Blast Mitigation Mini-Workshop II

October 14, 2010

Providence, RI

Workshop Organizers:
Arun Shukla, Carl-Ernst Rousseau, & Jimmie Oxley

This mini-workshop is the second of two such workshops organized by the DHS-URI Center of Excellence for Explosives, Mitigation and Response, separated by a period of 18 months. The center plans to organize several such future meetings as it seeks to gain a more complete understanding of the blast mitigation field. The technical aspects of this year's gathering are identical to those of the previous year. However, the population of those invited to offer their expertise was altogether different, as the center sought to expand the pool of contributors. The international panel of 40 experts in the field was participants at the IMPLAST 2010 meeting and came from academia, national laboratories, government, and industry. This report summarizes the various points that were discussed and will be used to adjust and refine the focus of the center.

Blast Mitigation Mini-Workshop II Findings

Framework of the workshop

The present workshop was launched with Dr. Arun Shukla's brief overview of the most significant findings that arose from the April 30, 2009 Mitigation workshop. Efforts to implement the proposed suggestions were also outlined. Dr. Stanley Woodson, from the U.S. Army then elaborated upon his *personal* views regarding the most notable hazards facing our infrastructure. His long expertise in that field guided his outlook. His address served as a catalyst for a group discussion that followed on the subject. Likewise, identical presentation/discussion formats were led by outstanding experts, namely Drs. Gerard Nurick, of the University of Cape Town, William Fourney, of the University of Maryland, and Michael Accorsi, of the University of Connecticut, with focuses, respectively, on materials testing, blast diagnosis, and structural materials.

Both workshops have equally aimed to identify future research directions in the field of blast mitigation. While the former workshop relied primarily on thoughts engendered by means of numerous plenary lectures, the present one relied mainly on self-generated ideas emanating from the assembled body. Whereas the first workshop lasted one full day, the second one was limited to a time period of three hours, with the assembly consisting primarily of researchers who had presented on the subject of blast mitigation at the 2010 IMPLAST conference. It is to be noted that the previous workshop was entirely American. The present one, on the other hand, was deliberately and distinctly cosmopolitan, with representation from every continent and hemisphere, and was so organized to infuse a global perspective into our research objectives.

Goals of workshop

The workshop sought to bring to light research areas that have been neglected due to lack of resources, or have been overlooked due to lack of foresight, yet significantly impede progress toward full understanding of blast mitigation. To that aim, military and law enforcement scientists and administrators, as well as engineers and researchers from academia, national laboratories, along with those from supporting industries were gathered, if not to reach a consensus and help prioritize our goals, but at least to help identify those areas of deficiency within an open forum. The present document outlines the results of those discussions.

Major findings

Challenges to the infrastructure

Infrastructure materials

Normal concrete has a compressive strength of 5 ksi (35 MPa), and up to 15 ksi (105 MPa) for special columns. However, at present 20 ksi (140 MPa) concrete is available but not being implemented in buildings. Also, mixing of concrete is far from being optimized, neither is the inclusion of fillers, such as fibers, that can greatly increase the tensile strength of the material.

Other new materials in development should be fully characterized, and design procedures for their use in infrastructure will be needed.

Additionally, it is noted that the state of soil modeling is still in its infancy, and efforts must be redoubled in the area.

Health monitoring of infrastructure

Efficient monitoring of bridges should be intensified, for constant structural health monitoring, both under normal conditions and following nefarious events. For instance, detection of a stress level briefly exceeding the material limit could trigger more intense scrutiny, though physical damage may not be visually apparent.

Stand-off distances

When addressing the needs of our infrastructure, the most significant concern relates to that infrastructure's ability to endure high rates of loading. Questions addressing the resilience of concrete-based materials in their ability to absorb impulsive energy still remain unanswered, particularly in cases corresponding to near-field standoff distances of explosives. This purely dynamic condition loses its severity as the explosive is increasingly removed from its target, thus assuming a more quasi-static demeanor. Unlike the former, the latter state is fully well defined and capable of being perfectly described by the most elementary numerical codes.

Joints and reinforcements

Of particular interest, within buildings are joint units, such as loaded columns or floor to wall junctions, the dynamic behaviors of which are unpredictable. This gap in understanding pertains not only to precast or more generally, concrete materials, but also to fastened and welded metallic structures. Their dynamic ductility, brittleness, elastic and plastic limits are all in question. In the absence of such fundamental knowledge, numerical codes are powerless to advance any sound solutions. The field, in the present case, far from advancing into such predictive behaviors, should devolve to the most basic and fundamental experimentations to bring forth this much needed and crucial understanding.

In addition to the basic behavior of concrete materials, the incorporation, into the concrete, of metal reinforcements, stirrups, either continuous or staggered, adds yet another component of uncertainty, and prevents a comprehensive assessment of all buildings.

Intricacies of multi- or simultaneous loading

The presence of multi-hazards also constitutes an area in need of investigation, as most research tackle one loading mode at a time, both for the sake of understanding the consequences of such a mode of loading, and for simplicity and practicality. In this complex and dynamic field, results cannot, however, be superimposed linearly. Proper loading interactions must be uncovered.

It should be recognized also that blasts are inevitably accompanied by a rise in temperature, a condition difficult to duplicate experimentally, thus the substantial gap in full modeling of building behavior.

Extraneous influences and venture into new modes of analysis and design

Another question arose, regarding the need for aesthetically pleasing buildings, and the current political and social momentum for inclusion of sustainable features into them. These two elements can be combined as pertaining to the category of overall building design, and have not yet been investigated to gauge their influence, either positive or negative, upon safety. Furthermore, at present, design codes are based solely on conventional materials, and have, thus far, ignored new materials that researchers have proposed as efficient blast barriers.

As a means of simplifying the design process, it was proposed that building and infrastructure design codes be updated, such that static safety factors, upon which they are currently based, be amplified, as a means of also encompassing blast and dynamic modes of loading. To that aim, the dynamic demands, loadings, distributions likely to be experienced by these structures must be clearly categorized. Also, the current capacity of these structures must be accurately assessed. Another question that arises is as follows: must an entire system always be modeled or tested in order to retrieve valuable data, or would carefully arranged sections of the system fulfill the same goals?

Furthermore, recognizing that, as compared to quasi-static events, dynamic ones are relatively one-dimensional, is it possible to evoke simple existing uni-dimensional physics-based models capable of explaining the behavior of building materials?

Challenges to the materials science

Need for a statistical-numerical option

The panel was unanimous in recognizing that experiments can hardly be repeated with faithful consistency. Errors, slight difference between materials such as flaws, even in those acquired from the same batch will cause deviations in experimental results. It is, thus, difficult to devise numerical codes displaying complete equivalence to experiments, unless certain degrees of stochastic logic are inserted into them.

"Equivalence" and fundamental behavior

The issue of equivalence was broadly discussed, first from a materials standpoint. Indeed, the general research trends consist in the independent evaluation of materials. However, how do materials studied and promoted by various researchers compare? No standard has been devised to help resolve this issue. The scientific community must gather to determine the means by which such judgments can be reached. Nevertheless, it is to be noted that no single material is able to fulfill the desirable requirements of all structures and loading conditions. Any consensus must necessarily be application specific.

It is unquestionable that materials must be tailored to specific dynamic applications, as none can be declared universally superior. However, there must exist some common aspects that specifically contribute to the effectiveness of these various high performing materials. It is up to our research community to try to identify those fundamental behaviors and use that acquired knowledge as a platform for the synthesis of new materials.

Uniformity and Outreach to code writers

The need for effective comparison methods extends also to experimental techniques. Experiments conducted using Hopkinson bars, will differ from those of an impactor, or from direct exposure to an explosive. It would be of great usefulness to supplement the *Static* ASTM standards with similar sections pertaining to *Dynamic* loading conditions.

Exchange of personnel would also be beneficial, as it would foster collaboration, as well as help refine the experimental techniques of the participating laboratories.

Scaling

Scaling of stresses and performance within the field of solid mechanics is routine. Dynamically, it is not as well understood. Yet most experiments must be performed at a miniaturized size, and must be inter- or extra-polated onto a structure that differ not only in size, but most importantly is interlaced with other materials, a condition that creates very complex boundary conditions. Resolution of scaling issues must be advanced to the forefront of blast mitigation research.

Challenges to understanding of blast

Depth of explosive burial

One issue of primary importance is that related to Improvised Explosive Devices (IEDs) which must be hidden or buried. The latter condition creates a problem. Indeed, whereas air blasts are fully understood, the loading characteristics of buried mines remain ambiguous. In the latter category, however, the state of the arts is mixed, as deep buried explosives have been successfully modeled numerically, to some extent. On the other hand, shallowly buried explosive are entirely unpredictable, and numerical codes are yet to mimic their energetic outcome when covered with either dry or wet sand.

Adequate loading profile

Another difficulty faced by researchers of explosive events is the monitoring of the actual pressure distribution. The recording means currently available are discrete and sparse. Full-field diagnosis is much needed, as this profile is needed for delivery into computer codes. Additionally, two phases coexist: gaseous (rushing air) and solids (flying sand or earth). The precise distribution of these two elements is also needed to reach accuracy in the numerically modeled structures.

Role of barriers

Interestingly, also, it was shown that air blasts are not impeded by large physical barriers. Instead, they embrace the contour of those barriers and resume their paths on the opposite side. Therefore, studies of the role, significance, and effects of barriers must the revisited.

The ultimate challenges: Communication

The last point discussed during the workshop relates to inter-agency communication. For instance, representatives from the U.S. Navy and the U.S. Army, present at the workshop, were surprised to be, unknowingly and independently, working on very similar problems. Both agencies are obviously seeking identical goals. However, the "need to know" culture within government agencies precludes sharing of information, a condition that is beyond the influential sphere of our research group. Information sharing from government agencies to research groups is even more dubious.

Beyond, government agencies, other research communities may also be working on common subjects. It was noted, for instance, that a conference on explosives was being held, the previous week, in Israel. It is, thus, incumbent upon our research body to seek out and collaborate with others engaging in similar activities.

Acknowledgements

We wish to acknowledge the financial contributions of the University of Rhode Island Center of Excellence for Explosives, Detection, Mitigation and Response (under the auspices of the Department of Homeland Security), the United States Office of Naval Research, , and the University of Rhode Island College of Engineering. The authors thank Dr. Stanley Woodson for his contributions to this report. We also thank all the attendees for participating in the workshop. Specials thanks to Drs. Stanley Woodson, of the U.S. Army Engineer Research and Development Center, Gerard Nurick, of the University of Cape Town, William Fourney, of the University of Maryland, and Michael Accorsi, of the University of Connecticut for leading the discussion sessions. Finally, we acknowledge the administrative contributions and support of the Society for Experimental Mechanics in making the workshop a success.

List of Attendees

Sandeep	Abotula	abotula.sandeep@gmail.com	
Michael	Accorsi	accorsi@engr.uconn.edu	
Hari	Arora	ha304@ic.ac.uk	
Wayne	Chen	wchen@purdue.edu	
Henry	Chu	Henry.Chu@INL.gov	
Steeve	Chung Kim Yuen	steeve.chungkimyuen@uct.ac.za	
Ian	Darnell	Darnell2@LLNL.gov	
Suresh	Devu	suresh.devu@baesystems.com	
Joseph	DiVito	joseph_divito@raytheon.com	
William	Fourney	four@umd.edu	
Rahul	Goel	rahulg@mit.edu	
Reuben	Govender	reuben.govender@uct.ac.za	
Michelle	Hoo Fatt	hoofatt@uakron.edu	
Paul	Hoper	p.hooper07@imperial.ac.uk	
Rajeev	Jain	rajeevjain63@gmail.com	
Dopa	Karagiozova	d.karagiozova@imbm.bas.bg	
Ali	Kazemi	a.kazemi@nedu.edu	
Puneet	Kumar	kr.puneet@gmail.com	
C Anil	Kumar	anilkumar.c@talatechnologies.com	
Janes	Leblanc	James.M.LeBlanc@Navy.Mil	
Vasant	Matsagar	matsagar@civitl.ac.in	
Yaser	Mirzaei	y.mirzaei@neu.edu	
Gerald	Nurick	Gerald.Nurick@uct.ac.za	
Jim	O’Daniel	James.L.O'Daniel@usace.army.mil	
Jimmie	Oxley	joxley@chm.uri.edu	
Venkitanarayanan	Parameswaran	venkit@iitk.ac.in	
Basant	Parida	basant.parida@qinetiq-na.com	
Allan	Pierce	adp@bu.edu	
Fabrice	Pierron	fabrice.pierron@chalons.ensam.fr	
R. J.	Pryputniewicz	rjp@wpi.edu	
Carl-Ernst	Rousseau	rousseau@uri.edu	
Mehrdad	Sasani	m.sasani@neu.edu	
Victor	Shim	vshim.me@nus.edu.sg	
Arun	Shukla	shuklaa@egr.uri.edu	
Michael	Sutton	sutton@cec.sc.edu	
Leslie C.	Taylor	lesliectaylor@yahoo.com	
Andrew	Vechart	avechart@mit.edu	
Erheng	Wang	erhengwang@gmail.com	
Steve	Weiss	steve.weiss@qqinetiq.na.com	
Jefferson	Wright	JeffersonWright@gmail.com	