THE DEVELOPMENT AND EVALUATION OF MODULAR BALLISTIC PANELS FOR FABRIC SHELTERS

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ABSTRACT

Modular ballistic panels, designed specifically for integration into fabric shelters, would provide a new force protection capability for our Warfighters. Today's fabric shelters do not possess organic ballistic protection. This Army program sought composite material systems that would meet fragmentation and blast protection requirements against mortar rounds, could be rapidly installed with a minimum number of Warfighters, and be affordable for Army shelter systems. This new shelter capability would provide an enhanced level of protection against specified threats while providing mobility and rapid deployment.

Performance requirements were established based primarily on mitigation of fragmentation threats as well as overcoming any associated blast overpressure. Multiple panel designs were developed, and through empirical evaluation, one design was selected for a first generation prototype. Panels were fabricated and fully integrated as a prototype into a standard Army shelter while at the same time preliminary modeling efforts showed the panels provide excellent protection from our target mortar.

1. INTRODUCTION

Expeditionary force protection presents unique operational requirements for today's military. Soft-walled shelters, or tents, are the first means of living and working facilities seen by troops deployed in theatre and remain their primary means of shelter for highly mobile units. By themselves, these tents do not protect the Soldiers living and working inside from the effects of munitions and mortar rounds. When logistical support arrives, hardening protective measures, such as sandbags, concrete barriers and HESCO Bastions ® are employed to shield Warfighters from these threats. However, before a forward operating base is established and these hardening protective measures have been put into place, our Warfighters remain more vulnerable to such attacks. Highly mobile units can also remain unprotected throughout the extent of their mission. The Natick Soldier Center (NSC) along with its technical partner, the Advanced Engineering Wood Composites Center at the University of Maine, has developed highly mobile, reusable, lightweight panels that can provide ballistic protection to troops from their first day in theatre and can be expeditious enough to travel with the most mobile units. This system of panels is called the Modular Ballistic Protection System (MBPS)

The MBPS is a passive method of force protection in that it prevents or mitigates the effects of munitions and explosive devices with panels that are simply attached to the tent frame, as seen in Figure1, without special tools or equipment. Within the environment of military tentage, parameters concerning ballistic performance, system design, cost and weight were driving factors in the development of MBPS.

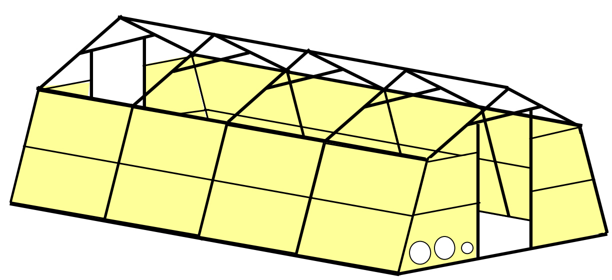

Fig. 1. MBPS overview

Modeling efforts and engineering analysis provided a basis for MBPS's panel designs and evaluation. Engineering analysis identified panel flexural strength requirements in association with blast load. A ballistic limit design tool was used to evaluate panel fragment mitigation capability when processed with munitions data, and a probabilistic based penetration model evaluated the viability of MBPS in a tent camp scenario. Preliminary ballistic testing aided in the selection of appropriate panel material composition and provided baseline experimental data for these models.

In a program that spans less than 18 months, the MBPS has progressed from a concept of improved force protection to a recent field evaluation in Southwest Asia. The MBPS's rapid progression has the potential to offer significant near term improvements in Force Protection.

2. DESIGN

The primary goal of the MBPS is to provide maximum protection to Warfighters while living and working in tents. In the low cost, highly mobile arena of military tentage, it is also imperative to control parameters of cost and mobility. As a result of frequent reports of mortar attacks, the MBPS program focused threat protection on mitigation of the fragmentation and blast threats associated with mortars. Fragmentation mitigation requirements were based on fabric body armor parameters so that MBPS could adequately protect personnel.

2.1 Primary Design Parameters

The mechanical performance of the MBPS panels is based primarily on fragment protection but also has consideration for blast overpressure capability and attachment technique. Fragmentation requirements were built around mitigation from a common mortar round. Mortars generally propel a high volume of small fragmentation at a high velocity and the MBPS panels are designed to minimize their penetration.

Along with the fragmentation threat, mortars possess an overpressure blast load associated with the detonation charge. The MBPS is designed to withstand this load through panel design and a unique attachment technique that connects the panels to the shelter frame. Through the use of high strength straps, very little of the blast load is transferred to the shelter's frame. The MBPS panels are designed to flex through the blast of the mortar. The MBPS panels are made of a sandwich design, with a wood core and a fiber matrix composite, giving the panels sufficient capability to meet the target static flexural strength.

2.2 Flexural Strength

A static design load of 1 psi was proposed that would simulate the dynamic pressures given off by a specified mortar threat. Several assumptions were made in determining this static design pressure. Based on The Unified Facilities Criteria and ASCE 7-02, the period of vibration for an equivalent structure was estimated as 0.1 sec (ASCE 7-02, 2003; Unified Facilities Criteria, 2005). Using this charge weight and the required standoff distance, a peak reflected pressure could be gathered either from CONWEP (Conventional Weapons Effects) or Army TM 5-1300 for a spherical air burst. A quasi-static equivalent pressure was found to be 0.92 psi using dynamic load factors calculated in accordance with equations listed in Structural Dynamics (Biggs, 1964). This pressure seemed reasonable for preliminary design given that, in conventional building construction, 1 psi static load is typically near capacity.

Literature on blast mitigation is typically directed towards permanent structures and is based primarily on increasing structure mass or munitions standoff (TM5-1300, 1990; Walker, 1998). Reducing vulnerability is largely accomplished through concrete type reinforcement or perimeter protection to increase distance from detonation (Stillion, 1999). Due to the nature of light weight, highly mobile military shelters, and the fact that indirect fire can infiltrate camp environments, the industry standards for design or mitigation of blast load were not directly applicable to the design of the MBPS, and field testing was essential for system analysis.

2.3 Secondary Design Parameters

In conjunction with providing protection from mortar threats, the design of the MBPS has to be one that is very mobile, quickly and easily integrated into an Army tent, and of relatively low cost.

A Tent Expandable Modular PERsonnel (TEMPER) tent was chosen as the host for MBPS as it is a standard Army tent which is in wide use. The MBPS panels are man portable and designed to install under the fabric of the TEMPER, eliminating any visual signature. The TEMPER has a 20-foot width and is extendable in 8-foot sections. The MBPS is designed to be installed in a 32-foot long TEMPER in 1 hour. Attachment techniques are designed to be simple and quick; no modification to the TEMPER frame is required. Panels are installed in a manner to transfer the majority of their weight into the ground. Panels are also slanted following the tent profile, as seen in Figure 2; this allows maximum available interior space while also aiding in the ballistic performance as the panel cross section seen by a fragment is larger. Panels are also ruggedized with a polymer coating which provides abrasion, ultraviolet, and moisture protection.

Fig. 2. MBPS installed in a TEMPER

Cost and weight were also significant design factors in the selection of panel components. In the world of ballistic protection, weight reduction is directly related to an increase in cost. To accommodate the cost restriction in the tent environment and to allow maximum use of this technology, a panel design with a relatively low cost was selected. The current panel design has a material cost of $10 per square foot and a weight of 4 lbs per square foot. Development of lower weight panel designs will continue in parallel to the current effort.

3. TESTING

In order to evaluate the MBPS response to the threats of mortars, ballistic, flexural strength and blast testing were performed. The ballistic testing determined the effectiveness of the panels in stopping small fragmentation while the flexural strength and blast testing evaluated the performance of the panels in response to the mortar's overpressure load.

3.1 Ballistic Testing

Parameters for ballistic performance were based on the fragmentation requirements of fabric based personnel armor. As a result, a variety of panel designs were subjected to Right Circular Cylinder (RCC) ballistic testing. In this test, steel cylinders of various masses – 2-, 4-, 16-, and 64-grain are shot at the target to obtain a "V-fifty velocity" (V50). Figure 3 shows a panel after testing. V50 is an industry standard which allows performance comparisons by providing one velocity at which the projectile is likely to penetrate the target panel 50% of the time. Tested panels were of a sandwich, composite construction made of Kevlar, Hexform®, E-glass and/or S-glass as outer layers together with a variety of core materials. Of the panels tested, only one composite panel lay-up of a proprietary design has passed the RCC testing and met remaining performance parameters.

Fig. 3. An MBPS panel after RCC testing

3.2 Flexural Testing

Quasi-static flexural testing was conducted at the AEWC Center following procedures outlined in ASTM D1037-99 and ASTM C 393 (ASTM D, 1999, ASTM C, 2000). The peak loads and maximum bending moments observed in the tests were used to estimate the distributed load capacity of a panel spanning 8 feet. In this fashion, the test data could be compared to the expected equivalent static pressure from the blast. Three-point bending was used and load and displacement data were collected. Samples of the panels were cut into 3 inch by 24 inch specimens and then placed in the test setup shown in Figure 4. A rubber patch was placed under the load head per ASTM C 393 to prevent compression buckling of the top fibers caused by the load head itself (Goslin, 2006).

Fig. 4. 3-Point Bend Test Setup

The specimens were tested with 22 inch spans. The peak loads and maximum bending moments observed in the tests were used to estimate the distributed load capacity of a panel spanning 8 feet. An example calculation is shown below in Equations (1) and (2). The moment calculations assumed the test load to be a point load at mid span.

M(pressure) = pressure x 3 inches (96 inches)^2/8 (1)

M(point load) = point load x 22 inches/4 (2)

Flexural test results showed that the panels met the design load of 1 psi.

3.3 Blast Testing

In February and April of 2006 the MBPS was subjected to blast testing, Figure 5, at Tyndall Air Force Base. The MBPS was installed in a 16-foot x 20-foot TEMPER and subjected to charge detonations equivalent to that of the target mortar round. In multiple tests, the stand-off distance of the charge started at 75 feet and was reduced to 21 feet. Both sidewall and endwalls were tested and the MBPS was evaluated with a variety of anchoring configurations. The MBPS performed well in all the tests; there were no component failures of the MBPS system, and maximum panel deflections of 0.5 to 2.5 inches were observed.

Fig. 5. MBPS Blast Test

3.3 Future testing

Future performance testing of the MBPS is planned at the U.S. Army Aberdeen Proving Ground test facility. The complete MBPS system will be evaluated for environmental ruggedness and durability. A live fire test of just the MBPS panels will be held the fall of 2006 and will be followed by a full shelter MBPS evaluation with live fire munitions.

Currently a MBPS prototype is deployed with a Marine Corp unit in Southwest Asia. As the Marines often have limited infrastructure, the MBPS will provide personnel protection where they often have none. Feedback is anticipated in 60 days.

4. MODELING

4.1 Ballistic limit

To assist in the preliminary design of the ballistic panels, V50 data was used as a ballistic limit to predict viability of the composite system against mortar attacks. When V50 data is plotted against the dimensionless parameter A_dA_p/m_p, where A_d is the areal density of the armor system, A_p is the presented area of the projectile and m_p is the mass of the projectile, the ballistic limit can serve as a boundary indicating when penetration of the panel by projectiles can occur. Projectiles with a velocity less than the ballistic limit will not penetrate through the panel material while those with a higher velocity will. With sufficient V50 data, design models such as those by Cunniff (Cunniff, 1999a; Cunniff, 1999b; Cunniff, 1999c) can be used to guide the future selection of panel material.

Based on available munitions data along with right circular cylinder (RCC) testing, a preliminary engineering analysis was completed to evaluate the effectiveness of the panel material. Using RCC test results for 2-, 4-, 16-, and 64-grain projectiles, the ballistic limit, shown in Figure 6, appears linear over the range of data. For a specific mortar threat, the velocities of the fragments were determined at a standoff distance of ten feet. Results showed that 99% of the projectile velocities fell below the ballistic limit, meeting preliminary panel design specifications.

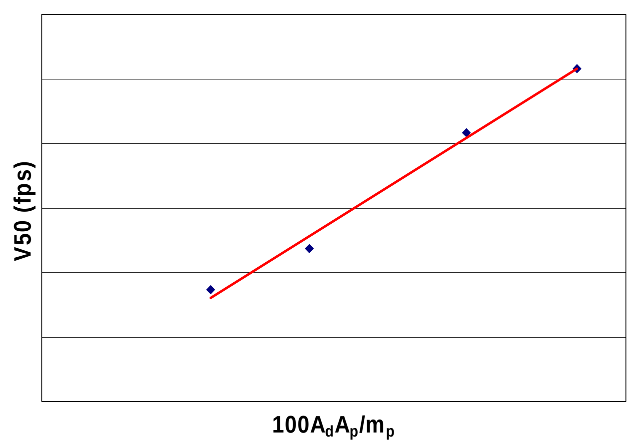

Fig. 6. V50 versus dimensionless parameter (trendline also shown)

4.2 Penetration model

The approach to predicting the effectiveness of the tent inserts in a base setting was to develop a spatially discrete representation of the camp domain, and then subject that domain to specific threats. Objects in the camp domain include tents (with or without inserts), soldiers, and other assorted objects. The threats are reproduced in the simulation using experimentally derived fragment tables. For a given domain, fragments emanating from the explosive, each having a specific mass, velocity, and trajectory, are individually tracked through the domain. Rules are established for the interaction between fragments and camp objects, and the lethality of each fragment can be evaluated.

An example simulation is illustrated in Figure 7. A segment of a camp domain is subjected to a particular mortar detonation. The camp is an array of 20-foot by 32-foot tents, and each tent includes a regular array of bunks, and a random distribution of occupants. These are seen as pixels of varying shades of gray in the figures. A subset of the total number of fragments coming off the mortar is shown in the figures. This subset includes the fragments that actually hit a soldier. Based on a combination of fragment mass and velocity, an incapacitation level can be assigned to the hit (Kokinakis, 1965). In the case of tents including inserts, an empirically derived energy approach was used to determine ballistic performance of the inserts. The form of the performance function was based on the kinetic energy of the fragments, and was established from ballistic performance data (including residual velocities) on the tent insert panels. Fragments with sufficient energy can penetrate the tent insert, but exit at a reduced velocity. Figure 7 shows the fate of fragments striking soldiers in unarmored tents (top) and armored tents (bottom). The figure shows the inserts stopping all but a few of fragments that otherwise could have penetrated the tent and had a potentially lethal impact. While any single simulation is deterministic, a series of simulations is run using the changing distribution of soldier locations to produce a statistical distribution of panel performance.

The model can be applied to camps of different layouts subjected to different threats. Upcoming live fire tests will be used to assess the predictions of the simulations.

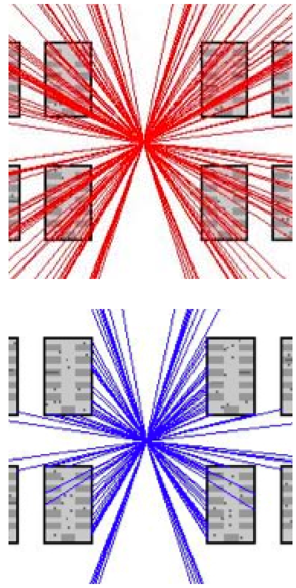

Fig. 7. Potentially lethal mortar fragments flying through a simulated TEMPER tent camp.

5. PROTOTYPE

After less than eighteen months the MBPS program has progressed from concept to prototype. To date two prototypes have been made with additional systems in process.

5.1 Configuration

MBPS provides man-portable panels that can be seamlessly integrated in a previously deployed Army TEMPER tent. The MBPS panels can be installed simply and easily without the use of tools or modification to the tent frame. Six panel shapes are used in the MBPS to fit the geometry of the TEMPER shelter. These included panels for the angled sidewalls, the vertical endwalls, as well as panels for the door system. Protected coverage is 99% of all area below seven feet. Each eight-foot module requires four sidewall panels and each endwall requires four endwall panels and two door panels.

Installation of the panels and associated hardware is facilitated by using simple or common connection hardware that is intuitive to manipulate. The MBPS panels are held in place using high strength straps provided with the kit. These straps thread through the handholds in the panels and attach to the aluminum framework of the TEMPER and are secured by steel buckles, Figure 8. Lower panels are installed first and the upper panels simply swing into position after resting their edge on brackets placed on the lower panels. The MBPS is installed under the fabric of the tent, Figure 9, and therefore does not create any unwanted visual signature.

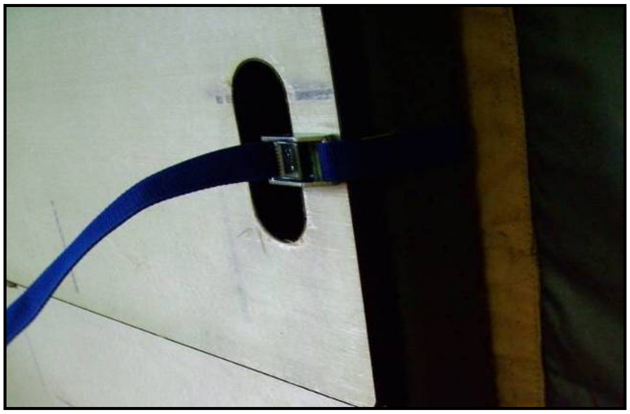

Fig. 8. Straps for panel installation

Fig. 9. Panel installation

The MBPS is designed with a full width sliding door, Figure 10, to provide complete protection on each of the two endwalls of the TEMPER shelter. Only two additional structural members are added with the kit to provide mounting locations for the panels on the endwall as well as mounting of the door system. The door design facilitates use and assembly and is also installed without the use of tools.

Fig 10. Sliding door

5.2 Integration

The second MBPS prototype, the latest design, was fully integrated into a standard Force Provider basic tent module (20 foot X 32 foot TEMPER) equipped with HVAC, liners, and lighting. The design provides seamless integration and will not hamper the shelter's use or the unit's mission.

All components of the MBPS are man portable. A 32' TEMPER can be fully integrated with the MBPS in approximately one hour with a four person crew. In support of the first MBPS prototype going to Southwest Asia, a comprehensive instruction manual, (Devine, 2006) and video were developed to assist troops installing and using the MBPS.

6. FUTURE WORK

Ongoing engineering development will mature this ballistic protection technology. Lessons learned through analytical engineering and lethality modeling, performance testing, and field evaluations will be incorporated into future designs. Live fire testing will provide further shelter performance data and allow model validation. The next generation of low weight composite panels will also undergo test and evaluation, and the MBPS will be redesigned to become a universal system, easily integrated into all Army shelters. Finally, design for assembly and manufacturing methods will allow the MBPS to rapidly enter large scale manufacture.

CONCLUSIONS

The MBPS is a system of ballistic panels that seamlessly integrates into fabric tents. Intended for highly mobile units and operating environments where full passive ballistic protection is not available, the MBPS offers lightweight and quickly deployable protection. Testing, engineering modeling and analysis tools have begun to verify the effectiveness of the ballistic panels against specified threats. A prototype MBPS system is currently under field evaluation in Southwest Asia and a second prototype will be subjected to live fire testing in FY07.

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