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DEVELOPMENT OF A COST-EFFECTIVE CLT PANEL CAPABLE OF RESISTING DOS/DOD DESIGN BASIS THREATS

FINAL ACCOMPLISHMENT REPORT

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EXECUTIVE SUMMARY

Buildings for the U.S. Department of State (DOS) and U.S. Department of Defense (DOD) often have to meet blast, ballistic resistance, and forced entry (FE) design requirements to mitigate the hazardous effects associated with terrorism. Historically, buildings exposed to these threats have been constructed using concrete or steel. However, the emergence of cross-laminated timber (CLT) presents an opportunity to provide a sustainable building material alternative to owners and architects developing such structures. Several wood characteristics (i.e., propensity to rupture in a brittle fashion upon being overstressed, relatively low penetration resistance) serve to limit CLT's effectiveness in resisting blast, ballistic, and FE threats. Thus, the purpose of this effort was to explore the feasibility of incorporating commercial-off-the-shelf (COTS) building materials (e.g., steel plate or wire mesh) into CLT panel designs in order to address these limitations. Particular emphasis was placed on ensuring the developed panel designs are cost competitive to facilitate their inclusion in actual buildings.

At the outset of the effort, a literature review was performed to determine the state-of-the-science with regard to designing CLT panels for blast, ballistic, and FE threats. The outcome of this literature review was that the ballistic performance of CLT panels represented the major technical barrier to complying with the DOS blast, ballistic resistance, and FE design requirements. Thus, the focus of candidate panel design development was to defeat the DOS ballistic threat.

Seven candidate panel designs that varied wood species (i.e., Spruce-Pine-Fir (South) (SPF-S), Hickory, and Sycamore) and integrated COTS materials into the panel's layup were developed. The candidate panel designs were limited to roughly 10 inches in thickness to be consistent with existing concrete and steel wall systems used in DOS facilities. In addition to the seven developed candidate panel designs, a baseline panel (i.e., 7-ply panel with SPF-S in both the major and minor strength directions) was used to benchmark cost and performance results. Small-scale destructive tests on candidate panel designs with embedded materials indicated that fiber tear, rather than adhesive debonding, was the mode of failure along the steel-timber bond line.

The seven candidate panel designs and baseline panel were subjected to ballistic testing performed in accordance with DOS regulations. Although empirically-based formulae indicated that only one of the candidate panel designs was expected to pass the ballistic testing, four of the eight designs stopped the ballistic threat in all of the tests. In addition to the ballistic testing, a single FE test was performed on the baseline panel to assess CLT's effectiveness in resisting an FE attack. This test found that the panel was capable of resisting an FE attack in accordance with DOS regulations for over 40 minutes, well more than the time required for most DOS construction.

The proof-of-concept testing indicated that embedding thin steel plates within the CLT panel was the most effective means (in terms of both cost and weight) of meeting the DOS ballistic resistance design requirements. Also, the inclusion of thin steel plates within the panel layup was done at a cost that is comparable to current wall construction used in DOS facilities. These findings are promising and indicate that follow-on full-scale flatwise bending tests (both quasi-statically and dynamically) on panels with embedded steel plates is warranted. The ability to embed a ductile, energy absorbing element within the CLT layup in a cost-effective fashion has the potential to make wood a viable competitor to reinforced concrete in the protective design space.

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LIST OF ACRONYMS

BR	Ballistic Resistance
CLT	Cross-Laminated Timber
COTS	Commercial-off-the-Shelf
DBT	Design Basis Threat
DIF	Dynamic Increase Factor
DOD	U.S. Department of Defense
DOS	U.S. Department of State
ECLT	Enhanced Cross-Laminated Timber
FE	Forced Entry
FPL	Forest Products Laboratory
FSP	Fragment Simulating Projectile
GFRP	Glass Fiber Reinforced Polymer
HE	High Explosive
K&C	Karagozian & Case, Inc.
NCM	Normalized Cost Multiplier
PDC	Protective Design Center
SPF	Spruce-Pine-Fir
SPF-S	Spruce-Pine-Fir (South)
SST	Simpson Strong Tie
SYP	Southern Yellow Pine
UHMWPE	Ultra-High Molecular Weight Polyethylene
UOttawa	University of Ottawa
USACE	U.S. Army Corps of Engineers

CHAPTER 1

PROJECT OVERVIEW

1.1 BACKGROUND

Buildings used by the U.S. Department of State (DOS) and U.S. Department of Defense (DOD) often have to meet blast, ballistic resistance (BR), and forced entry (FE) design requirements to mitigate the hazardous effects associated with terrorism. Historically, DOS and DOD buildings exposed to these threats have been constructed using concrete and steel. A significant amount of testing has been performed to demonstrate the ability of these building materials to resist blast, ballistic, and FE threats. A relatively smaller number of tests have been performed on wood construction for similar threats. At least part of this stems from the relative difficulty of designing light-frame wood construction to resist these threats efficiently and economically.

However, the emergence of mass timber construction, and cross-laminated timber (CLT) in particular, both in the U.S. and internationally presents an opportunity to provide a sustainable building material alternative to owners and architects developing DOS/DOD buildings. The solid, panelized nature of CLT allows for both inherent strength and ease of construction. Furthermore, as connections for CLT panels typically consist of steel and timber elements, ductile energy-absorbing panel attachments are relatively easy to design. Although past U.S. Forest Service sponsored efforts (e.g., grant numbers 15-DG-11052021-222 and 17-JV-11111133-02) have been used to generate design guidance for CLT construction exposed to blast loads (i.e., PDC-TR 18-02 [1]), these efforts did not consider FE/BR threats or the enhanced blast design basis threat (DBT) required for DOS construction.

1.2 RECENT ADVANCES IN CLT CONSTRUCTION

Cross-laminated timber, since originating in Europe near the end of the 20th century, has garnered international attention for raising wood structures to new heights [2]. Though CLT uses materials familiar to conventionally framed timber construction, advances in adhesive lamination technology have made CLT panels revolutionary. The CLT manufacturing process lays up large volumes of standard solid-sawn or veneer lumber into composite wood panels that resemble precast concrete in size and utility [3]. Two multi-story apartment buildings constructed approximately a decade ago, the 9-story Stadthaus in East London and the 10-story Forté in Melbourne, featured the versatility of CLT panels functioning as both slabs and walls [4, 5]. Developers of Stadthaus and Forté claimed significantly reduced carbon footprints of construction as a result of carbon sequestered in the wood and carbon avoided by substituting wood for construction materials that consume more energy during production and structural erection. As a relatively lightweight and installation-friendly alternative to precast concrete, CLT has enhanced construction efficiencies inherent to prefabricated panel systems. Aesthetic possibilities of architecturally exposed CLT, furthermore, has renewed interest in commercial wood buildings [6].

Proponents of CLT construction point to the economic, environmental, and social benefits of the material as part of a lifecycle connecting forests to urban building needs [7]. Sustainable potential and growing enthusiasm over the novelty of CLT are spurring increased development. The novelty of CLT, however, highlights the need for new design strategies that address the risks of using wood materials in taller and more substantial buildings. The performance record of CLT in the United States is rapidly expanding to meet this need, with recent and ongoing research that is proving CLT capable of withstanding various building hazards. Full-scale compartment fire tests of two-story CLT buildings provided the basis for building code revisions that generally permit CLT buildings to rise taller than light-framed timber construction [8, 9]. Full-scale seismic shake-table tests of two-story timber construction have demonstrated the resiliency of CLT walls subjected to multiple and successive simulations of major historical earthquakes [10]. Follow-up testing of a 10-story CLT structure is scheduled to follow major upgrades to the University of California, San Diego seismic shake-table that will simulate earthquake ground-motions with greater degrees of freedom for enhanced realism [11]. Recent tests of CLT safe-rooms have proven CLT's effectiveness in resisting timber missile impacts fired in accordance with standards simulating impacts from wind-borne debris [12, 13].

1.3 OBJECTIVES

The overarching goal of this effort was to develop a cost-competitive CLT panel capable of resisting the DOS' blast, ballistic, and FE DBTs. As the demonstration testing to verify the developed panel(s) can resist the DOS' blast, ballistic, and FE DBTs is expensive and the fact that it was unknown whether or not commercial-off-the-shelf (COTS) materials could be cost-effectively incorporated into CLT panel designs at the effort's outset, the effort was deliberately limited to small-scale proof-of-concept testing. Specific goals of the effort included:

- Goal 1: To collate research investigating the blast, ballistic, and FE resistance of CLT into a state-of-the-science report.

- Goal 2: To develop candidate panel designs that can resist the DOS' blast, ballistic, and FE DBTs while considering cost, programmatic, aesthetic, and detailing issues associated with DOS facilities.

- Goal 3: To perform proof-of-concept testing on down-selected candidate panel designs to determine which candidates deserve additional research and testing.

1.4 GENERAL APPROACH

The effort commenced with a kick-off meeting at Karagozian & Case, Inc. (K&C) in Los Angeles, California, on 23 August 2019. Representatives from K&C, the Forest Products Laboratory (FPL), SmartLam, ZGF Architects, DOS Bureau of Diplomatic Security, U.S. Army Corps of Engineers (USACE) Protective Design Center (PDC), and Georgia Tech attended the meeting in-person or via teleconference. Following this meeting, three tasks were performed in succession: (1) performing a literature review, (2) developing candidate panel designs, and (3) performing proof-of-concept testing.

The first task involved collating research investigating the blast, ballistic, and FE resistance of CLT into a state-of-the-science report. At the outset of the effort, blast testing had been performed on structures constructed of 3 and 5-ply CLT panels of different grades up to loads of

30 psi / 150 psi-ms [14, 15] and shock tube testing had been performed on 3 and 5-ply Grade E1 panels and their connections [16, 17, 18, 19]. Additionally, ballistic testing had been performed on eight engineered CLT panels and the relative cost versus performance of each had been assessed [20]. No known forced entry testing had been performed specifically on CLT panels at the outset of this effort.

Using the results of this literature review, various candidate panel designs were developed. The developed candidate panel designs included different species of wood as well as embedded COTS materials. COTS materials used included steel mesh and steel plate. In addition to considering panel performance, a team of stakeholders was assembled to ensure the cost, programmatic, aesthetic, and detailing issues encountered on DOS buildings were considered:

- SmartLam, an American CLT manufacturer, provided feedback concerning the feasibility and cost impacts of embedding COTS materials within CLT panel layups.

- ZGF Architects, an architect that has designed many DOS buildings worldwide, provided feedback concerning the impact of the inclusion of COTS materials in CLT panel designs from an aesthetic and detailing perspective.

- Representatives from the DOS Bureau of Diplomatic Security and U.S. Army Corps of Engineers were engaged to provide feedback concerning the programmatic issues involved with including CLT panels on DOS and DOD facilities.

Following candidate panel design development, proof-of-concept tests were performed on candidates and a baseline panel (i.e., unmodified 7-ply CLT panel) to assess the candidates' efficacy in resisting the ballistic and FE threats defined in DOS standard SD-STD-01.01, Revision G [21]. (Based on blast testing previously performed, it is expected that panels designed to resist the ballistic and FE threats will also be able to resist the DOS blast threat.) Square foot costs were generated for each candidate panel design to assess relative cost competitiveness with other forms of DOS construction. Proof-of-concept ballistic testing was performed using the three ballistic threats identified in SD-STD-01.01 on 1.5-foot by 1.5-foot candidate panel design tiles. Each candidate panel design had three specimens exposed to each ballistic threat. Additionally, an FE test was performed on an 8-foot by 8-foot specimen of the baseline CLT panel to assess what, if any, improvements would be needed to meet DOS FE design requirements.

1.5 REPORT OUTLINE

The remaining chapters of this final accomplishment report describe the following:

- Chapter 2 provides a summary of publicly-available literature relevant to the blast, ballistic, and FE response of CLT panels.

- Chapter 3 describes the process and methodology followed during this effort.

- Chapter 4 summarizes of the results of the testing conducted during this effort.

- Chapter 5 summarizes the conclusions generated as a result of this effort.

CHAPTER 2

LITERATURE REVIEW

Past efforts focused on investigating the response of CLT to blast loads have documented references relevant to the response of wood materials at high strain rates and beyond the point of rupture [22, 23]. The literature review performed as part of this effort supplements these past efforts and specifically focuses on the response of wood materials to highly-concentrated impacts associated with ballistic and FE threats. Prior to delving into the ballistic and FE response of wood materials, a brief overview of blast testing efforts on CLT panels and systems that have been conducted over the last decade is provided in Section 2.1. Section 2.2 focuses on research relevant to ballistic threats while Section 2.3 focuses on research relevant to FE threats.

2.1 BLAST TESTING RESEARCH INVOLVING CLT

Over the past decade, efforts involving CLT panels and simulated (i.e., using a shock tube) or actual blast loads have been led by the USACE PDC, the University of Ottawa (UOttawa), and WoodWorks. The subsections that follow summarize the testing performed and conclusions gleaned from these efforts.

2.1.1 USACE PDC Efforts

In 2015 and 2016, the USACE PDC led a series of shock tube tests aimed at investigating the flatwise bending response of 3-ply, 5-ply, and 7-ply Grade E1 CLT panels manufactured by Nordic Structures. The tests were performed at BakerRisk's shock tube in La Vernia, Texas. The clear span of all panels tested was 12 feet. A total of 28 shock tube tests were performed on 9 CLT panels (i.e., (3) 3-ply, (3) 5-ply, and (3) 7-ply) with loads ranging from 2.9 psi / 20 psi-ms to 14.4 psi / 370 psi-ms. Panels were tested multiple times until visible signs of failure were observed. The peak panel deflections measured during these tests ranged from 1 to 4 inches. Further details concerning this testing is included in Ref. [16, 17].

2.1.2 UOttawa Efforts

UOttawa has performed and published papers concerning three shock tube testing programs related to CLT and blast loads.

The first testing program focused on investigating the flatwise bending response of 3-ply and 5-ply Grade E1 CLT panels manufactured by Nordic Structures. The tests were performed at UOttawa's shock tube and involved a load-transfer device that converted the pressure generated by the shock tube into a concentrated load at panel mid-span. The clear span of all panels tested was 7.33 feet. A total of 20 shock tube tests were performed on 12 CLT panels (i.e., (8) 3-ply and (4) 5-ply) with loads ranging from 0.8 psi / 9 psi-ms to 8.5 psi / 100 psi-ms. The peak panel deflections measured during these tests ranged from 0.25 to 6 inches. An average dynamic increase factor (DIF) of 1.28 was assigned based on the test results. Further details concerning this testing is included in Ref. [18].

The second testing program focused on investigating the response of CLT boundary connections to simulated blast loads. Two types of steel angle connections were considered: (1) the ML24Z angle manufactured by Simpson Strong-Tie (SST) and (2) an L2x2x0.25 angle with a specified yield stress of 50 ksi. The angles were installed on 5-ply Grade E1 CLT panels manufactured by Nordic Structures. The tests were also performed at UOttawa's shock tube and involved the aforementioned load-transfer device. The span of all panels tested was 6.83 feet. A total of 11 shock tube tests were performed with loads ranging from 9.0 psi / 87 psi-ms to 12.6 psi / 121 psi-ms. The peak panel deflections measured during these tests ranged from 2 to 11 inches. An average DIF of 1.31 was assigned based on the test results, which correlates well with that assigned in Ref. [18]. It was also observed that the actual strength of the connection was significantly larger than allowed by code and that the predominant mechanisms of connection failure observed were wood crushing and steel angle yielding. Further details concerning this testing is included in Ref. [19].

The third testing program focused on investigating the flatwise bending response of 3-ply, 5-ply, and 7-ply Grade E1 CLT panels manufactured by Nordic Structures that had been retrofitted with either steel straps or glass fiber reinforced polymer (GFRP) sheets. The tests were also performed at UOttawa's shock tube and involved the aforementioned load-transfer device. The clear span of all panels tested was 6.83 feet. A total of 21 shock tube tests were performed on 17 CLT panels (i.e., (7) 3-ply, (8) 5-ply, and (2) 7-ply) with loads ranging from 4.9 psi / 63 psi-ms to 13.5 psi / 188 psi-ms. The peak panel deflections measured during these tests ranged from 1.7 to 11 inches. The inclusion of steel straps appeared to have a minimal impact on the ultimate resistance of the panel but significantly augmented its post-peak ductility. The application of GFRP appeared to enhance the ultimate resistance and post-peak ductility of the CLT panels. Further details concerning this testing is included in Ref. [24].

2.1.3 WoodWorks Efforts

Two phases of high explosive (HE) field testing were performed on three two-story, single-bay CLT structures at Tyndall Air Force Base. In general, structures were comprised of 3-ply wall and roof panels and a 5-ply first elevated floor panel. Each structure was constructed using a different grade of CLT (i.e., grade designations V1, E1, and V4, which were manufactured by DR Johnson, Nordic Structures, and SmartLam, respectively) and included window and door openings consistent with an actual building. Self-tapping screws and adhesive anchors were utilized in concert with steel angles and pre-fabricated angle brackets manufactured by SST and MiTek to connect the constituent panels of each structure to each other and the foundation.

A total of seven HE field tests were performed to demonstrate the effectiveness of CLT for a spectrum of blast loads. Figure 2-1 shows the detonation associated with Test 3. Ruptured panels were removed and replaced prior to performing the next test. Peak reflected pressures and impulses ranging from 5 psi / 20 psi-ms to 27 psi / 134 psi-ms were measured at the surface of the structure facing the charge. Tests 1, 2, 4, and 6 were designed to stress the CLT structures within their respective elastic limits. Tests 3, 5, and 7 were designed to push the structures beyond their elastic limits such that post-peak response could be observed. In Tests 4 and 5, the front walls facing the charge were loaded with additional superimposed axial load via large concrete blocks. In Tests 6 and 7, the 3-ply front wall panels facing the charge were replaced with 5-ply Grade V1 panels.

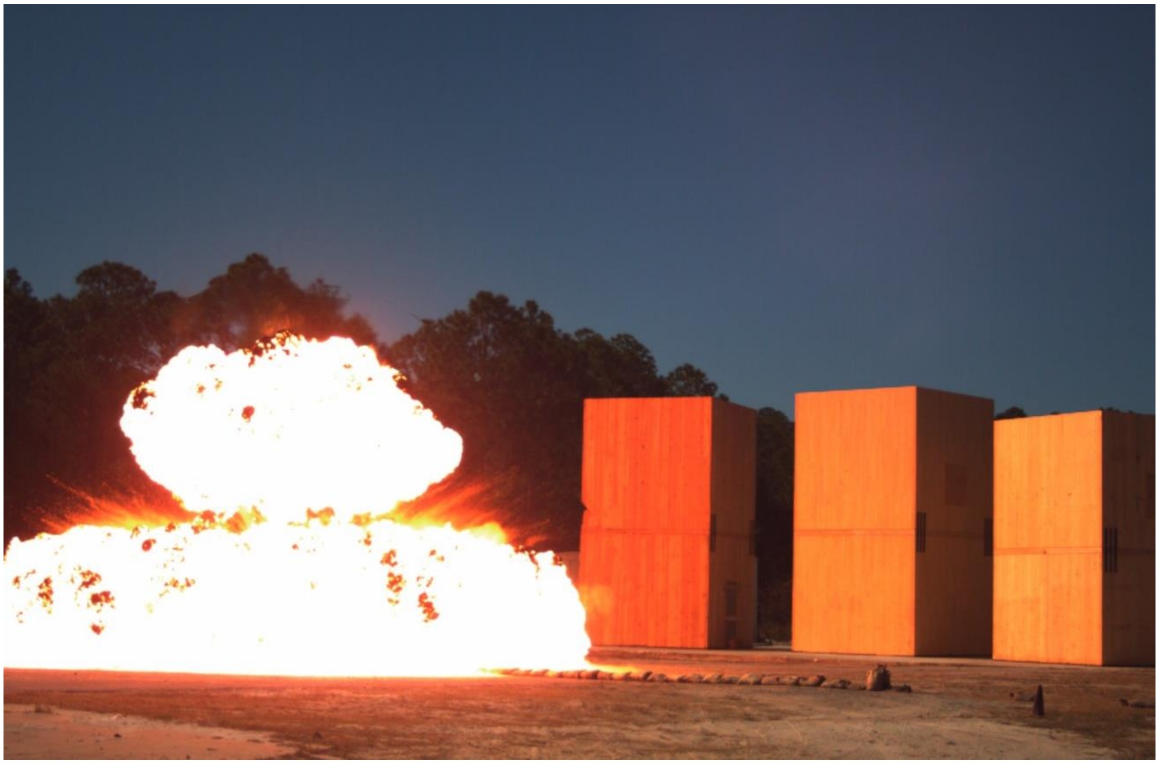


Figure 2-1. Photograph of Blast Test 3 Performed at Tyndall AFB.

Based on the results of these tests, analysis guidance for CLT construction exposed to blast loads was documented in PDC-TR 18-02 [1]. As part of this analysis guidance, quantitative response limits for use with single degree-of-freedom dynamic analysis models were defined.

2.2 BALLISTIC RESEARCH INVOLVING TIMBER

2.2.1 Introduction

The modern science and engineering of armoring for impacts, known as "terminal ballistics" in contemporary terminology, originated during the 18th century when mathematicians began systematically examining the penetration induced by cannonballs, and encompasses a range of present-day military weapons that includes gunfire [25]. The section that follows addresses research related to the performance of wood subject to gunfire that operates in the ordnance range of impact velocities. Though wood was among the first materials used for armoring, the modern applications of wood being used for BR has waned. Metal alloys and massive concrete walls dominate conventional BR solutions for structures while composite materials and ceramics prevail in personnel and vehicle armoring applications.

Having progressed through decades of engineering evolution, the projectiles of terminal ballistics have become very efficient at penetrating targets. At the most fundamental level, armor may work in several different ways. First, imagine a material and structure so hard and stiff relative to the projectile that virtually no penetration happens at all. The sophistication of modern weaponry makes this condition increasingly more difficult to achieve. Therefore, the prevailing methods of armoring default to absorbing the kinetic energy of projectiles, typically through sacrificial material failure and, if possible, fragmentation of the projectile. The impacts happen on the order of milliseconds, which strains the materials so highly that conventional assumptions of the engineering properties cannot adequately predict the mechanics of penetration. The resultant failures and various energy-absorbing mechanisms of the materials further complicate characterizations of the mechanical behavior. Therefore, even the most rigorous theoretical models of penetration mechanics typically rely upon empirical data. Limited observability of projectiles penetrating targets, however, limits the insights of empirical data. The motion of projectiles through targets, in other words, typically cannot be tracked in real time, even with the most sophisticated experimental apparatus.

2.2.2 Pre-20th Century

There is a relatively small amount of testing in the open literature (as compared for that of concrete and metal alloys) documenting the ballistic resistance of wood. Johnson highlighted testing and formulae used to characterize the penetration response of wood up until 1986 [26]. Of note is the work performed by French artillerists and ballisticians in the 19th century, who developed various sectional pressure formulae founded on classical mechanics. The basic form of these sectional pressure formulae is shown in Equation (2-1), where *M* is the mass of the projectile and *A* is the cross-sectional area of the projectile.

$$F = ma = -\frac{M}{A} * \frac{d^2x}{dt^2} \tag{2-1}$$

Among the most popular of these sectional pressure formulae is that proposed by J.V. Poncelet in 1829, which posited that the target's resisting pressure, *F*, is proportional to the sum of the target material's shatter strength, β, and its inertia stated as αv^2, where v is the impact velocity of the projectile [27]; this formula is included as Equation (2-2). Solving Equation (2-2) for *x* yields a closed-formed formula (i.e., Equation (2-3)) to compute penetration depth, *X*, where *i* is a form factor introduced to account for the nose shape of the projectile.

$$\frac{d^2x}{dt^2} = \frac{-(\alpha v^2 + \beta)A}{M} \tag{2-2}$$

$$X = \frac{M}{2A\alpha i} \ln\left(1 + \frac{\alpha}{\beta} v^2\right) \tag{2-3}$$

The coefficients β and α for several wood species (i.e., oak, beech, hornbeam, ash, elm, fir, birth, and poplar) were determined experimentally and published around 1838 [28]. For the remainder of the 19th century leading up to World War I, the basic form of this formula remained intact as future investigators such as Resal [29] and Levi-Civita [30] proposed minor modifications

2.2.3 UFC Formulae

Further investigation of wood ballistic penetration occurred during the 20th century via experimental testing. Much of this testing is export controlled, but a publicly available formula to predict the wood thickness required to prevent perforation in inches, T_w, derived from this testing is recorded in UFC 4-023-07 [31]. This formula is reproduced here as Equation (2-4), where ρ is the wood density in lb/ft^3, w is the projectile weight in pounds, H is the wood hardness in pounds, and D is the projectile diameter in inches.

$$T_w = 9837 \left(\frac{v^{0.4113} w^{1.4897}}{\rho \left(\frac{\pi D^2}{4} \right)^{1.3596} H^{0.5414}} \right) \tag{2-4}$$

Another equation from UFC 4-023-07 pertinent to wood construction estimates the residual velocity in ft/s, v_r, of a bullet perforating a target as a function of impact velocity in ft/s, v, actual target thickness in inches, t, and T_w as defined in Equation (2-4):

$$v_r = v \left[1.0 - \left(\frac{t}{T_w} \right)^{0.5735} \right] \tag{2-5}$$

The density and hardness of several wood types (i.e., pine, maple, green oak, marine plywood, balsa, fir plywood, and hickory) in both "wet" and "dry" states are also included in UFC 4-023-07. It is interesting to note several things when comparing the Poncelet and UFC formulae:

- In both formulae, the penetration depth of the projectile is a function of a wood's mass and either a hardness or toughness (i.e., "shatter strength") parameter. Toughness and Janka hardness for several wood species is included in FPL-GTR-190 [32]. Where toughness and hardness information is not reported in FPL-GTR-190, compression strength perpendicular to grain is well correlated with Janka hardness [33] and could possibly be used as a proxy for comparison purposes.

- There is no nose shape factor in the UFC formula, which implies that the coefficients in this formula have been defined assuming the worst-case nose shape (i.e., the ogive nose characteristic of modern ammunition).

To meet DOS standards for ballistic resistance, construction must resist perforation by three shots of various ogive-nosed bullets, including the 30-caliber, 7.62-mm NATO M80 round that weighs 147 grains (0.02 pounds), measures 0.30 inches in diameter, and is fired at a velocity up to 2800 ft/s. For the M80 threat, which is the largest round in SD-STD-01.01 that CLT enclosures would need to withstand, Equation (2-4) estimates that 179 inches of pine or 59 inches of hickory would be required to completely stop the projectile.

2.2.4 Recent Ballistic Testing Efforts

Buchar et al. conducted impact experiments, using 7.62-mm rifle rounds on five hardwoods and a spruce, to determine V50 ballistic limits, or velocity at which half the bullets perforate the target, across a range of thicknesses [34]. In the V50 results that Buchar et al. tabulated, European beech recorded the highest velocity of 551.7 m/s (1810 ft/s) at a thickness of 335 mm (13.19 in). For lower risk of ballistic perforation, Buchar et al. offered a model to predict the plate thickness in millimeters required to stop a projectile, h_{lim}, based on the projectile striking velocity in m/s, V_0, projectile mass in grams, m, and two material-specific constants, a_0 and a_1, in N and N-s/m, respectively, that are experimentally derived by measuring striking and residual projectile velocities and solving the equation of motion:

$$h_{lim} = -\left[-\frac{a_0 \ln(a_0)}{a_1^2} - \frac{V_0}{a_1} + \frac{a_0 \ln(a_0 + a_1 V_0)}{a_1^2}\right] m \tag{2-6}$$

Buchar et al. tabulated results of Equation (2-6) for six woods tested in ballistic impact and estimated target thicknesses of 744.20 mm (29.3 in) and 556.48 mm (21.91 in), for spruce and European beech, respectively, to allow for a zero probability of perforation by a 7.62-mm ogive-nosed bullet. In addition to these results, Buchar et al. observed that denser woods, except for maple, slowed bullets more effectively. Ballistic resistance, furthermore, was directly correlated to dynamic properties (e.g., crushing strength) measured in high strain rate testing performed using a Split Hopkinson Pressure Bar. Dissections of perforated specimens revealed that the projectile paths were typically straight and caused by a process sufficiently described as one dimensional in nature.

To elaborate on this theory of ballistic penetration in wood, Smrž et al. tested ten types of timber with three different projectiles to develop a more generalized model for the ballistic penetration of wood plates [35]. In addition to the 7.62-mm bullet, these experiments added steel spheres and blunt-nosed cylindrical Fragment Simulating Projectiles (FSPs). Among the three types of penetrators, FSPs penetrated least, and 7.62-mm bullets penetrated furthest into the wood specimens. Smrž et al. determined the striking velocity in m/s at which no perforation occurs, V_{lim}, by varying projectile impact velocity in m/s, V_0, as well as the residual velocity in m/s, V_r, while holding target thickness to 55 mm (2.17 in.) and wood material constant. Quadratic functions generally fit plots of the data points tracking residual velocity versus impact velocity, so that solving the quadratic equation for a value of zero would yield the limit velocity, V_{lim}, for each projectile and wood type. For example, for 7.62-mm bullets, limit velocities of 179 m/s (587 ft/s) and 219 m/s (718.5 ft/s) were derived for spruce and hornbeam, respectively. Again, spruce represented the only softwood in the study, and hornbeam outperformed all hardwoods, including beech. The experiments tested additional wood plates of varying thickness, up to 0.10 m (3.94 in), using FSPs to establish general relationships between V_{lim} and plate thickness, h. Linear relationships took shape across the 0.01 m (0.4 in) to 0.10 m (3.94 in) range of specimens tested. Values of the a_0 and a_1 experimentally derived constants were determined for four hardwoods and two projectile types added since the Buchar et al. study.

Buchar et al. and Smrž et al. developed models of ballistic penetration of wood based on the first two of three terms proposed by Dehn as a unified theory of penetration [36]:

$$F = a + b\dot{P} + c\dot{P}^2 \tag{2-7}$$

where F represents the force generated by the penetrator striking the target and $\dot{P}$ represents the nose-velocity of the projectile measured with respect to the target face. The constant a represents a bond-breaking force in the target material that Buchar et al. and Smrž et al. denoted as a_0. The constant b represents effects of target viscosity that Buchar et al. and Smrž et al. denoted as a_1. Dehn considered the $b\dot{P}$ term negligible relative to the other two terms of Equation (2-7), because gaps between the penetrator and target typically minimize the forces that develop from friction. The third term considers material density and cross-sectional area of the projectile nose to determine energy absorption, yet the two studies that reference this unified model for ballistic impact of wood targets dropped this last term of the expression. Whether the first two terms of Equation 4 sufficiently describe wood perforation is plausible yet untested.

2.2.5 Densified versus Natural Hardwoods

Regardless of material, numerous ballistic models consider density as a critical factor in ballistic resistance. For this reason, hardwoods and densified woods rank among the most promising timber materials for perforation-resistant targets. Natural hardwoods have been used for centuries and have a history of performance, despite a lack of consensus regarding practical and accurate modeling of penetration mechanics for realistic threats. Therefore, improving the properties of wood has had tremendous appeal.

Needs for advanced materials during the World War II era spurred the development of several densified wood composites, like impreg, compreg, staypak, and papreg, which were prototyped and tested by the United States Department of Agriculture, Forest Service, FPL [32]. Chapter 19, Tables 19-1 and 19-2, of the *Wood Handbook* compares engineering properties of these specialty wood composites with yellow birch plywood, the strongest plywood historically produced in the United States. Impreg flooded the cellular structure of wood with adhesive resin to achieve greater density, hardness, stiffness, and strength in almost every category, except tension parallel to grain, toughness, and impact strength. Compreg impregnated the cellular structure of wood with adhesive resin and applied high compressive pressure during the curing process to achieve even greater density, hardness, stiffness, and strength than impreg, but the toughness and impact strength of compreg still lagged natural plywood. Staypak highly compressed wood, without impregnation, to achieve even greater density than compreg. Although compreg had slightly higher strength properties in a few categories, staypack most notably matched the toughness and impact strength of natural plywood. Papreg, a highly compressed laminate of resin infused paper sheets, matched staypak and exceeded all in hardness but, like impreg and compreg, sacrificed toughness and impact strength.

Within the last few years, Song et al. has described a two-step process of wood densification that chemically removes lignin for denser packing of fibers under high pressure and heat during adhesive lamination [37]. For a cylindrical rod penetrating through thin laminates, Song et al. showed a threefold increase in energy-absorption achieved by the densified wood laminate, relative to a natural wood plate of the same thickness. Recent tests, summarized by Chinn and Randow and conducted at the Ballistic Research Laboratory at the U.S. Army Aberdeen Proving Ground and the Engineering Research and Development Center, fired two types of projectiles (0.50-caliber FSP and 7.62-mm M80 ball) at several nail-laminated hardwoods and a commercially produced densified wood laminate branded as Delignit®-Panzerholz® Protect bullet-resistant panel, to determine V50 limit velocities [38, 39]. Chinn and Randow observed that the Delignit®-Panzerholz® Protect panel had fractured bullets in a limited number of cases. Bullets that remained intact and perforated the densified wood panels, however, left the exit face with spalling that resulted from splintering of the material. Panzerholz absorbed more energy per unit mass than either white oak or sycamore hardwoods, according to data tabulated by Chinn and Randow, but white oak was able to cause bullets to tumble in some cases and splintering upon exit of projectiles was far less in the natural hardwoods. Chinn and Randow plotted the V50 limit velocities for 0.50-caliber FSP penetrators versus areal density for a variety of wood materials for comparison with ultra-high molecular weight polyethylene (UHMWPE), the lightest and most expensive armor, and several metal alloys (see Figure 2-2). As expected, the ballistic performance of wood materials falls significantly short of ductile metal alloys and UHMWPE. Within wood products, however, the plot of V50 versus areal density revealed interesting results. Hardwoods and Panzerholz® outperformed softwood CLT, yet because of densification, natural hardwoods appear to perform better than Panzerholz® when areal density becomes a main factor for comparison. In similar fashion, American sycamore, a wood that is lighter than oak yet known for interlocked grain and high split-resistance in nailing, nearly performed as well as white oak, according to the V50 and areal density plot.

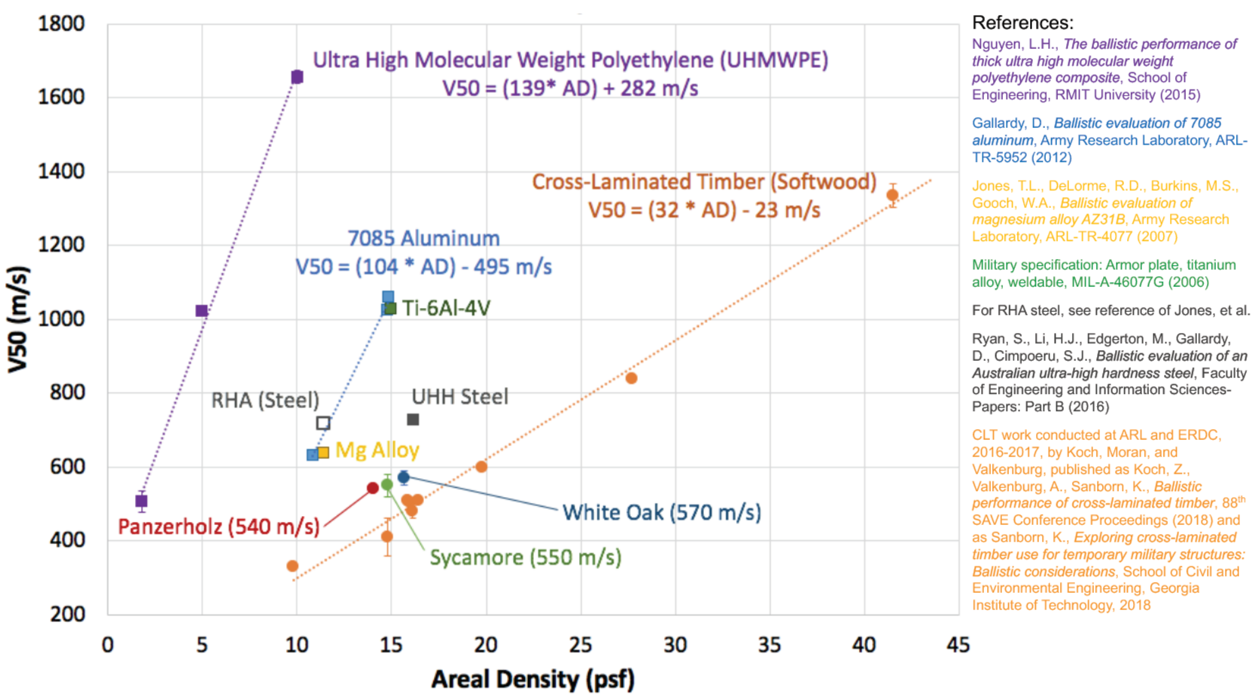


Figure 2-2. 0.50-Caliber FSP V50 vs. Areal Density for Various Materials. [38]

2.2.6 CLT Ballistic Testing Efforts

In a study of softwood CLT targets, Sanborn et al. discovered that UFC equations consistently overpredicted the penetration of spherical steel projectiles, by a wide margin [40]. To develop more accurate estimates, Sanborn et al. calibrated seven models of ballistic penetration to fit the results of tests conducted on 3- and 5-ply CLT made from two commercial categories of softwoods, Spruce-Pine-Fir (SPF) and Southern Yellow Pine (SYP). Among the seven expressions, Sanborn et al. examined four models that estimate ballistic penetration depth based on a rationale of physics and three models that primarily rely on empirical fits of a few key penetrator and target material parameters. Among the approaches rooted in mechanical theory, three classical expressions of penetration mechanics known as the Euler-Robins, Resal, and Poncelot models, only partially fit the test data across various ranges of striking velocities. Force Law, the fourth physics-based model of the study, demonstrated a reasonable fit of penetration depth data, over a broader range of striking velocities. As expected, models that recalibrated the empirically derived constants, from previously developed expressions of the THOR and UFC U.S. military test programs, fit the data best. Sanborn et al, cautioned, however, that even the closest fitting models may be limited to the SPF and SYP laminated wood targets and spherical penetrators of the study. According to the empirically fitted models of Sanborn et al., steel spheres striking at a velocity of 2800 ft/s may penetrate approximately 12 inches or 9 inches into SPF and SYP CLT, respectively.

Considering the limitations of softwoods, which would require impractical depths to resist perforation, Sanborn developed the concept of enhanced cross-laminated timber (ECLT), embedding other materials to reinforce wood within the composite layup [20]. Sanborn tested eight types of ECLT layups, including four variations of steel, two variations of fiberglass fabric, an aramid-epoxy composite, and an ultra-high molecular weight polyethylene (UHMWPE). The four metal interlayer types included perforated steel plate, expanded steel sheet, continuous mild steel plate, and continuous hardened steel plate. Mechanical fasteners tied the perforated steel, expanded steel, and UHMWPE interlayers to each respective wood panel. The remaining five of eight interlayer materials adhesively bonded to wood using a two-component epoxy. Each interlayer material reinforced the CLT, as indicated by reduced ballistic penetration depth or residual velocities, relative to unreinforced CLT. According to perforation resistance, Sanborn respectively ranked UHMWPE, hardened steel, and mild steel plate and first, second, and third most effective in tests using spherical steel projectiles. Adding weighted factors for areal density and costs of each option, Sanborn ranked mild steel plate reinforcement first among the eight options to reinforce softwood CLT. As a pioneering study of ECLT, therefore, Sanborn addressed many questions regarding feasible production of reinforced CLT.

2.2.7 Timber Ballistic Research Summary

In building construction, areal density takes on lesser priority, but overall wall thickness remains a prime consideration. For competitiveness with steel plate armor, reinforced concrete, and concrete masonry structures used in current DOS structures, the CLT panel must stop bullets within 8 to 12 inches of target thickness. Cost adds another primary factor to the performance assessment of CLT as a ballistic shield.

Based on previous ECLT research by Sanborn [20], softwoods will require steel embedment in the layups to be effective in stopping realistic terminal ballistic threats. Though effective, high-tech materials like UHMWPE and densified wood composites, remain much too expensive to justify use in armoring building construction.

Based on estimates of the limit thickness for 7.62-mm rounds, offered by current literature, hardwoods do not provide enough perforation resistance to stop bullets within 8 to 12 inches of panel thickness.

2.3 FORCED ENTRY INVOLVING TIMBER

As with evaluating wood for ballistic resistance, empirical methods, as opposed to analytical, methods are generally used to quantify the FE resistance of a particular wall system. FE resistance ratings are defined in the standards adopted by various jurisdictions. In addition to defining FE resistance ratings, these standards define the toolset that may be used to defeat a window/wall/door system. Some jurisdictions allow for the use of power tools as part of the FE attacker toolset whereas other jurisdictions do not. The standard adopted by the DOS (i.e., SD-

STD-01.01 [21]) for both FE and BR resistance defines three levels of FE resistance (i.e., 5-minute, 15-minute, and 60-minute) and does not include power tools in its FE attackers toolset. It should be noted that the list of allowable tools slightly varies with the desired FE resistance rating in Revision G of SD-STD-01.01.

A large amount of FE testing has been performed on various types of wall, door, and window assemblies. Prior to the development of CLT, and more generally mass timber, light-frame wood construction dominated the wood construction market. FE tests performed on wood stud walls indicated that the points of connection (e.g., where the stud connects to the top or bottom plate) served as the likely point of failure [41]. A typical FE rating for a wood stud wall would be on the order of 5 minutes based on the toolset and test procedure documented in SD-STD-01.01, Revision G.

Various references tabulate and prescribe FE ratings for various types of construction. Wood appears on these tables in the form of plywood and light-frame wood construction. The most readily accessible of these manuals is UFC 4-020-01 [42]. Other manuals that are export controlled (e.g., UFC 4-020-02FA [43]) define FE ratings for various types of wood construction. It should be noted that none of these manuals currently considers mass timber construction. Furthermore, there was no known FE testing that had been performed on CLT panels at the outset of this effort.

CHAPTER 3

METHODOLOGY

To accomplish the objectives stated in Chapter 1, the effort was divided into three major phases: (1) literature review, (2) candidate panel design development, and (3) proof-of-concept testing. The results of the literature review phase are described in Chapter 2. Section 3.1 describes how the candidate panel designs were developed and Section 3.2 describes the rationale undergirding the proof-of-concept testing performed under this effort.

3.1 CANDIDATE PANEL DESIGNS

3.1.1 Architectural Context

Diplomatic facilities for all countries have often sought distinction by design, for national cultural reflection, prominence, permanence, safety, and security. While over time they have taken all manner of stylistic forms, the demands of terrorism-prone modern society have imposed upon architects the imperative of security, blast and ballistic resistance. Massive, rigid structures of concrete and steel are built through intensive labor over extraordinary construction terms to meet the performance requirements, and yet must be graciously formed and decorated to bring warmth and livability to the work and living places; and not surprisingly, often with wood. While timber framing and cladding systems have been mostly displaced by more robust materials for high-security facilities, recent developments in mass timber and CLT offer welcome and attractive alternatives to structural framing systems for secure facilities that not only overcome traditional material strength issues, but also bring forth many other benefits worth consideration:

- CLT as a high strength-to-weight ratio and carries weight and ductile resiliency advantages over concrete and steel.

- Through structural simplicity and pre-fabrication, CLT carries with it smaller construction forces, tighter construction tolerances, and quicker construction time over traditional methods, leading to more cost-effective buildings in remote areas.

- CLT is a low impact material with a lower embodied carbon footprint, and generates reduced waste, leaving a significantly lighter environmental footprint than concrete or steel.

- A higher degree of on-site quality and construction tolerance can be achieved through panel and frame prefabrication.

- Mass timber and cross-laminate timber products are inherently fire-resistive and can themselves be exposed within interiors to reduce the need for covering finishes, and bring the tactile beauty of wood to interior environments products (e.g., see Figure 3-1).

Plywood laminate, by its inherent strength, has previously been used as a low-grade material for FE hardening. CLT has the potential to afford FE protection on a much greater scale.

In addition to its technical merits, CLT, when used with mass timber or in hybrid with concrete or steel, offers the warmth, grace and material refinement of wood to key representational and work areas within our diplomatic facilities that has been otherwise limited to interior finish and trim materials. Moreover, it embodies one of the many forward-thinking construction strategies needed to achieve a more sustainable future.

Figure 3-1. Exposed Mass Timber in First Tech Credit Union Headquarters.

3.1.2 Development Principles

Based on the results of the literature search and the architectural context listed above, the following principles were formulated to guide the development of candidate CLT panel designs for the proof-of-concept testing.

- Existing concrete and steel wall systems used in DOS facilities are generally 8 to 12 inches thick. Thus, an effort was made to keep the CLT candidate panel designs to roughly 10 inches in thickness. The baseline panel selected for this effort was the 7-ply SL-V4 panel manufactured by SmartLam; this panel is 9.625 inches thick and is manufactured using No. 2 Spruce-Pine-Fir (South) (SPF-S) lumber in both directions. No. 2 SPF-S has a relatively low density, hardness, and toughness (i.e., when compared to other wood species), and thus serves as a reasonable estimate for the lower bound ability of wood to resist the DOS ballistic DBT.

- Based on the literature search, it was apparent that the baseline CLT panel by itself would be insufficient to stop the DOS ballistic DBT. Thus, CLT panels would need to be enhanced with different species of wood with greater density, hardness, and/or toughness or another material altogether. This information, combined with the fact that significant blast testing efforts involving CLT have been performed in the recent past, informed the decision to start with ballistic, rather than FE, proof-of-concept testing.

- As the candidate panel designs would need to resist both blast and ballistic threats, it was decided to use symmetric layups to allow for equal inbound and rebound stiffness and strength. Also, instead of lumping the ballistic resistant material in the center of the panel, which would be ideal for only a ballistic threat, materials that were embedded were placed closer to the panel extremities to allow for enhanced blast resistance as well.

- As discussed above, a primary reason architects are interested in using CLT is because of the natural wood finish afforded by the solid wood panel. Thus, the CLT panel's interior surface was kept free of blast or FE/BR cladding materials that would impede the desired aesthetic.

- In most cases, CLT panels will have an external cladding that could serve to provide a measure of blast and FE/BR resistance. However, without knowing the cladding a priori, and to expand the flexibility of the developed candidate panel designs, it was assumed that the panel itself will need to completely resist the DOS ballistic DBTs.

- Cost was a primary consideration in the development of these designs. While other materials (e.g., densified wood, FRP, UHMWPE) could undoubtedly serve to enhance the blast, ballistic, and FE resistance of CLT panels, the inclusion of these materials would be markedly more expensive than the candidate panels designs developed.

3.1.3 Candidate Panel Design Descriptions

Using the above principles, a total of seven candidate panel designs (and one baseline design) were developed for the purpose of conducting ballistic proof-of-concept testing. These eight candidate panel designs, as well as notes concerning the rationale undergirding their development, are described in Table 3-1. Additionally, Figure 3-2 shows sections through each of the candidate panel designs.

Based on pre-test calculations conducted using the equations in UFC 4-023-07, Design 8 was the only design for which there was certainty that all of the DOS ballistic DBT would be stopped. The purpose of selecting candidate panel designs that might not stop the DOS ballistic DBT was to comparatively assess various hardwood and steel combinations to determine an optimal combination of each from both a cost and performance perspective.

Table 3-1. Candidate Panel Designs Tested in Proof-of-Concept Ballistic Testing.

ID	Name	Description	Notes
1	Baseline	7-ply SL-V4 panel (No.2 SPF-S in both major and minor strength directions)	To be used as baseline for other results
2	All Hardwood	7-ply panel; Select and Better Shagbark Hickory in both major and minor strength directions	Densest, hardest, and toughest domestic species that is readily available; meant to serve as upper bound on what wood can do alone
3	Hardwood + Softwood Combination	7-ply panel; Select and Better Shagbark Hickory in major strength direction; No.2 SPF-S in minor strength direction	To assess relative effectiveness of alternating layers of different densities and effectiveness of hardwood
4	Interlocking Grain + Softwood Combination	7-ply panel; Select and Better American Sycamore in major strength direction; No.2 SPF-S in minor strength direction	To assess relative effectiveness of alternating layers of different densities and effectiveness of lumber with interlocking grain
5	Embedded Steel Plate (Thin)	7-ply SL-V4 panel w/ mild steel plate (0.12" thick ASTM A36) at 1-2 and 6-7 ply interfaces	Best cost vs. performance for the E-CLT tested by Sanborn [20]; to assess feasibility of embedding plates in CLT w/ adhesive; to be used as baseline for comparison w/ wire mesh options
6	Embedded Steel Mesh (Fine)	7-ply SL-V4 panel w/ steel wire cloth (0.137" opening size, 47% open area, 0.063" wire diameter, McMaster Carr part no. 9219T153) at 1-2, 3-4, 4-5, and 6-7 ply interfaces	To assess ease of incorporating mesh between CLT panel layers and relative cost increase associated with more panel insertions
7	Embedded Steel Mesh (Coarse)	7-ply SL-V4 panel w/ steel wire cloth (0.13" opening size, 27% open area, 0.12" wire diameter, McMaster Carr part no. 9219T147) at 1-2 and 6-7 ply interfaces	To assess ease of incorporating mesh between CLT panel layers and relative cost increase associated with less panel insertions
8	Embedded Steel Plate (Thick)	7-ply SL-V4 panel w/ mild steel plate (0.25" thick ASTM A36) at 1-2 and 6-7 ply interfaces	To have a candidate panel design that will stop DOS ballistic threat inside panel

(a) Design 1: Baseline.

(b) Design 2: All Hardwood.

(c) Design 3: Hardwood + Softwood Combination.

(d) Design 4: Interlocking Grain + Softwood Combination.

(e) Design 5: Embedded Steel Plate (Thin).

(f) Design 6: Embedded Steel Mesh (Fine).

(g) Design 7: Embedded Steel Mesh (Coarse).

(h) Design 8: Embedded Steel Plate (Thick).

Figure 3-2. Illustrations of Developed Candidate Panel Designs.

3.1.4 Candidate Panel Design Fabrication

SmartLam fabricated candidate panel design tiles to be used in the proof-of-concept ballistic testing out of 3-foot by 3-foot panels that were subsequently cut into four 18-inch by 18-inch tiles. Photographs showing completed tiles from the side for each candidate panel design are included as Figure 3-3.

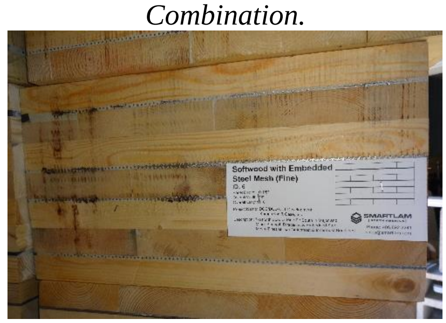
(a) Design 1: Baseline.

(b) Design 2: All Hardwood.

(c) Design 3: Hardwood + Softwood Combination.

(d) Design 4: Interlocking Grain + Softwood Combination.

(e) Design 5: Embedded Steel Plate (Thin).



(f) Design 6: Embedded Steel Mesh (Fine).

(g) Design 7: Embedded Steel Mesh (Coarse).

(h) Design 8: Embedded Steel Plate (Thick).

Figure 3-3. Through-Thickness View of Candidate Panel Design Tiles.

It should be noted that the thickness of candidate panel designs varied from the baseline panel thickness (i.e., 9.625 inches) due to factors involved with the wood species utilized and materials incorporated within the layup.

- Plies of hickory and sycamore had to be planed to 1.25 inches (rather than the typical 1.375-inch thick ply used in the baseline panel) on account of board wane.
- The timber plies in Designs 5 and 8 (i.e., those with embedded steel plates) were held constant at 1.375 inches even though the panel thickness would increase slightly.
- Built-up adhesive bond lines were necessary to integrate the steel mesh inside of the CLT panel. This dimension was 0.126 inches for Design 6 and 0.24 inches for Design 7.

The final nominal thicknesses of the candidate panel design tiles are listed in Table 3-1. The measured thicknesses of the tiles that were tested are listed in Appendix B.

Table 3-2. Nominal Thicknesses of Candidate Panel Designs.

Design	1	2	3	4	5	6	7	8
Thickness [in]	9.625	8.75	9.125	9.125	9.865	10.129	10.105	10.125

Of primary importance was ensuring that embedding items within the CLT panel would not cause bond failures at ply interfaces. Towards this end, destructive testing involving a crowbar and 10-pound hammer was used to try and separate the embedded steel items from the adjacent timber plies. Photographs showing the results of these tests are included as Figure 3-4a through c. It is observed that the failure mode at the bond line is predominantly wood fiber tear, which indicates that the bond between the steel and the wood was not the weak point.

Additionally, a cyclic delamination test in accordance with AITC Test T110 was performed to assess if the embedded steel plate designs would fail at the bond line. The results of this test indicated that although there were localized areas of delamination, no complete failures occurred. Figure 3-4d shows a section through the panel at the end of one of these tests.

(a) Destructive testing on Design 8: Embedded Steel Plate (Thick).

(b) Destructive testing on Design 6: Embedded Steel Mesh (Fine).

(c) Destructive testing on Design 7: Embedded Steel Mesh (Coarse).

(d) AITC Test T110 on Design 8: Embedded Steel Plate (Thick).

Figure 3-4. Post-Test Photographs of Testing Performed to Assess Bond Line Integrity.

3.2 PROOF-OF-CONCEPT TESTING

Two types of proof-of-concept testing was performed as part of this effort. Ballistic testing was performed on the eight candidate panel designs described in Section 3.1. Forced entry testing was only performed on the baseline panel (i.e., Design 1). Testing was performed in accordance with SD-STD-01.01, Revision G.

3.2.1 Ballistic

Information concerning the ballistic testing performed as part of this effort is described in this section. Testing was performed at HP White Laboratories in Aberdeen, Maryland. Further information concerning this ballistic testing test setup and specimens tested is included in the test report included as Appendix B.

3.2.1.1 *TEST SPECIMENS*

The test specimens subjected to ballistic testing are described in Section 3.1.4 and shown in Figure 3-3.

3.2.1.2 *TEST SETUP*

Candidate panel design tiles were mounted on a rigid steel frame during ballistic testing. Figure 3-5 includes a photograph showing this frame.

Figure 3-5. Test Specimen Mounting for Ballistic Testing.

3.2.1.3 *TEST PROTOCOL*

The three projectiles from SD-STD-01.01, Revision G, were shot at the eight CLT candidate panel design tiles at the maximum velocities identified in Table 3-3. Each tile was shot with each type of SD-STD-01.01 projectile in a triangle pattern. Three duplicate tests were performed for each projectile / candidate panel design combination leading to a total of 72 shots performed. The target velocities correspond to the upper bound velocity specified for each projectile in Table 1 of SD-STD-01.01, Revision G. Residual velocities were measured using two high speed video feeds (i.e., from above and from the side) and penetration depth into the panel was measured using computed radiography.

Table 3-3. SD-STD-01.01 (Revision G) Ballistic Resistance Test Ammunition.

Cartridge	Velocity Range	
	Minimum [ft/s]	Maximum [ft/s]
7.62 mm, M80, ball, 147 gr.	2,700	2,800
5.56 mm, M193, ball, 55gr.	3,135	3,235
5.56 mm, M855, ball, 63 gr.	2,950	3,050

3.2.2 Forced Entry

Information concerning the FE testing performed as part of this effort is described in this section. Testing was performed at Intertek in York, Pennsylvania. Further information concerning this testing is included in the test report included as Appendix D.

3.2.2.1 TEST SPECIMEN

A single 8-foot by 8-foot panel of Design 1 was manufactured by SmartLam and subjected to FE testing. The purpose of only performing the FE testing on Design 1 was to assess how well the baseline panel would respond to the FE testing protocol defined in SD-STD-01.01. The response of this panel would then be able to inform the extent of future FE testing on CLT panels that would be necessary.

3.2.2.2 TEST SETUP

The test specimen was mounted in a rigid steel frame as shown in Figure 3-6.

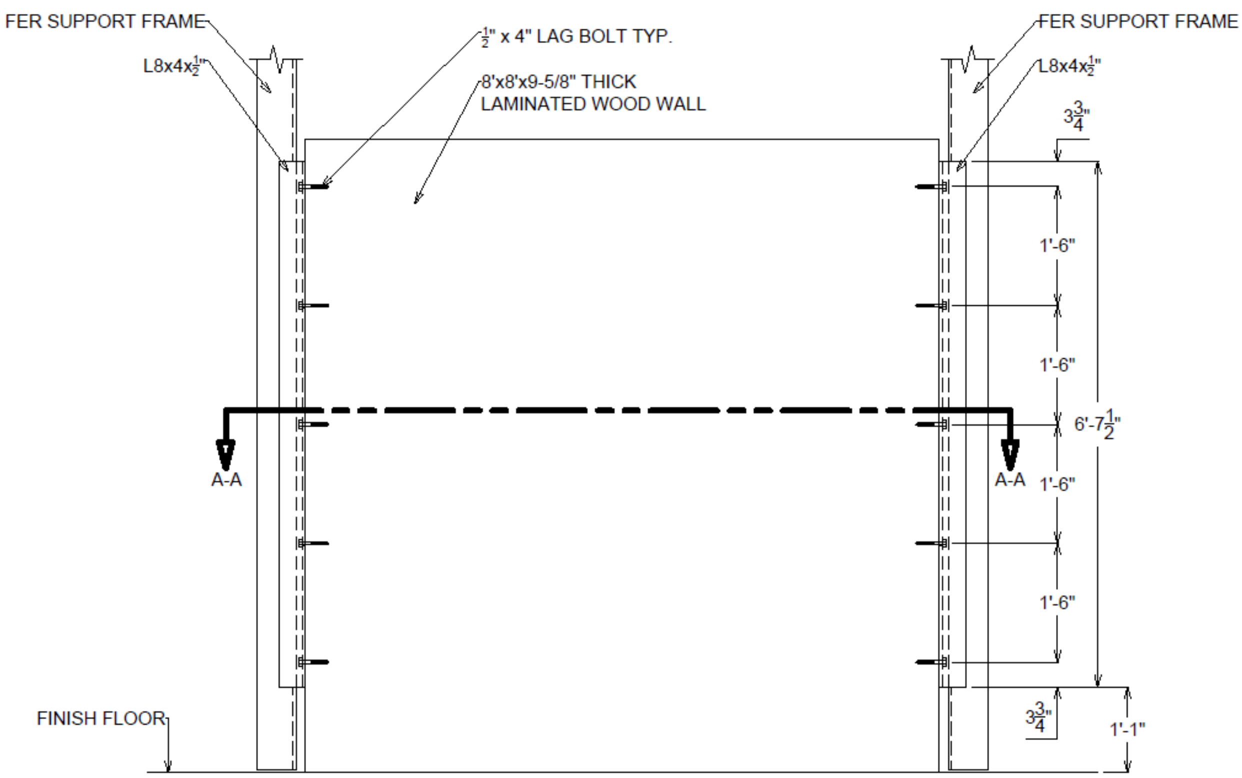


Figure 3-6. Test Specimen Mounting for Forced Entry Testing.

3.2.2.3 TEST PROTOCOL

The 60-minute test protocol defined in SD-STD-01.01 was followed for the FE test. The attack focused on the center of the panel. All aspects of the SD-STD-01.01 protocol were followed.

CHAPTER 4

RESULTS / DISCUSSIONS / FINDINGS

The results of the proof-of-concept tests are described in this chapter. Section 4.1 focuses on the ballistic proof-of-concept testing and Section 4.2 focuses on the FE proof-of-concept testing. Section 4.3 summarizes the findings from the proof-of-concept testing.

4.1 BALLISTIC TESTING

4.1.1 Results

The three projectiles from SD-STD-01.01 were fired into each candidate panel design tile. Figure 4-1 shows the entry and exit faces of Panel 1A following the M80 round ballistic test.

(a) Entry Side of Panel. *(b) Exit Side of Panel.*

Figure 4-1. Panel 1A Following Ballistic Testing.

Designs 2, 5, 7, and 8 stopped all three projectiles in each of the three tests performed, Designs 3 and 6 stopped the M193 and M855 projectiles in each of the three tests performed, and Designs 1 and 4 did not stop each of the three projectiles in at least one of the tests performed. Further details from each test are included in Appendix B.

Table 4-1 summarizes the results from the ballistic proof-of-concept testing performed. The average penetration depth listed in Table 4-1 is equal to the average (i.e., across the three tests performed) depth of penetration divided by the total thickness of the panel. Computed radiography scans were used to measure the penetration depth. The scan was centered on the exit edge of the panel, so a calculation correction was necessary to account for image distortion (i.e., the image distorts as one moves away from the centering point – i.e., the back of the panel). Thus, the average penetration depth shown in Table 4-1 is based on the Calculated (C) rather than the Measured (M) values given in the computed radiography report included as Appendix C. Figure 4-2 illustrates these Calculated and Measured values for Panel 5A.

Table 4-1. Summary of Ballistic Testing Results.

Projectile / Target Velocity	Not Penetrated	Average Penetration Depth %	Penetrated	Average Residual Velocity [fps]
7.62 mm, M80, ball, 147 gr. V_{target} = 2800 fps	2 (All Hardwood) 5 (Thin Plate) 7 (Coarse Mesh) 8 (Thick Plate)	2 (88%) 5 (85%) 7 (84%) 8 (61%)	1 (Baseline) 3 (Hardwood + Softwood) 4 (Interlocking + Softwood) 6 (Fine Mesh)	1 (2435) 3 (2061) 4 (2201) 6 (419)
5.56 mm, M193, ball, 55 gr. V_{target} = 3235 fps	2 (All Hardwood) 3 (Hardwood + Softwood) 5 (Thin Plate) 6 (Fine Mesh) 7 (Coarse Mesh) 8 (Thick Plate)	2 (41%) 3 (63%) 5 (63%) 6 (49%) 7 (59%) 8 (43%)	1 (Baseline) 4 (Interlocking + Softwood)	1 (1394) 4 (612)
5.56 mm, M855, ball, 63 gr. V_{target} = 3050 fps	2 (All Hardwood) 3 (Hardwood + Softwood) 5 (Thin Plate) 6 (Fine Mesh) 7 (Coarse Mesh) 8 (Thick Plate)	2 (51%) 3 (67%) 5 (78%) 6 (58%) 7 (65%) 8 (72%)	1 (Baseline) 4 (Interlocking + Softwood)	1 (885) 4 (553)

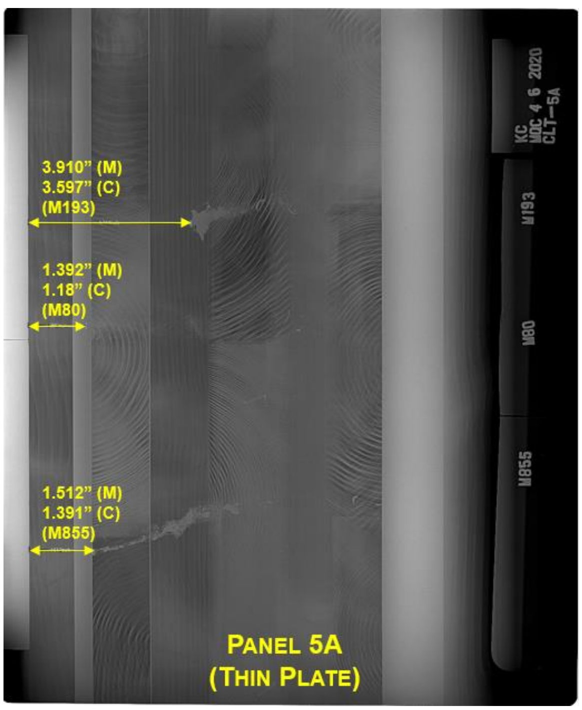
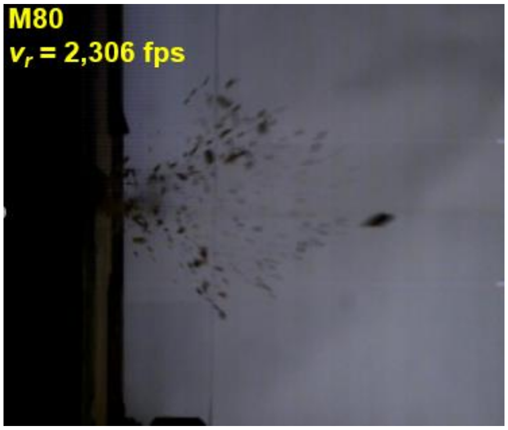


Figure 4-2. Computed Radiography Scan for Panel 5A.

When the projectile penetrated the panel, residual velocity was measured used high speed videos feeds from the top and the side. Figure 4-3 shows screenshots of all three SD-STD-01.01 rounds exiting Panel 1A.



(a) M80 round.

(b) M193 round.

(c) M855 round.

Figure 4-3. Screenshots Showing Exit Damage for Panel 1A.

Table 4-2 reorganizes the data shown in Table 4-1 to compare the average depth of penetration (as a percentage of the total panel thickness) for the various projectiles and candidate panel designs tested. Penetration values of 100-percent indicates the panel was perforated in at least one of the three tests.

Table 4-2. Summary of Penetration Results.

ID	Description	Projectile		
		M80	*M193*	*M855*
1	Baseline	100%	100%	100%
2	All Hardwood	88%	41%	51%
3	Hardwood + Softwood	100%	63%	67%
4	Interlocking + Softwood	100%	100%	100%
5	Thin Plate	85%	63%	78%
6	Fine Mesh	100%	49%	58%
7	Coarse Mesh	84%	59%	65%
8	Thick Plate	61%	43%	72%

4.1.2 Discussion

The results of each candidate panel design were compared with weight and cost information provided by SmartLam shown in Table 4-3. The Normalized Cost Multiplier (NCM) in Table 4-3 is equal to the square foot cost to manufacture the candidate panel design divided by the square foot cost to manufacture the baseline candidate panel design (i.e., Design 1). The cost information shown in Table 4-3 is intended for relative costing purposes and is based on small-scale production and current lumber prices.

Table 4-3. Preliminary Cost & Weight Information for Candidate Panel Designs.

ID	Description	Normalized Cost Multiplier	Weight [1] [psf]
1	Baseline	1.00	22.2
2	All Hardwood	2.86	39.5
3	Hardwood + Softwood	2.08	32.0
4	Interlocking + Softwood	1.68	25.0
5	Thin Plate	1.86	32.7
6	Fine Mesh	5.49	31.2
7	Coarse Mesh	4.03	33.1
8	Thick Plate	2.22	41.8

[1] Average of square foot weight of three tiles tested in ballistic proof-of-concept testing.

Table 4-4 compares the difference between the entry and exit velocities, ΔV, measured in the ballistic testing divided by the weight in pounds per square foot (psf) listed in Table 4-3. Additionally, these ΔV/psf values are then normalized by the maximum value for each projectile in order to rank the relative effectiveness of each candidate panel design in terms of weight. Only designs that stopped all of the projectiles in every test are ranked.

Table 4-4. Weight Comparison and Rank.

(a) ΔV / psf.

ID	Description	Projectile		
		M80	*M193*	*M855*
1	Baseline	**18**	**84**	**98**
2	All Hardwood	**71**	**82**	**78**
3	Hardwood + Softwood	**24**	**101**	**96**
4	Interlocking + Softwood	**23**	**105**	**101**
5	Thin Plate	**85**	**100**	**94**
6	Fine Mesh	**77**	**105**	**99**
7	Coarse Mesh	**85**	**98**	**93**
8	Thick Plate	**66**	**77**	**74**

(b) Normalized ΔV / psf.

Projectile			AVG	Rank
M80	*M193*	*M855*		
0.21	0.80	0.97	**0.66**	**-**
0.83	0.78	0.77	**0.79**	**3**
0.28	0.96	0.95	**0.73**	**-**
0.27	1.00	1.00	**0.76**	**-**
1.00	0.96	0.93	**0.96**	**1**
0.90	1.00	0.98	**0.96**	**-**
1.00	0.93	0.92	**0.95**	**2**
0.78	0.74	0.73	**0.75**	**4**

Table 4-5 is similar to Table 4-4 except that ΔV is divided by the NCM listed in Table 4-3 instead of the panel's weight.

Table 4-5. Cost Comparison and Rank.

(a) ΔV / NCM.

ID	Description	Projectile		
		M80	*M193*	*M855*
1	Baseline	**395**	**1858**	**2180**
2	All Hardwood	**980**	**1131**	**1072**
3	Hardwood + Softwood	**363**	**1553**	**1476**
4	Interlocking + Softwood	**339**	**1563**	**1507**
5	Thin Plate	**1493**	**1760**	**1646**
6	Fine Mesh	**437**	**596**	**560**
7	Coarse Mesh	**701**	**805**	**765**
8	Thick Plate	**1255**	**1457**	**1391**

(b) Normalized ΔV / NCM.

Projectile			AVG	Rank
M80	*M193*	*M855*		
0.26	1.00	1.00	**0.75**	**-**
0.66	0.61	0.49	**0.59**	**3**
0.24	0.84	0.68	**0.59**	**-**
0.23	0.84	0.69	**0.59**	**-**
1.00	0.95	0.76	**0.90**	**1**
0.29	0.32	0.26	**0.29**	**-**
0.47	0.43	0.35	**0.42**	**4**
0.84	0.78	0.64	**0.75**	**2**

Reviewing the results of Table 4-4 and Table 4-5 indicates Design 5 (i.e., embedded thin steel plates) offers the most ballistic resistance value in terms of both cost and weight.

4.2 FORCED ENTRY TESTING

4.2.1 Results

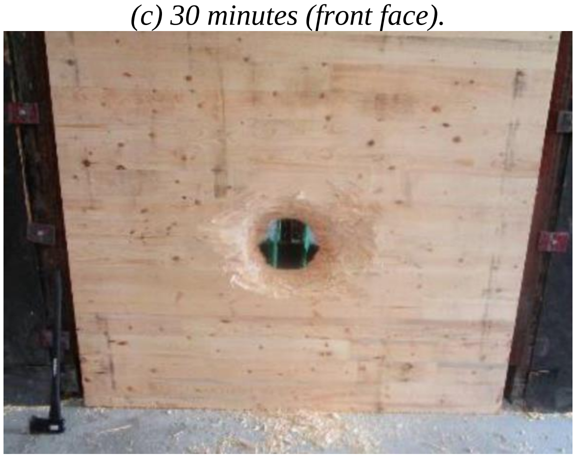
The FE test lasted a total of 44 minutes. The damage to the front and back faces of the wall following each 15-minute interval are shown in Figure 4-4. Initial perforation of the panel occurred at roughly the 24-minute mark but the SD-STD-01.01 requirement to be able to pass a 12-inch (D) by 12-inch (H) cylinder or a 12-inch by 12-inch by 8-inch box through the opening generated almost doubled the time of the test. Not surprisingly, the predominant tool of use during the course of the test was the wood axe.

(a) Pre-test condition.

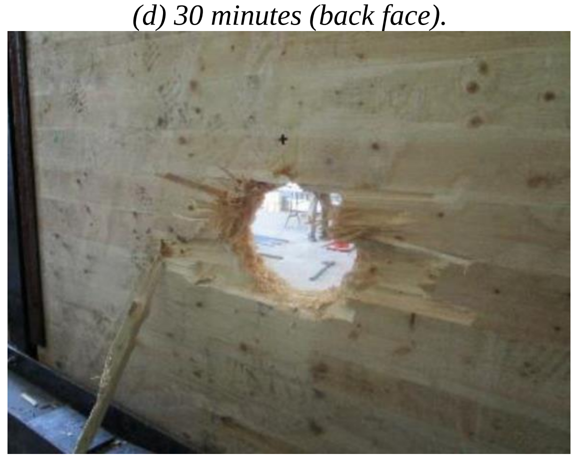
(b) 15 minutes (front face).

(c) 30 minutes (front face).

(d) 30 minutes (back face).



(e) 44 minutes (front face).



(f) 44 minutes (back face).

Figure 4-4. FE Test Photographs.

4.2.2 Discussion

The baseline CLT panel tested in the FE proof-of-concept test is likely to be the worst performer among the candidate panel designs when exposed to the blunt impact of a wood axe (or other tools in the SD-STD-01.01 toolset). Its relatively low density and hardness make it susceptible to being broken down quickly by a wood axe. CLT panels composed of different species with higher density or hardness should perform better in an FE test.

Many DOS facilities require 15-minute FE protection on the exterior envelope of the building up to the first floor. It is clear from this test that a 7-ply CLT panel of virtually any softwood species should be able to meet this requirement. As modification to the CLT panel is already required to comply with the DOS blast and ballistic resistance design requirements, it is likely that these required modifications will allow for CLT panels to achieve over 60 minutes of protection based on the results of this FE test.

4.3 SUMMARY

The proof-of-concept tests demonstrated the following key conclusions:

- Steel materials can be integrated into CLT panel layups without the use of mechanical anchorage such as thru-bolts. Although Sanborn indicated that steel-timber bond line failure was possible without this anchorage [20], small-scale destructive tests on these candidate panel designs indicated that fiber tear, rather than adhesive debonding, was the mode of failure along the steel-timber bond line.

- CLT panels can be modified to defeat the ballistic DBT defined in SD-STD-01.01 in a relatively cost-effective fashion. Among the candidate panel designs considered, the optimal means of defeating these projectiles is by introducing steel plates into the layup. While the addition of steel plates adds cost, the cost markup associated with integrating plates is smaller than introducing wire mesh or species of hardwood that could defeat the DOS ballistic threat projectiles.

- The baseline CLT panel was very effective by itself in stopping the FE attack defined in SD-STD-01.01. A standard 7-ply CLT panel consisting of No. 2 SPF-S lumber in both the major and minor strength directions was capable of resisting FE attack for 44 minutes. If 60-minute protection is desired, a harder and/or more dense wood, or some kind of steel element can be incorporated into the CLT panel's layup to provide this protection.

CHAPTER 5

SUMMARY / CONCLUSIONS / RECOMMENDATIONS

5.1 SUMMARY & CONCLUSIONS

Buildings for the DOS and DOD often have to meet blast, ballistic, and FE design requirements to mitigate the hazardous effects associated with terrorism. Historically, buildings exposed to these threats have been constructed using concrete and steel. However, the emergence of CLT presents an opportunity to provide a sustainable building material alternative to owners and architects developing such structures. Several wood characteristics (i.e., propensity to rupture in a brittle fashion upon being overstressed, relatively low penetration resistance) serve to limit CLT's effectiveness in resisting blast, ballistic, and FE threats. Thus, the purpose of this effort was to explore the feasibility of incorporating COTS building materials into CLT panel designs in order to address these limitations and meet DOS blast, ballistic, and FE design requirements. Particular emphasis was placed on ensuring the developed panel designs are cost competitive to facilitate their inclusion in actual buildings.

At the outset of the effort, a literature review was performed to determine the state-of-the-science with regard to designing CLT panels for blast, ballistic, and FE threats. The outcome of this literature review was that the ballistic performance of CLT panels represented the major technical barrier to complying with the blast, ballistic, and FE provisions of SD-STD-01.01 (i.e., the DOS standard responsible for defining FE/BR design requirements). Thus, the focus of candidate panel design development was to defeat the ballistic threat.

Seven candidate panel designs that varied wood species (i.e., SPF-S softwood, Shagbark Hickory hardwood, and American Sycamore hardwood) and COTS materials (i.e., steel plate, steel wire mesh) integrated into the layup were developed. The following principles governed candidate panel design development:

- The candidate panel designs were limited to roughly 10 inches in thickness to be consistent with existing concrete and steel wall systems used in DOS facilities.

- Symmetric CLT panel layups were developed to allow for equal inbound and rebound stiffness and strength in light of the DOS blast DBT.

- The CLT panel's exterior and interior surfaces were kept free of blast or FE/BR cladding materials in order to not impede viewing the wood's natural finish and remove the need for potentially costly cladding systems.

- The COTS materials integrated into the panel considered cost. (This principle effectively eliminated some materials (e.g., densified wood, FRP, UHMWPE) from consideration.)

In addition to the seven developed candidate panel designs, a baseline panel was used to benchmark cost and performance results. The baseline panel selected for this effort was the 7-ply SL-V4 panel manufactured by SmartLam; this panel is 9.625 inches thick and is manufactured using No. 2 SPF-S lumber in both directions. No. 2 SPF-S has a relatively low density, hardness, and toughness (i.e., when compared to other wood species), and thus serves as a reasonable estimate for the lower bound ability of wood to resist the DOS ballistic DBT.

The seven candidate and baseline panel designs were subjected to ballistic testing performed in accordance with SD-STD-01.01. Three duplicate tests were performed for each candidate design / ammunition round combination. The testing indicated that a CLT panel with embedded steel plates represented the optimal means to defeat the DOS ballistic DBTs from both a cost and weight perspective.

Following the ballistic testing, a single FE test was performed on the baseline CLT panel (i.e., 7-ply SPF-S in both directions) to assess the effectiveness of CLT in resisting an FE attack. This test found that the panel was capable of resisting an FE attack in accordance with SD-STD-01.01 for 44 minutes.

The following general conclusions can be made from this work:

- Steel materials can be integrated into CLT panel layups without the use of mechanical anchorage such as thru-bolts. Although Sanborn indicated that steel-timber bond line failure was possible without this anchorage [20], small-scale destructive tests on these candidate panel designs indicated that fiber tear, rather than adhesive debonding, was the mode of failure along the steel-timber bond line.

- CLT panels can be modified to defeat the ballistic DBT defined in SD-STD-01.01 in a relatively cost-effective fashion. Among the candidate panel designs considered, the optimal means of defeating these projectiles is by introducing steel plates into the layup. While the addition of steel plates adds cost, the cost markup associated with integrating plates is smaller than introducing wire mesh or species of hardwood that could defeat the DOS ballistic threat projectiles.

- The baseline CLT panel was very effective by itself in stopping the FE attack defined in SD-STD-01.01. A standard 7-ply CLT panel consisting of No. 2 SPF-S lumber in both the major and minor strength directions was capable of resisting FE attack for 44 minutes. If 60-minute protection is desired, a harder and/or more dense wood, or some kind of steel element can be incorporated into the CLT panel's layup to provide this protection.

5.2 NEXT STEPS

As past blast testing on CLT panels has shown CLT panels can effectively resist blast loads in a predictable fashion, the focus of this effort was specifically to investigate the FE/BR aspects of protective design. Additionally, blast testing of CLT panels is costly and thus it behooves one to advance through a candidate selection process prior to proceeding with blast testing. As the results of this effort indicated that it is feasible to defeat the DOS ballistic and FE DBTs with a CLT panel in a cost-effective fashion, additional tests are warranted to demonstrate CLT performance across all of the DOS DBTs:

- While small-scale destructive testing indicated that CLT panels with embedded steel plates can be fabricated so as not to delaminate at bond lines prior to wood fiber tear, this finding has not yet been tested at the panel level. Testing investigating the quasi-static out-of-plane response of CLT panels is necessary.

- Similarly, blast testing to confirm that CLT panels with embedded steel plates do not exhibit bond line failure under high strain rates is needed as well.

- The testing performed to this point has focused on the panel itself. Additional efforts specifically related to detailing around openings (i.e., doors, windows) and panel seams are required to ensure the blast, ballistic, and FE resistance is maintained at these locations in CLT panels. Additional testing or analysis that is approved by the DOS is necessary to qualify these areas are in conformance with DOS protective design criteria.

- Attendant with the above, design procedures to establish the CLT panel strength under quasi-static (i.e., PRG 320) and blast loads (i.e., PDC-TR 18-02) have only been established for CLT panels without embedded materials. These standards would need to be updated to allow incorporation of materials into CLT panel layups.

APPENDIX A

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APPENDIX B

BALLISTIC TESTING REPORT

H.P. White Laboratory, Inc.

An Intertek Company ISO-5.10-FR15.10

Ballistic Resistance – Test Report

Client:	**Karagozian and Case** Attention: Mark Weaver 700 N. Brand Blvd., Suite 700 Glendale, CA 91203 United States
Report date:	**30 March 2020**
Job number:	HPW000009999A
Test procedure and supporting documentation:	Per Customer Instructions SD-STD-01.01
Sample receipt, identification information, and disposition:	The sample(s) were received on **4 March 2020**. Sample item identification and description details are provided on the attached data record(s). The test sample(s) were inspected prior to testing and no anomalies were discovered. Sample(s) will be returned or discarded per customer instructions. H.P. White will only hold sample(s) as required by specific test protocols.
Test date(s) and location:	Testing commenced on **9 March 2020**, at the H.P. White Laboratory, Inc. facilities located at 3114 Scarboro Road, Street, Maryland. Testing concluded on **10 March 2020**.
Report prepared by:	Chris D'Amario, Engineer
Report reviewed by:	Rob Kinsler, Chief of Technical Operations
Revision number and date:	NA
Supplement to report:	NA
Test data transmittal method and storage location:	This test report and test data were transmitted via email in a manner compliant with ISO 17025 requirements. Permanent electronic and hardcopy files are maintained in accordance with HPWLI data storage policy on data storage systems, filed by job number.
Disclaimer:	Testing was performed on sample(s) provided by the client. H.P. White Laboratory, Inc. holds no responsibility for sample selection methods. This report is based on data obtained from testing only the sample(s) submitted and should NOT be interpreted as an endorsement by H.P. White Laboratory, Inc. of the continuing quality or performance of any other items of the same, or similar, design. This report must not be used by the client to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the Federal Government. This testing was performed by H.P. White Laboratory, Inc. to client specification, and the test results are the property of the client, who holds all rights of reproduction or publication of this report and related test data.
Destination control statement:	This document may contain items controlled by the U.S. government and authorized for export only to the country of ultimate destination for use by the ultimate consignee or end-user(s) herein identified. They may not be resold, transferred, or otherwise disposed of, to any other country or to any person other than the authorized ultimate consignee or end-user(s), either in their original form or after being incorporated into other items, without first obtaining approval from the U.S. government or as otherwise authorized by U.S. law and regulations.

Karagozian and Case
Attention: Mark Weaver
30 March 2020
HPWLI HPW000009999A

Test Procedures

Ballistic Resistance Testing: All testing was conducted on an indoor range at ambient conditions, in accordance with your instructions and the general provisions of SD-STD.01.01. Testing was conducted using caliber 7.62mm Ball, M80, 149gr.; 5.56mm Ball, M193, 55gr.; 5.54x45mm, M855, 62gr. ammunition. The test sample(s) were positioned 20.0 feet from the muzzle of the barrel to produce zero (0°) degree obliquity impacts. Photoelectric infrared screens were located at 5.0 feet and 15.0 feet which, in conjunction with electronic chronographs, were used to compute bullet velocities at 10.0 feet forward of the muzzle. The striking velocity was computed using standard drag formulas. Complete and partial penetrations were determined by visual examination of the high-speed video to obtain the residual velocity of the complete penetrations. Table I provides a summary of information on the attached data record(s).

Table I: Ballistic Resistance, Summary of Results

Sample No.	Thickness (in)	Size (in.)	Weight (lbs.)	Caliber	Obliquity (degrees°)	Shots (a)	Velocity (fps)	Residual Velocity (fps)	Penetrations
1-A	9.75	18 x 18	49.0	M80	0°	3	2848	2306	1
				M193			3244	1846	1
				M855			3068	656	1
1-B	9.75	18 x 18	49.5	M80	0°	3	2833	2484	1
				M193			3254	1267	1
				M855			3079	612	1
1-C	9.75	18 x 18	51.6	M80	0°	3	2808	2514	1
				M193			3258	1070	1
				M855			3047	1387	1
2-A	8.9375	18.75 x 18.75	97.5	M80	0°	3	2806	-	0
				M193			NR	-	0
				M855			3095	-	0
2-B	8.875	18.75 x 19	96.0	M80	0°	3	2808	-	0
				M193			3244	-	0
				M855			3064	-	0
2-C	8.875	18.25 x 18.75	94.8	M80	0°	3	2807	-	0
				M193			3240	-	0
				M855			3051	-	0
3-A	9.25	18.75 x 18	76.0	M80	0°	3	2801	2031	1
				M193			3221	-	0
				M855			3044	-	0
3-B	9.25	18.75 x 18.5	76.0	M80	0°	3	2823	2090	1
				M193			3264	-	0
				M855			3077	-	0
3-C	9.1875	18.5 x 18.5	76.3	M80	0°	3	2822	(b)	1
				M193			3208	-	0
				M855			3094	-	0
4-A	9.125	18 x 18	56.3	M80	0°	3	2738	2315	1
				M193			3223	-	0
				M855			3084	705	1
4-B	9.125	18 x 18	56.9	M80	0°	3	2786	1858	1
				M193			3233	-	0
				M855			3073	612	1
4-C	9.125	18 x 18	55.4	M80	0°	3	2783	2430	1
				M193			3235	1836	1
				M855			3078	341	1

Karagozian and Case
Attention: Mark Weaver
30 March 2020
HPWLI HPW000009999A

ISO-5.10-FR15.10

Table I: Ballistic Resistance, Summary of Results

Sample No.	Thickness (in)	Size (in.)	Weight (lbs.)	Caliber	Obliquity (degrees°)	Shots (a)	Velocity (fps)	Residual Velocity (fps)	Penetrations
5-A	9.9375	18.5 x 18.5	76.9	M80	0°	3	2791	-	0
				M193			3248	-	0
				M855			3059	-	0
5-B	9.875	18.5 x 18.5	77.2	M80	0°	3	2813	-	0
				M193			3298	-	0
				M855			3062	-	0
5-C	10	18.5 x 18.5	79.1	M80	0°	3	2748	-	0
				M193			3298	-	0
				M855			3088	-	0
6-A	10.1875	19 x 19	77.5	M80	0°	3	2818	-	0
				M193			3269	-	0
				M855			3044	-	0
6-B	10.1875	18.75 x 19	77.4	M80	0°	3	2823	1079	1
				M193			3283	-	0
				M855			3102	-	0
6-C	10.25	19 x 19.25	79.4	M80	0°	3	2816	177	1
				M193			3255	-	0
				M855			3070	-	0
7-A	10.3125	19 x 19.25	83.6	M80	0°	3	2818	-	0
				M193			3260	-	0
				M855			3074	-	0
7-B	10.3125	18.75 x 19	81.0	M80	0°	3	2835	-	0
				M193			3247	-	0
				M855			3092	-	0
7-C	10.3125	19 x 19	84.0	M80	0°	3	2812	-	0
				M193			3219	-	0
				M855			3070	-	0
8-A	10.125	18.5 x 18.5	99.1	M80	0°	3	2745	-	0
				M193			3209	-	0
				M855			3085	-	0
8-B	10.125	18.5 x 19	101.0	M80	0°	3	2793	-	0
				M193			3228	-	0
				M855			3056	-	0
8-C	10.125	18.75 x 18.25	100.9	M80	0°	3	2804	-	0
				M193			3248	-	0
				M855			3109	-	0

(a) See individual data record(s) for specific footnotes/remarks
(b) Did not obtain high speed video for this shot, did not obtain residual velocity

Report prepared by:

Chris D'Amario
Engineer

Report reviewed by:

Rob Kinsler
Chief of Technical Operations

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 18 x 18 x 9.75 in.
Thicknesses : NA
Avg. Thick. : NA
Description : BASELINE SOFTWOOD

Sample No. : 1-A
Weight : 49.0 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3503	2855	3503	2855	2855	6	2848	Bullet	
2	2	3070	3257	3071	3256	3257	13	3244	Bullet	
3	3	3246	3081	3246	3081	3081	13	3068	Bullet	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 1-B
Size : 18 x 18 x 9.75 in.
Weight : 49.5 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : BASELINE SOFTWOOD

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3521	2840	3522	2839	2840	6	2833	Bullet	
2	2	3060	3268	3062	3266	3267	13	3254	Bullet	
3	3	3234	3092	3234	3092	3092	13	3079	Bullet	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 18 x 18 x 9.75 in.
Thicknesses : NA
Avg. Thick. : NA
Description : BASELINE SOFTWOOD

Sample No. : 1-C
Weight : 51.6 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3552	2815	3554	2814	2815	6	2808	Bullet	
2	2	3056	3272	3058	3270	3271	13	3258	Bullet	
3	3	3268	3060	3268	3060	3060	13	3047	Bullet	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 18.75 x 18.75 x 8.9375 in.
Thicknesses : NA
Avg. Thick. : NA
Description : BASELINE HARDWOOD

Sample No. : 2-A
Weight : 97.5 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3556	2812	3556	2812	2812	6	2806	None	
2	2	NR	NR	NR	NR	NR	NR	NR	None	
3	3	3217	3108	3218	3108	3108	13	3095	None	

REMARKS :

FOOTNOTES :

Filename : 000009999 (2-A) 7475 KARAGOZIAN AND CASE.Pen

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 18.75 x 19 x 8.875 in.
Thicknesses : NA
Avg. Thick. : NA
Description : BASELINE HARDWOOD

Sample No. : 2-B
Weight : 96.0 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3552	2815	3554	2814	2815	6	2808	None	
2	2	3070	3257	3071	3256	3257	13	3244	None	
3	3	3250	3077	3250	3077	3077	13	3064	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 18.25 x 18.75 x 8.875 in.
Thicknesses : NA
Avg. Thick. : NA
Description : BASELINE HARDWOOD

Sample No. : 2-C
Weight : 94.8 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3555	2813	3555	2813	2813	6	2807	Spall	
2	2	3074	3253	3075	3252	3253	13	3240	None	
3	3	3263	3065	3264	3064	3064	13	3051	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 3-A
Size : 18.75 x 18 x 9.25 in.
Weight : 76.0 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : HARDWOOD/SOFTWOOD COMBO A

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3561	2808	3563	2807	2807	6	2801	Bullet	
2	2	3092	3234	3093	3233	3234	13	3221	None	
3	3	3271	3057	3272	3056	3057	13	3044	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 3-B
Size : 18.75 x 18.5 x 9.25 in.
Weight : 76.0 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : HARDWOOD/SOFTWOOD COMBO A

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3534	2830	3535	2829	2829	6	2823	Bullet	
2	2	3051	3278	3052	3277	3277	13	3264	None	
3	3	3236	3090	3237	3089	3090	13	3077	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 3-C
Size : 18.5 x 18.5 x 9.1875 in.
Weight : 76.3 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : HARDWOOD/SOFTWOOD COMBO A

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3536	2828	3536	2828	2828	6	2822	Bullet	
2	2	3104	3222	3105	3221	3221	13	3208	None	
3	3	3218	3108	3219	3107	3107	13	3094	None	

REMARKS :

FOOTNOTES :

Filename : 000009999 (3-C) 7475 KARAGOZIAN AND CASE.Pen

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 4-A
Size : 18 x 18 x 9.125 in.
Weight : 56.3 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : INTERLOCKING GRAIN AND SOFTWOOD COMBO A

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3642	2746	3645	2743	2745	6	2738	Bullet	
2	2	3090	3236	3091	3235	3236	13	3223	None	
3	3	3228	3098	3229	3097	3097	13	3084	Bullet	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 4-B
Size : 18 x 18 x 9.125 in.
Weight : 56.9 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : INTERLOCKING GRAIN AND SOFTWOOD COMBO A

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3581	2793	3583	2791	2792	6	2786	Bullet	
2	2	3081	3246	3081	3246	3246	13	3233	None	
3	3	3240	3086	3241	3085	3086	13	3073	Bullet	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 4-C
Size : 18 x 18 x 9.125 in.
Weight : 55.4 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : INTERLOCKING GRAIN AND SOFTWOOD COMBO A

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. — Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. — Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. — Lot No. : HPW-0028
(4) : — Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3584	2790	3586	2789	2789	6	2783	Bullet	
2	2	3078	3249	3079	3248	3248	13	3235	Bullet	
3	3	3235	3091	3236	3090	3091	13	3078	Bullet	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 5-A
Size : 18.5 x 18.5 x 9.9375 in.
Weight : 76.9 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR 10Ga. STEEL

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3574	2798	3577	2796	2797	6	2791	None	
2	2	3066	3262	3067	3261	3261	13	3248	None	
3	3	3255	3072	3256	3071	3072	13	3059	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 5-B
Size : 18.5 x 18.5 x 9.875 in.
Weight : 77.2 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR 10Ga. STEEL

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3546	2820	3548	2818	2819	6	2813	None	
2	2	3020	3311	3021	3310	3311	13	3298	None	
3	3	3252	3075	3253	3074	3075	13	3062	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 5-C
Size : 18.5 x 18.5 x 10 in.
Weight : 79.1 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR 10Ga. STEEL

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3630	2755	3633	2753	2754	6	2748	None	
2	2	3020	3311	3020	3311	3311	13	3298	None	
3	3	3224	3102	3225	3101	3101	13	3088	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 19 x 19 x 10.1875 in.
Thicknesses : NA
Avg. Thick. : NA
Description : SPRUCE-PINE-FIR FINE MESH

Sample No. : 6-A
Weight : 77.5 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3540	2825	3542	2823	2824	6	2818	None	
2	2	3046	3283	3047	3282	3282	13	3269	None	
3	3	3271	3057	3271	3057	3057	13	3044	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 6-B
Size : 18.75 x 19 x 10.1875 in.
Weight : 77.4 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR FINE MESH

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3533	2830	3535	2829	2830	6	2823	Bullet	
2	2	3033	3297	3034	3296	3297	13	3283	None	
3	3	3210	3115	3210	3115	3115	13	3102	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 19 x 19.25 x 10.25 in.
Thicknesses : NA
Avg. Thick. : NA
Description : SPRUCE-PINE-FIR FINE MESH

Sample No. : 6-C
Weight : 79.4 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3543	2822	3544	2822	2822	6	2816	Bullet	
2	2	3059	3269	3060	3268	3269	13	3255	None	
3	3	3243	3084	3244	3083	3083	13	3070	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 19 x 19.25 x 10.3125 in.
Thicknesses : NA
Avg. Thick. : NA
Description : SPRUCE-PINE-FIR COARSE MESH

Sample No. : 7-A
Weight : 83.6 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3540	2825	3541	2824	2824	6	2818	None	
2	2	3055	3273	3056	3272	3273	13	3260	None	
3	3	3239	3087	3239	3087	3087	13	3074	None	

REMARKS :

FOOTNOTES :

Filename : 000009999 (7-A) 7475 KARAGOZIAN AND CASE.Pen

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 7-B
Size : 18.75 x 19 x 10.3125 in.
Weight : 81.0 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR COARSE MESH

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3518	2843	3520	2841	2842	6	2835	None	
2	2	3067	3261	3068	3259	3260	13	3247	None	
3	3	3220	3106	3221	3105	3105	13	3092	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/9/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 7-C
Size : 19 x 19 x 10.3125 in.
Weight : 84.0 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR COARSE MESH

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3547	2819	3549	2818	2818	6	2812	None	
2	2	3093	3233	3095	3231	3232	13	3219	None	
3	3	3243	3084	3244	3083	3083	13	3070	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/10/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Size : 18.5 x 18.5 x 10.125 in.
Thicknesses : NA
Avg. Thick. : NA
Description : SPRUCE-PINE-FIR 1/4" STEEL PLATE

Sample No. : 8-A
Weight : 99.1 lbs.
Hardness : NA
Plies/Laminates : NA

Date Rec'd. : 3/4/2020
Via :
Returned :

SET-UP

Shot Spacing : PER CUSTOMER REQUEST
Witness Panel : NA
Obliquity : 0 deg.
Backing Material : NA
Conditioning : AMBIENT

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Primary Vel. Location : 10.0 ft. From Muzzle
Residual Vel. Screens : NA
Residual Vel. Location : NA
Range to Target : 20.0 ft.
Target to Wit. : 0.0 in.

Range No. : 7
Temp. : 62 F
BP : 30.42 in. Hg
RH : 34%
Barrel No./Gun :
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3634	2752	3635	2751	2751	6	2745	None	
2	2	3103	3223	3104	3222	3222	13	3209	None	
3	3	3226	3100	3229	3097	3098	13	3085	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/10/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 8-B
Size : 18.5 x 19 x 10.125 in.
Weight : 101.0 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR 1/4" STEEL PLATE

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3572	2800	3573	2799	2799	6	2793	None	
2	2	3085	3241	3086	3240	3241	13	3228	None	
3	3	3257	3070	3259	3068	3069	13	3056	None	

REMARKS :

FOOTNOTES :

H.P. White Laboratory, Inc.

BALLISTIC RESISTANCE TEST

Client : 7475: KARAGOZIAN AND CASE

Job No. : 000009999 Test Date : 3/10/20

TEST PANEL

Manufacturer : KARAGOZIAN AND CASE
Sample No. : 8-C
Size : 18.75 x 18.25 x 10.125 in.
Weight : 100.9 lbs.
Date Rec'd. : 3/4/2020
Thicknesses : NA
Hardness : NA
Via :
Avg. Thick. : NA
Plies/Laminates : NA
Returned :
Description : SPRUCE-PINE-FIR 1/4" STEEL PLATE

SET-UP

Primary Vel. Screens : 5.0 ft., 15.0 ft.
Range No. : 7
Shot Spacing : PER CUSTOMER REQUEST
Primary Vel. Location : 10.0 ft. From Muzzle
Temp. : 62 F
Witness Panel : NA
Residual Vel. Screens : NA
BP : 30.42 in. Hg
Obliquity : 0 deg.
Residual Vel. Location : NA
RH : 34%
Backing Material : NA
Range to Target : 20.0 ft.
Barrel No./Gun :
Conditioning : AMBIENT
Target to Wit. : 0.0 in.
Gunner : D'AMARIO
Recorder : MILLER

AMMUNITION

(1) : 7.62mm Ball, M80, 149 gr. Lot No. : HPW-M80SJ-01
(2) : 5.56mm Ball, M193, 55 gr. Lot No. : HPW-0078
(3) : 5.56x45mm, M855, 62 gr. Lot No. : HPW-0028
(4) : Lot No. :

APPLICABLE STANDARDS OR PROCEDURES

(1) : SD-STD-01.01
(2) :
(3) :

Shot No.	Ammo.	Time 1 (usec)	Velocity 1 (ft/s)	Time 2 (usec)	Velocity 2 (ft/s)	Avg. Vel. (ft/s)	Vel. Loss (ft/s)	Strike Vel. (ft/s)	Penetration	Footnotes
1	1	3557	2811	3559	2810	2811	6	2804	None	
2	2	3066	3262	3067	3261	3261	13	3248	None	
3	3	3203	3122	3204	3121	3122	13	3109	None	

REMARKS :

FOOTNOTES :

APPENDIX C

BALLISTIC TESTING COMPUTED RADIOGRAPHY REPORT

Radiographic Inspection Report

Page 1 of 2

DT No. 54841 Date 4/8/2020 Time of Completion N/A

Customer Karagozian & Case Project CR of CLT Panels

PO No. N/A Component No. See below

Material Wood Thickness Varies Reinforcement N/A IQI N/A Joint Type N/A

Exposure Tech SWE/SWV Source to Film Distance 97” UG Factor Sat Original ☒ Repair ☐ No .N/A

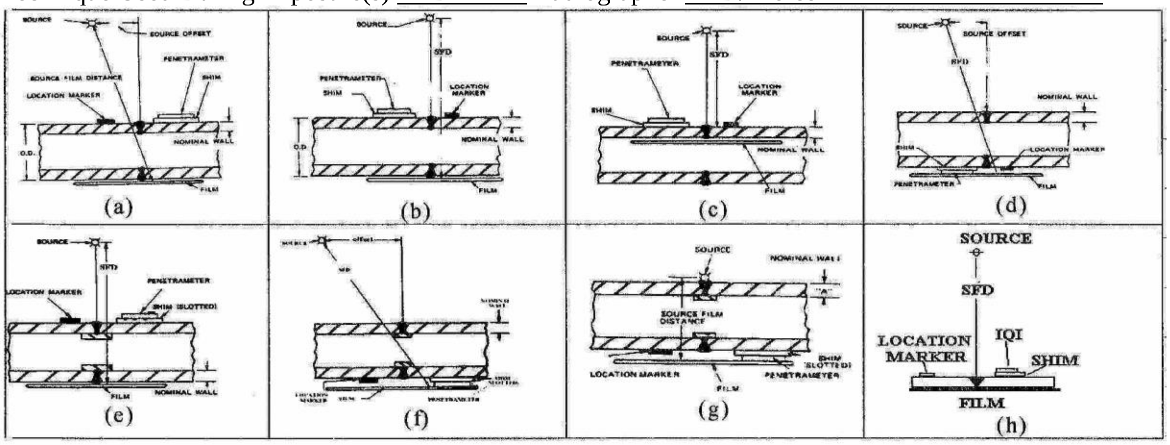
Procedure Spec. MQC CRI-1 Rev. 0 Interpretation Std. Information Only Class/Grade N/A

X-Ray Machine S/N 29508A Focal Spot 3mm Ir-192 Isotope S/N N/A Phys. Dimen. N/A

KV 100 MA 10 Time 6 Min. Curies N/A Exposure Time N/A

Film Type ST-VI Size 14” X 17” Screens N/A Per Exposure 1 Per Cassette 1

Technique Used During Exposure(s) B Radiographer B. Pierce NDT Level N/A



Technique Remarks

Exposure Identification	View	ACCEPT	REJECT	SLAG	POROSITY	L.O.F.	I.P.	CONCAVITY	BURN THROUGH	UNDERCUT	CRACK	OTHER	Quality Level	Film Density	Remarks
CLT Panels	2-A,B,C												N/A	N/A	See following page for
	3-A,B,C												N/A	N/A	measurements
	4-A,B												N/A	N/A	
	5-A,B,C												N/A	N/A	
	6-A,B,C												N/A	N/A	
	7-A,B,C												N/A	N/A	
	8-A,B,C												N/A	N/A	

✓ – Acceptable X – Rejectable Radiographer N/A NDT Level N/A

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Daily Report Supplement

Project Name: Computed Radiography of various CLT panels DT No: 54841

Customer Name: Karagozian & Case Date: 4/7/2020

Inspection of: Projectile penetration in CLT Panels Technician: Brian Pierce

Panel	Round			Depth as measured			Calculated Depth		
	M80	M193	M855	M80	M193	M855	M80	M193	M855
1-A	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
1-B	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
1-C	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
2-A	1	1	1	1.913"	5.014"	4.608"	1.555"	4.546"	4.177"
2-B	1	1	1	1.939"	6.423"	4.841"	1.577"	5.823"	4.389"
2-C	1	1	1	surface	5.986"	5.115"	0"	5.427"	4.637"
3-A	0	1	1	N/A	2.599"	2.837"	N/A	2.391"	2.75"
3-B	0	1	1	N/A	4.075"	4.035"	N/A	3.75"	3.712"
3-C	0	1	1	N/A	4.585"	2.975"	N/A	4.218"	2.737"
4-A	0	1	0	N/A	2.173"	N/A	N/A	1.998"	N/A
4-B	0	1	0	N/A	.943"	N/A	N/A	.867"	N/A
4-C	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
5-A	1	1	1	1.392"	3.910"	1.512"	1.18"	3.597"	1.391"
5-B	1	1	1	2.055"	3.642"	2.598"	1.743"	3.35"	2.39"
5-C	1	1	1	1.909"	4.317"	2.929"	1.636"	3.971"	2.695"
6-A	1	1	1	1.884"	5.573"	3.941"	1.597"	5.127"	3.626"
6-B	0	1	1	N/A	5.417"	4.13"	N/A	4.983"	3.799"
6-C	0	1	1	N/A	5.841"	5.996"	N/A	5.374"	5.516"
7-A	1	1	1	1.85"	4.118"	4.577"	1.569"	3.789"	4.212"
7-B	1	1	1	2.108"	4.602"	3.825"	1.787"	4.233"	3.519"
7-C	1	1	1	1.931"	5.189"	3.533"	1.636"	4.774"	3.25"
8-A	1	1	1	5.006"	6.524"	2.937"	4.244"	6"	2.701"
8-B	1	1	1	4.632"	6.119"	3.366"	3.927"	5.63"	2.956"
8-C	1	1	1	4.404"	6.073"	3.006"	3.734"	5.588"	2.765"
0 = Round penetrated panel; should not be in panel									
1 = Round should be in panel									
Note: Measurements taken from the exit side of the panels.									

APPENDIX D

FORCED ENTRY TESTING REPORT

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U.S. FOREST SERVICE FORCED ENTRY TEST REPORT

SCOPE OF WORK
SD-STD-01.01 REVISION G (AMENDED) TESTING ON 9-5/8 INCH THICK 7-PLY CROSS-LAMINATED TIMBER PANEL

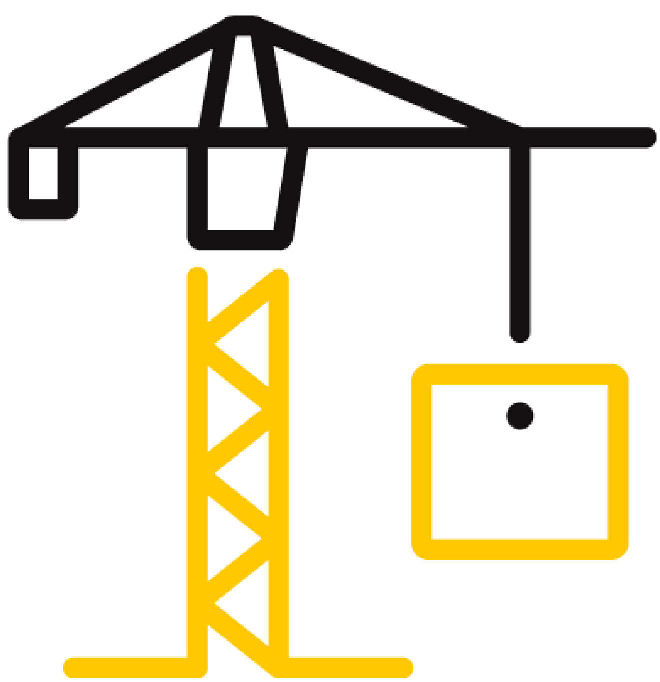
REPORT NUMBER
L1309.01-119-12 R0

TEST DATE
06/30/20

ISSUE DATE
07/22/20

PAGES
12

DOCUMENT CONTROL NUMBER
ATI 00712 (07/24/17)
RT-R-AMER-Test-2801



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TEST REPORT FOR U.S. FOREST SERVICE
Report No.: L1309.01-119-12 R0
Date: 07/22/20

REPORT ISSUED TO
U.S. FOREST SERVICE
One Gifford Pinchot Drive
Madison, Wisconsin 53726-2398

SECTION 1
SCOPE

Intertek Building & Construction (B&C) was contracted by the U.S. Forest Service, Madison, Wisconsin to perform testing in accordance with SD-STD-01.01, Revision G (Amended) on a 9-5/8 inch thick, 7-ply cross-laminated timber panel. Results obtained are tested values and were secured by using the designated test methods. Testing was conducted at the Intertek B&C test facility in York, Pennsylvania.

This report does not constitute certification of this product nor an opinion or endorsement by this laboratory.

SECTION 2
SUMMARY OF TEST RESULTS

Product Type: 9-5/8 inch thick, No. 2 Spruce-Pine-Fir (South) plies in both directions 7-ply Cross-Laminated Timber Panel
Specimen ID: 7.a.V4 (SPFS)
Testing Category: SD-STD-01.01, Revision G (Amended) - 60 minute protection level

TEST SPECIMEN NO. 1
Failed to achieve 60-minute protection level
Total attack time to failure: 44 minutes and 00 seconds

For INTERTEK B&C:

COMPLETED BY:	Robert G. Spayd	**REVIEWED BY:**	V. Thomas Mickley, Jr., P.E.
TITLE:	Technician II	**TITLE:**	Senior Staff Engineer
SIGNATURE:		**SIGNATURE:**	
DATE:	07/22/20	**DATE:**	07/22/20

RGS:vtm/aas

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SECTION 3
TEST METHODS

The test specimen was evaluated in accordance with the following:

> **SD-STD-01.01, Revision G (Amended 1993)**, *Certification Standard, Forced Entry and Ballistic Resistance of Structural Systems*

The specimen was evaluated to the following testing levels in accordance with SD-STD-01.01 Revision G (Amended):

> **Forced Entry Resistance:** 60 minutes

SECTION 4
MATERIAL SOURCE/INSTALLATION

The test specimen was provided by SmartLam North America in good condition. Representative samples of the test specimens will be retained by Intertek B&C for a minimum of four years from the test completion date.

The specimen was attached on both sides with 1/2 inch lag bolts to two steel angles oriented to form a Z-shaped section appropriate for the depth of the wall construction. Installation of the tested product was performed by Intertek B&C.

SECTION 5
LIST OF OFFICIAL OBSERVERS

NAME	COMPANY
Mark Weaver, S.E.	Karagozian & Case (Remote)
Alec Williamson	DOS DS (Remote)
Jessica Inman	DOS DS (Remote)
Shane Maxemow	DOS OBO (Remote)
Harry Kappler	DOS OBO (Remote)
Adam Senalik	FPL (Remote)
Marco Lo Ricco	FPL (Remote)
Robert Tudhope	SmartLam (Remote)
Jason Cattelino	SmartLam (Remote)
Jim Henjum	SmartLam (Remote)
Steve Marshall	SmartLam (Remote)
Peter van der Meulen	ZGF (Remote)
Lauren Stewart	Georgia Tech (Remote)
Karen Gesa	WoodWorks (Remote)
Travis A. Hoover	Intertek B&C
V. Thomas Mickley, Jr., P.E.	Intertek B&C

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SECTION 6
EQUIPMENT

SD-STD-01.01, Revision G (Amended), Certification Standard, Forced Entry and Ballistic Resistance of Structural Systems

Table II. Forced Entry Test Resources

RESOURCE	DESCRIPTION	QUANTITY	UTILIZATION
Active Personnel	--	6	Yes
Sledge Hammer	12 lbs, Double Faced, 30 inch	2	Yes
Carpenter Hammer	3 lbs	2	No
Carpenter Hammer	1 lb	2	No
Ram	120 lbs, 2 Man, 4 X 4 inch	1	No
Wood Splitting Maul	9 lbs, 35 inch	1	Yes
Wood Axe, Single Bit	3-1/2 lbs, 36 inch	2	Yes
Crowbar, Pinch Bar	60 inch	2	Yes
Crowbar, Ripping Bar	48 inch	2	No
Crowbar	24 inch	2	No
Metal Wedge, Wood Splitting	9 X 2-1/2 inch	4	No
Hacksaw	12 inch	2	Yes
Keyhole Saw	Wood, 12 inch	1	No
Bolt Cutters	48 inch	1	No
End Nippers	14 inch	1	No
Chisel, Cold	1 inch	2	No
Chisel, Cold	3/4 inch	2	No
Chisel, Masonry	2-1/4 inch	2	No
Screwdriver, Flat Blade	10 inch	2	No
Screwdriver, Flat Blade	Medium, 1/4 inch	2	No
Screwdriver, Phillips	10 inch	2	No
Screwdriver, Phillips	No. 1	2	No
Channel Locks	10 inch	1	No
Adjustable Wrench	15 inch	1	No
Adjustable Wrench	10 inch	1	No
Punch	3/8 inch	1	No
Punch	1/4 inch	1	No
Torch, Propane	Portable	1	No
Vice Grip	12 inch	1	No
Push Broom	Wooden	1	No

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SECTION 7
TEST SPECIMEN DESCRIPTION

MANUFACTURER	SmartLam North America
PRODUCT TYPE	Cross-Laminated Timber Panel
SPECIMEN ID	7.A.V4 (SPFS)
OVERALL SIZE	96 inch x 96 inch x 9-5/8 inch thick
SHEATHING/FINISH	N/A
REENFORCEMENT	N/A
MATERIAL	1-3/8 inch thick, No. 2 SPF (South) plies in both directions, 7-ply

SECTION 8
TEST PROCEDURE

Each sample was rigidly mounted for forced entry resistance testing. The resources (tools) for forced entry testing were provided to test personnel, in addition to a 305mm x 305mm x 200mm (12 inch x 12 inch x 8 inch) rigid rectangular shape and a 305mm x 305mm (12 inch x 12 inch) cylinder representing a man passable opening. A tripod-mounted video camera was used to record the entire forced entry test sequence. Concentrated assault team members are listed in the following table.

Test Personnel

NAME	AGE (yrs)	WEIGHT (lbs)	ITERATION
Lee Lerew	24	150	1, 2 and 3
Andrew Johnston	25	175	1, 2 and 3
Jordan Gault	23	245	1, 2 and 3
Richard Hartman	33	180	1, 2 (half) and 3
Cory Straub	33	215	2 (half) and 3
Tyler Holland	30	210	1 and 2
Isaiah Gebhart	36	185	1, 2 and 3

Description of Attack

TEST SPECIMEN NO.	SPECIMEN ID	LOCATION OF ATTACK
1	7.A.V4 (SPFS)	Center of Wall

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SECTION 9
TEST RESULTS

The assault team was given no prior instruction, or additional tools. The assault team began their attack at the direct center of the wall specimen and continued until a man passable opening was created. The assault team created a 28 inch by 21 inch 7-1/4 inch deep crater during the first 15-minute iteration. The specimen was penetrated approximately 9-minutes (24-minutes total attack time) into the second 15-min iteration. At the completion of the second 15-minute iteration (30-minute total attack time) the crater was 29 inch by 22 inch with a penetration opening measuring 10 inch by 4 inch. Failure of specimen occurred 14 minutes (44-minute total attack time) into the third iteration of the testing with a penetration opening measuring 14 inch by 12 inch that was large enough to pass the 305mm x 305mm (12 inch x 12 inch) cylinder through. Total time elapsed was 44 minutes and 00 seconds. The wood splitting maul and single bit wood axes were used most frequently to attain forcible egress. During the 44-minute duration of the attack, no members of the team were physically injured. One member of the team left the attack, midway through the second iteration, for a short period of time to address an upset stomach caused by fatigue and heat. He was able to return and continued the attack after a short rest. Two other members of the team developed blisters on their hands but remained in the attack.

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Date: 07/22/20

SECTION 10
PHOTOGRAPHS

Photo No. 1
Specimen Label

Photo No. 2
Test Tools

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Photo No. 3
Specimen Side with Steel Angles

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Photo No. 4
Specimen Pre-Test

Photo No. 5
Specimen After First 15-min Iteration

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TEST REPORT FOR U.S. FOREST SERVICE
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Photo No. 6
Front of Specimen After Second 15-min Iteration

Photo No. 7
Back of Specimen After Second 15-min Iteration

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Photo No. 8
Front of Specimen After Failure

Photo No. 9
Back of Specimen After Failure

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TEST REPORT FOR U.S. FOREST SERVICE
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Photo No. 10
Specimen w/Test Cylinder

SECTION 11
REVISION LOG

REVISION #	DATE	PAGES	REVISION
0	07/22/20	N/A	Original Report Issue