grade V1	250	100
Steel Studs – EIFS	600S162-43; 600S162-54; 600S162-68	8’ – 12’	50,000 psi	361	151

Conventional Construction Standoff Distances for 3-Ply CLT with Brick Veneer Cladding.

Wall Type	Sections	Span	Min. Static Material Strength	EWI Standoff Distance	EWII Standoff Distance
Reinforced Concrete	≥ 6”	12’ – 20’	3,000 psi	66	16
CLT – Brick Veneer	3-ply	10’ – 12’	Grade E1	75	25
Reinforced Masonry	8” – 12”	10’ – 14’	1,500 psi	86	30
CLT – Brick Veneer	3-ply	10’ – 12’	Grade V4	150	45
CLT – Brick Veneer	3-ply	10’ – 12’	Grade V1	155	55
Steel Studs – Brick Veneer	600S162-43; 600S162-54; 600S162-68	8’ – 12’	50,000 psi	187	75

As part of its education program, WoodWorks will share the results of this testing and provide information on how blast test engineers can use mass timber solutions where they weren’t previously permitted. For workshop dates and locations, A/E/C professionals can sign up to receive emails on events in their region or view the upcoming event calendar at www.woodworks.org.

WoodWorks would like to recognize the financial contribution made by the U.S. Forest Service and the Softwood Lumber Board as well as the material donations by DR Johnson, Nordic, SmartLam, MyTiCon, Hilti, and American Direct. Additionally, construction labor was provided by Lendlease. Testing partners included Karagozian & Case, Inc., the University of Maine, and Tyndall Air Force Base Air Force Civil Engineering Center (AFCEC). This project would not have been possible without the complete teamwork of all involved.