Blast effects and protective structures: an interdisciplinary course for military engineers

M. Z. Zineddin
Department of Civil and Environmental Engineering,
HQ USAFA/DFCE, USA

Abstract

The increase of terrorist threats over the last decade highlighted the need to protect both civilian and military facilities from explosive accidents or hostile activities. We have observed an increasing need to protect against industrial explosive accidents, criminal activities, and social/subversive unrest. This problem may, in fact, exceed the previous reasons for addressing blast effects and protective structures (i.e., military-sponsored work on fortifications). Obviously, the future of engineering education programs has to be shaped accordingly. Careful attention must be devoted to typical modern civilian and military facilities whose failure could severely disrupt the social and economic infrastructure of nations. Therefore, military engineers need to:

- Know how to assess threats, hazards and abnormal energetic loading incidents.
- Have knowledge of how such facilities (office buildings, schools, hospitals, power stations, industrial facilities, etc.) behave under blast, shock, impact, and fire loads.
- Know how to design such facilities to protect lives and property.
- Know how to conduct effective rescue operations and forensic investigations.

This elective course on blast effects and protective structures is aimed at addressing a broad range of technical issues dealing with mitigating the severe loading effects associated with abnormal loading incidents (e.g., blast, shock, impact, etc.). This elective course will employ extensive course notes, references, various manuals, other handout materials, and a collection of computer applications to be used by engineers.

Keywords: blast effects, protective structures, military engineers, USAFA.

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1 Introduction

Terrorism is not a new phenomenon, and one can find historic references that such activities have existed for more than two thousand years. More recently, the use of terrorism as a means to achieve national objectives was a primary cause for WWI. Many regions around the world have been increasingly burdened by this phenomenon during the last quarter century (e.g., the Middle East). The locations, causes, participants, intensities, and means have been changing rapidly. Vehicle bombs have become the preferred mechanism for terrorist attacks, followed by the use of hand-carried explosive devices, and the newly evolving threat of weapons of mass destruction (WMD).

Clearly, in today's geopolitical environment, the need to protect both military facilities and civilian populations from terrorism and social/subversive unrest has escalated significantly. This situation is true for many parts of the world, and it may exceed the previous reasons for the development of protective technologies.

This brief summary highlights the fact that the free world has always been reacting to terrorism. The previously observed levels of anti-terrorist preparedness and protective prevention measures have been unimpressive. Unless these conditions change dramatically, the consequences for society could be quite grave.

Since the indications are that explosive devices will continue to be a primary hazard, the emphasis in this write-up will be on blast, shock, and impact. Structural design for safety and physical security requires a sound background in fortification science and technology. One must realize that loading environments associated with many relevant threats (impact, explosion, penetration, etc.) are extremely energetic, and their duration is measured in milliseconds (i.e., about one thousand times shorter than typical earthquakes). Structural responses under short-duration dynamic effects could be significantly different from the much slower loading cases, requiring the designer to provide suitable structural details. Therefore, one must explicitly address the effects related to such severe loading environments, in addition to considering the general principles used for structural design to resist conventional loads. One must be familiar with the background material available for structural consideration and design, as well as up to date on the experience gained from recent terrorist bombing incidents.

Typical engineering curriculums within the military academies have focused on preparing cadets to become engineering officers with hardly any emphasis dedicated to blast effects, protective structures and anti-terrorism security.

2 Development and implementation

The following summarize the recommended actions required to address this effort:

- To mobilize the local scientific community (including government, private, and academic) for this effort.
- To establish comprehensive and complementary short-term and long-term research and development activities in protective science and

technology to ensure the safety of government, military, and civilian personnel, systems, and facilities under evolving terrorist threats.
- To launch effective technology transfer and training vehicles that will ensure that the required knowledge and technologies for protecting government, military, and civilian personnel, systems, and facilities form terrorist attack will be fully and adequately implemented.
- To establish parallel and complementary programs that address the non- technical aspects of this general problem (i.e., culture, religion, philosophy, history, ethnicity, politics, economics, social sciences, life science and medicine, etc.) to form effective interfaces between technical and non-technical developments.

This paper describes an interdisciplinary course in blast effects and protective structures, aimed at educating future military engineers against any potential threat of terrorism. A course outline will be briefly discussed, which spans from; threats and hazard assessment; Conventional and Nuclear Environments; Conventional and Nuclear Loads on Structures; Behavior of Structural Elements; Dynamics Response and Analysis; Connections, Openings, Interfaces and Internal Shock and Structural Systems – Behavior and Design Philosophy. It is not the intent of this paper to discuss the course plan in any great detail, since the course planning and implementation are still an ongoing process.

3 Course contents

This course can be taught to undergraduate seniors in both science and engineering majors. The issue of blast effects and protective structures is so broad and diverse that to make the course very useful and attractive to cadets, we consider the course topics as essential for a 3-credit course.

3.1 Course description

The purpose of this course, as stated explicitly above, is aimed at addressing a broad range of technical issues dealing with mitigating the severe loading effects associated with abnormal loading incidents (e.g., blast, shock, impact, etc.). This course will introduce students to the effects of conventional and nuclear weapons on structures and equip them with the tools to define the threat of hazards, define the loads on structures, make a structural assessment of potential cause-and-effect relationships, and recommend mitigation measures for designing or modifying the structural system to protect occupants from the effects of explosive devices.

This course will present the latest information on designing buildings to save lives—from understanding the nature of threats to analysis and design—and will provide students with practical information on performance and design requirements for hardened facilities. In addition, this course will provide information on blast damage assessment issues that will provide forensic and rescue personnel with information vital to their efforts after a catastrophic structural failure. The course may be outlined as discussed below.

3.2 Course outline

3.2.1 Block 1: threats and hazards assessment

Block one begins with a general background discussion addressing the need for man to evolve his efforts in warfare to create a multi-layered approach of taking preventative measures to ensure a safe, sound society. Each student must learn how to conduct a thorough threat and hazard assessment, employing a significant measure of probabilistic analysis and data available in a wide variety of sources as well as a complete understanding of the adversary. Students should utilize a threat and hazard assessment method similar to that provided in *ASCE, 1999*. Understanding the characteristics of explosive processes, devices, and weapons aids the student in preparing a thorough assessment of adversary capabilities. The adversary will use his capabilities against a desired target, requiring the student to conceptualize how to protect a given structure; a basic protective planning and design philosophy is needed. Realizing the threats allows the student to assess the hazards inherent on a target. Thus, a brief summary explaining blast effects on structures, both locally and globally, is necessary. Additional research in many areas of blast effects is crucial to reflect the need to understand ever-evolving weapon systems and utilize new experimental and analytical tools to ensure overall public safety.

3.2.2 Block 2: conventional and nuclear environments

Block two addresses the technical side of analyzing blast effects in conventional and nuclear environments. An explosion can create airblast, ground shock, ejecta, fragments, fire, thermal, chemical, radiation, and electromagnetic pulse effects. Each explosive effect is given an “equivalent TNT” value that translates into a tangible force on a structure that can be included in a structural design.

3.2.3 Block 3: conventional and nuclear loads on structures

Conventional and nuclear loads differ significantly, a point that the design approach must accommodate. Another stark difference exists between current design procedures and information gathered from recent research. Block three addresses the technical information concerning these two topics.

3.2.4 Block 4: behavior of structural elements

Block four contains an overview of the behavior of structural elements to include dynamic loading, material properties of steel and concrete, flexural resistance, shear resistance, column loading, and frame response. This chapter provides a review of the current materials available for blast-resistant design. The *Technical Manual 5-866-1* used by the Army and *Technical Manual 5-1300* used by the Army, Navy, and Air Force, and *ASCE, 1985*, *ASCE, 1997*, and *ASCE 1999*, contain the bulk of information used by non-governmental organizations.

3.2.5 Block 5: dynamics response and analysis

Dynamic response and analysis is a crucial evaluation step when analyzing an explosive structural impact. Different methods of analysis are required for specific situations and loading cases. The two mentioned in block five are the

Single Degree Of Freedom (SDOF) and Multiple Degree Of Freedom (MDOF) analysis methods. A few not expounded upon in the paper are the finite element, finite difference, and hybrid methods.

3.2.6 Block 6: connections, openings, interfaces and internal shock

Block six focuses on the behavior of specific structural elements and the necessary implementation for design, as well as on the effects of internal shock. Connections make modeling a beam or structure difficult, but are necessary to analyze since in reality, simply supported, fixed, hinged or free conditions rarely are completely accurate. Connections must withstand the blast effects in order for the structure to function properly. Therefore, it is necessary to spend, in many cases, more time ensuring connection components are adequate than on other structural components to assure exceptional structural performance.

3.2.7 Block 7: structural systems – behavior and design philosophy

The threats discussed are very energetic, and with such a short duration require unconventional structural analysis methods. The design philosophy involves architectural and functional considerations, load considerations, structural system behavior, structural system and component selection, as well as other safety considerations. Block seven also discusses the development of a “loading envelope” to encompass a multi-protection design (earthquake plus blast effects.)

4 Case study and tools

The Blast Effects and Protective Structures course had a case study due for each of the seven blocks, making seven total case studies. To apply a definition in this course, a case study is a challenging practical problem aimed at introducing the student to the given block’s concept. Many of the case studies required students to gather information from instructors and professors in multiple departments with various specialties and fields of study, as well as information from a plethora of sources.

The blast effects resources used for the majority of the case studies are as follows: *Technical Manual 5-866-1*; *Technical Manual 5-1300*; and *ASCE 1999*. In addition, the following software programs were used: “CONWEP”; “BLAST-X”; “SHOCK Version 1.0”; and “FRANG Version 1.0.” The software allows for calculation of internal shock and gas pressures. Each program has its specific strengths. “SHOCK Version 1.0” allows for the calculation of average barrier reflected shock pressures and impulses due to an incident and reflected waves from one to four reflection surfaces. “FRANG Version 1.0” allows for the “calculation of the time history of gas pressure and impulse resulting from an explosion within a room” (FRANG Version 1.0 statement). It can account for venting through both an uncovered vent and a vent covered by a frangible panel. The “CONWEP” software is an assortment of conventional weapons effects calculations based on TM 5-855-1, allowing the user to apply a variety of blast effects ranging from airblast to fragment and projectile penetrations to ground shock and receive empirical results as output. “BLAST-X” is intended to perform shock wave and pressure calculations of internal or external explosions on a structure.

5 Conclusion

Terrorism is not a new concept, striving to strike fear in the hearts of citizens in rival nations. Historical examples of such activities date back two thousand years. Most recently in the United States, non-state actors have demonstrated that one of the world's most powerful nations is not immune to terrorism. Many regions around the world have been increasingly burdened by this phenomenon during the last quarter century (e.g., the Middle East). Techniques and methods to most effectively execute terrorism are evolving every day, creating new and challenging problems for security personnel.

Clearly, in today's geopolitical environment, the need to protect both military facilities and civilian populations from terrorism and social/subversive unrest has escalated significantly. Current levels of preparedness and protection in many key, nationally important structures are inadequate. This brief summary highlights the fact that in order to protect the civilian and military populace from disaster, blast, shock, and impact on certain structures must be accounted for in the design portion of such buildings.

Structural design for safety and physical security requires a sound background in the fortification science and technology. The loading environments associated with many relevant threats (impact, explosion, airblast, penetration, etc.) are extremely energetic and short-lasting (i.e., about one thousand times shorter than typical earthquakes.) The dynamic structural effects will typically be significantly different from slower, conventional loading cases, requiring the engineer to utilize an unconventional paradigm to create design solutions to complicated blast effects. One must be familiar with current world events and terrorist tactics, as well as current analysis and design methods to create effective designs. Therefore, one must explicitly address the effects related to such severe loading environments, in addition to considering the general principles used for structural design to resist conventional loads.

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