Terrorist Threats Against the Pentagon

by

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ABSTRACT

The terrorist attack of 11 September 2001 against the Pentagon prompted USACE to perform a 30-day study to assist in the development of anti-terrorist methods for the Pentagon structure. Drawing on years of experience and model development, USACE provided and analyzed structural concepts for the rebuild and renovation of the Pentagon. USACE personnel assisted in the damage assessment immediately following the terrorist event, analyzed the current configuration and design concepts of the Pentagon wall system using simplified engineering-level and high performance computational models, and developed strength measures that were inserted into a PC-based vulnerability assessment code. Recommendations were provided to the Pentagon Renovation Program.

KEYWORDS: blast effects; Pentagon renovation; retrofit; structural assessment; terrorist attack; vulnerability

1.0 INTRODUCTION

Following the 11 September 2001 terrorist attack on the Pentagon, USACE entered into a 30-day study agreement with the Pentagon Renovation Program managers to assist in the evaluation and development of physical anti-terrorist measures for the Pentagon. USACE is uniquely qualified to blend state-of-the-art research, simple and sophisticated analytical techniques, and practical engineering into a focused study to provide concepts for anti-terrorist measures. The bombing of the Marine Corps barracks in Lebanon in 1984 was the motivation for the U.S. Army to establish one of the first research programs to address the effects of terrorist weapons on conventional buildings and develop improved design and retrofit methods for these facilities. During the past 15 years, experimental and analytical studies have resulted in significant improvements in the understanding of the response of conventional aboveground structures to blast effects. The studies have led to the development of guidelines and computer software for assisting engineers in evaluating and designing protective measures.

At the time of the 11 September attack, the Pentagon was undergoing a renovation that included retrofit measures to increase the resistance of the structural envelope to terrorist attack, particularly for blast effects. Although the Pentagon Renovation Project took great advantage of state-of-the-art technology available at the time, this technology is steadily advancing. The opportunity now exists to incorporate recent advances into the areas to be reconstructed, as well as areas not yet renovated.

2.0 PURPOSE

The purpose of the 30-day study was to examine protective measures for the Pentagon for a range of potential types of threats and threat levels that include airblast from explosive detonations, fire hazards, and chemical/biological/radiological weapons. The focus was general protection for all building occupants, rather than localized protection for specific critical assets. The 30-day study was not an effort to design for specific performance in response to a specific defined threat. This paper will summarize the blast response of the unretrofited Pentagon and the added protect provided by the existing retrofit used in wedge 1.

3.0 11 SEPTEMBER 2001 EVENT

U.S. Army Corps of Engineers personnel conducted a Pentagon damage assessment from 14-17 September 2001. The overall purpose of this initial forensic study was to investigate the extent of the damage caused by the plane that crashed into the Pentagon on 11 September. An important part of this effort was gathering information on the performance of the retrofitted components of the Pentagon. While, the recent retrofit upgrade techniques employed in the building's renovated sections were intended to increase protection against vehicle bombs, the response of the retrofit components under the 11 September loads provides insight into the overall effectiveness of the upgrades. The structure experienced the extraordinarily energetic localized impact of the plane itself, secondary impacts, and the complex external/internal blast and fire loads from the fuel carried within the plane. While the complexity of the loading complicates a quantitative determination of the exact load/response relationship, a qualitative assessment of the relative response of the retrofit components as compared to the non-retrofit components is feasible. This is possible because the plane struck close to the interface between the retrofit and the non-retrofit building sections.

Figure 1 is a schematic of the layout of the Pentagon. Wedge 1 consists of sections 3 and 4 as shown in this figure. The impact location and orientation are also indicated on the figure. The exterior wall near the impact location is shown as Figure 2. The boundary of Wedge 1 (retrofitted) with Wedge 2 (non-retrofitted) is shown near the left side of the figure. The impact occurred near column line 14 of Wedge 1. The collapsed region (Figure 3) extended from the expansion joint near column line 11 to column line 18. Windows near the Wedge 1 - Wedge 2 boundary are shown in Figure 4. Damage to the non-retrofitted windows is higher than damage to the retrofitted windows, although the retrofitted windows are closer to the impact area and subsequent fuel fire/blast.

The retrofit of Wedge 1 was effective in saving lives during the events of 11 September 2001. While, the retrofit upgrades were intended to increase protection against vehicle bombs, they appeared to have been effective in mitigating some of the secondary effects of the plane impact. The retrofit windows responded in a ductile and tough manner to the blast loads and were also able to resist substantial fragment impacts. The windows also remained intact even when apparently engulfed in the fireball of burning fuel, preventing entry of the fire into the upper floors. The tube steel members worked as intended and may also have played a part in the resilience of the building, a possibility that was not evaluated in this study. The annotated photographic documentation of the response of both the non-retrofit and retrofit windows may prove useful in future analytical and experimental efforts to improve protection against terrorist attack.

4.0 UN-RETROFITTED PENTAGON CONFIGURATION

The unretrofitted wall analyzed consists of 5-1/2 inches of limestone facade with an 8-in., two wythe, unreinforced brick infill wall. The floor height varies but is taken as a nominal 10 ft for this analysis. The horizontal span between columns is 10 ft on-center. The construction quality of the edge support conditions of the masonry wall (gap between wall and columns or grout fill) is uncertain, but it is assumed that the wall is supported on all 4 sides (two-way action) without the support rigidity that could induce arching (compressive membrane action). The limestone façade was assumed to respond in one-way action between column lines. In addition, nearly every bay except those on the fifth floor has a window. The window analyzed is 7-feet high by 5-feet wide (outside dimensions), with ¼-inch thick annealed glass.

5.0 EXISTING (WEDGE 1) RETROFIT

The retrofits currently used in the Pentagon renovation (Figure 5) include blast hardened windows, supported by horizontal tubes that frame into vertical tubes that run from floor slab to floor slab. The 6"x6" or 8"x8" tubes transfer the dynamic reactions from the windows and the exterior masonry walls to the floor slabs. The E-Ring retrofit window for the W1 type consists of an insulated, or double pane glazing. The outer pane is ¼ in. thick thermally tempered glass, with a ½ in. air gap. The inner pane is a laminate consisting of 3/8 in. thermally tempered glass, .090 in. PVB inner layer, and 3/8 in. thermally tempered glass. In addition, a geotextile membrane is used over the interior surface of the masonry wall to prevent the masonry from becoming a debris hazard during a blast event.

6.0 ANALYSIS

The analyses assume that the Pentagon frame is sufficient to resist the loads transferred to it from the exterior walls. Evaluations of the original and retrofitted Pentagon structures were performed using the Antiterrorist (AT) Planner software [1]. AT Planner is a PC-based computer code that assists installation-level personnel in analyzing the vulnerability of buildings and their occupants to the effects of terrorist vehicle bombs. The program also contains information to aid in developing protective measures.

AT Planner is being developed to present concepts and procedures for protecting deploying forces from terrorist/saboteur attack using expedient methods that require a minimum of engineer resources. Recent experience has shown that the demand for military engineering in support of antiterrorism has risen dramatically as the Army is drawn into a succession of operations other than war. In these situations, U.S. troops may be subject to attack by unfriendly civilian or paramilitary groups. AT Planner is a Windows 95-based application suitable for operation on a notebook computer by combat engineer officers, and draws on completed and ongoing research related to the protection of fixed facilities from terrorist attack as well as work on field fortifications. AT Planner is based on references 2-7. AT Planner provides standoff distance evaluations, structural damage and window hazard calculations, protective measures checklist for terrorist threats, and vehicle velocity calculations and barrier recommendations. When a vulnerability analysis from a terrorist bomb is calculated in AT Planner, blast pressure is calculated at the center of each structural bay on a structure. Angle of incidence is considered in calculating airblast levels on structures, but clearing effects and shielding effects are not. AT Planner uses PI (Pressure Impulse) diagrams to allow a user to quickly estimate building damage from a vehicle bomb attack. A description of a PI curve is shown in Figure 6. The hazard/protective levels used by AT Planner in this study are shown in Figure 7. AT Planner has a set of default damage diagrams and the capability to read in user specified diagrams. The AT Planner default building components (excluding windows and non-reinforced masonry walls) are normalized so that the user can modify the span and thickness of the component. The user specified diagram is not normalized; therefore a different diagram must be developed for each different building layout. For this reason, a significant amount of time was spent studying construction diagrams in order to determine nominal specifications before the damage diagrams were developed.

Wall response calculations were performed using the Wall Analysis Code [8] (WAC). WAC is a single-degree-of-freedom (SDOF) model designed specifically to calculate the response of reinforced and unreinforced concrete and masonry walls to airblast loads. Window response/hazard predictions were made with HAZL [9]. These response predictions were used to develop the PI diagrams that were input into AT Planner to perform the blast evaluations. The PI diagrams for the walls were validated by performing analyses using higher-fidelity, finite element (FE) structural response models described in Appendix 3.D.

Range-to-effect (RTE) and PI curves for the Ring E walls and windows were developed and entered into AT-Planner. In addition, PI curves for the reinforced concrete roof panels required to perform AT Planner assessments. Roof panel retrofits were not required for blast protection in subsequent scenarios – the curves used for the roof panels are constant throughout this report. RTE curves for this report are shown for components exposed to normally reflected loads. They are not shown for roof panels since realistic roof loads are closer to incident pressures rather than normally reflected pressures. The damage levels obtained from the supporting FE models match well with the PI diagrams developed using WAC, thus validating the PI diagrams. The PI curves presented above are used in AT Planner to define safe stand-offs around the Pentagon for the large and small truck bomb threats as shown in Figure 8 (the windows control these stand-offs).

To analyze the existing retrofits response to blast load, SDOF models of the wall and window systems were developed. The wall model did not consider the effects of window failure. The resistance of the wall included the strength of the façade, the masonry wall, and the tubular framing system (dominant contribution). The wall system model was used in WAC to generate RTE and PI curves and these curves were validated with FE analyses. The high level PI curves were used in AT Planner to define safe stand-offs around the Pentagon for the large and the small truck bomb threats. The custom PI diagrams for the window and wall retrofits of the exterior wall of the E-Ring were used for all walls. Damage plot in figure 9 are intended to illustrate damage to the outside of the E-Ring only.

7.0 RECOMMENDED RESEARCH/ EVALUATION

Doors in the exterior wall of the E-Ring need to be designed to resist the same bomb size - standoff combination that the E-Ring exterior walls and windows are designed to. Other components of the exterior shell of the Pentagon need to be evaluated for the same conditions used to design the E-Ring exterior. Components that need to be evaluated include the walls windows and doors on the back of the E-Ring and on the backs and fronts of the A-, B-, C-, and D-Rings. The roofs of the two-story portions of the buildings located between the D- and E-Rings and between the C- and D-Rings also need to be evaluated.

Further blast hardening should be considered in conjunction with proposed plans to relocate public roads and/or further control access to the Pentagon roads and parking areas. The Pentagon should be evaluated against other reasonable threats. The wall/window retrofit or rebuild selected for use in the Pentagon rebuild/restoration should be tested to verify the level of protection provided.

8.0 REFERENCES

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9.0 ACKNOWLEDGMENT

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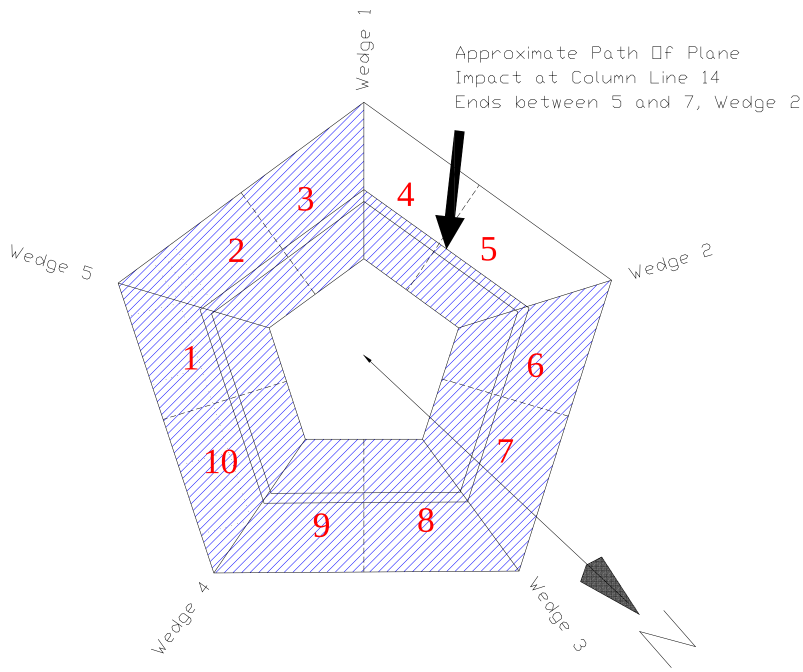

Figure 1. Layout of Pentagon showing impact location.

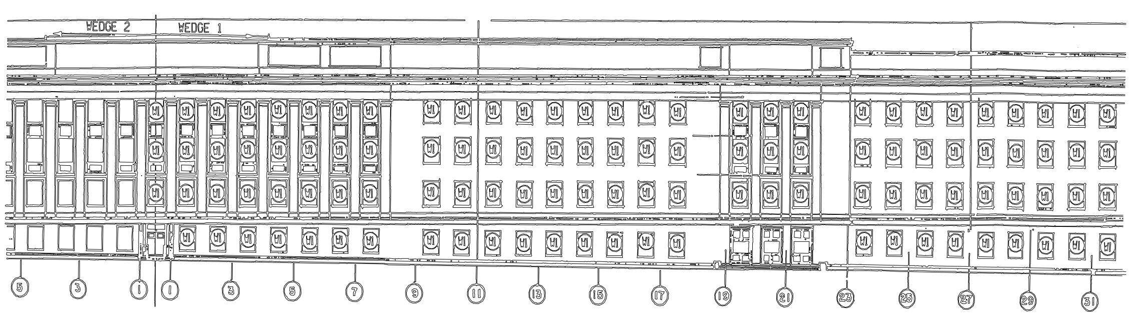

Figure 2. Exterior of E-Ring of Pentagon Wedge 1 and 2 with column line designations. W1 designation on windows denotes non-operable (fixed) retrofit window. Impact occurred near Column Line 14, collapsed region extended from construction joint at Column Line 11 to Column Line 18.

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Figure 3. Collapsed section/plane impact area in Wedge 1. Plane entered the 1st floor at an angle of approximately 40 degrees from perpendicular moving toward the left into Wedge 2.

Figure 4. Exterior view of transition between Wedge 1 (on right, retrofit) and Wedge 2 (on left, non-retrofit). First floor non-retrofit window adjacent to transtion may be High Hazard blast response. Second and 3rd floor fire damage. Approximately 135 ft (44.2 m) North of plane impact point.

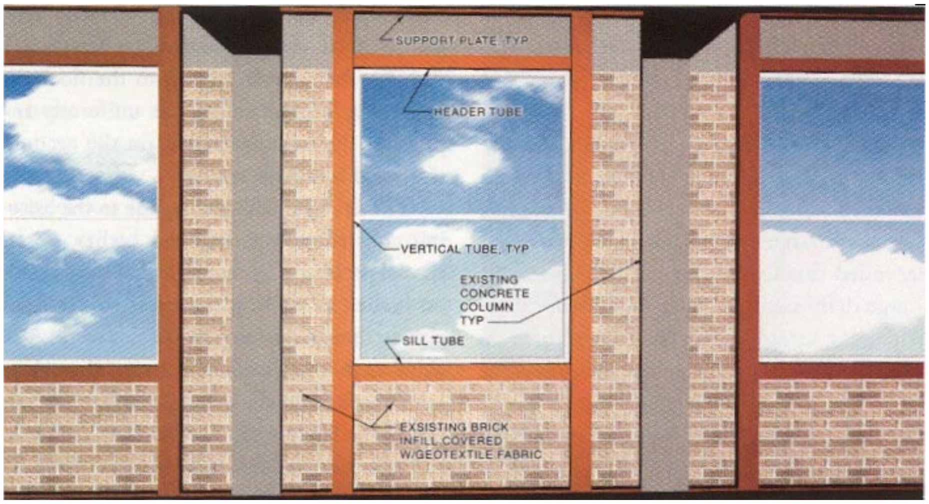
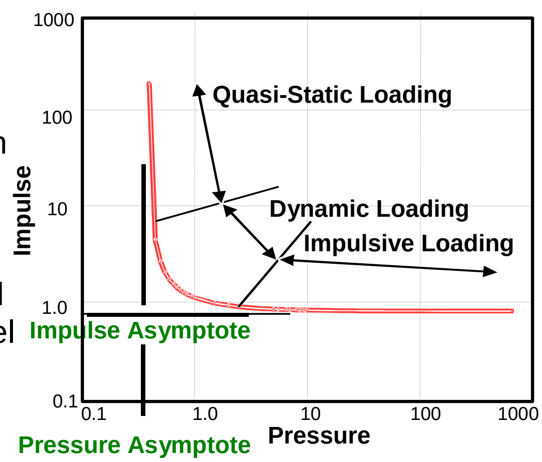


Figure 5. Current retrofits.

Pressure Impulse Curve

A pressure-impulse (PI) diagram is an iso-response curve for a particular structure loaded with a particular load history type.

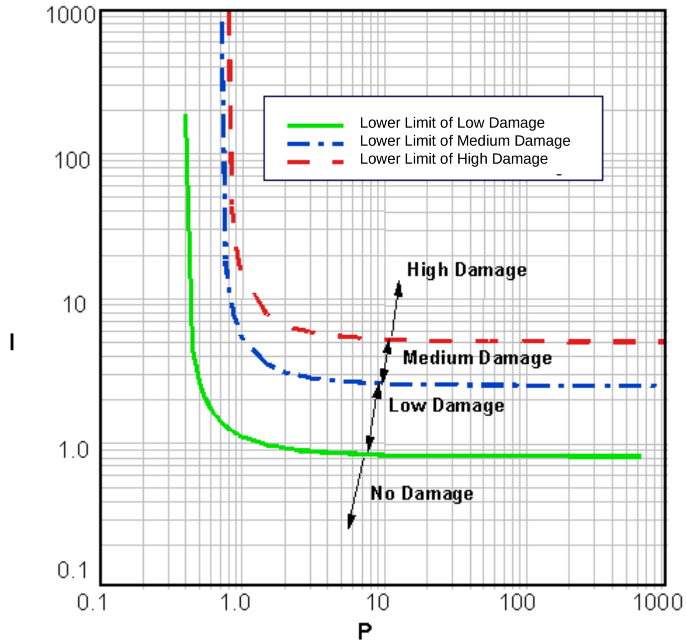
The PI curve divides the plot into two regions: (1) the area above and to the right where the response level of the PI curve is exceeded and (2) the area below and to the left.



At low impulse (short duration loads), the response is essentially independent of peak pressure and depends only on the impulse.

At low pressures (long duration loads), the response is independent of impulse and depends only on the peak quasi-static load.

Figure 6. PI curve description.



No damage: No appreciable damage; the component is reusable without repair. This damage level can be equated with a **High Level of Protection**.

Low damage: The component is probably repairable and it has provided a generally adequate level of protection to personnel and equipment from the effects of the explosion. This damage level can be equated with **a Medium Level of Protection**.

Medium/Moderate Damage: Repair of the component is not feasible, but it has not collapsed, and it has provided substantial protection to personnel and equipment from the effects of the explosion. This damage level corresponds to the greatest degree of damage that might be accepted, thus it can be equated with a **Low Level of Protection**.

High Damage: The component is definitely beyond repair but it has not necessarily completely collapsed. It has undergone a deformation such that it cannot be counted on with high certainty to protect personnel and equipment from the effects of the explosion. This damage level is equated with "**Collapse**" as it is used in terms of a **Level of Protection**. However, components with 100% damage will most probably not be collapsed in the general usage of this word.

Figure 7. Hazard/Protection Levels.

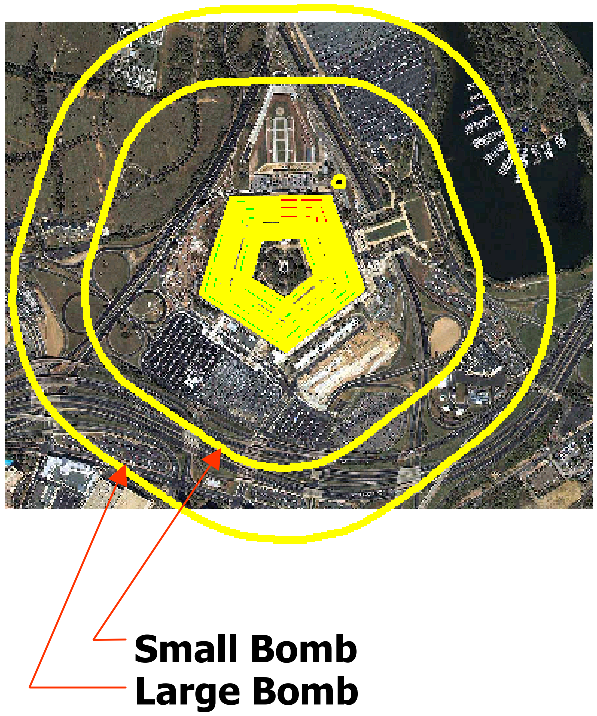


Figure 8. Stand-offs to prevent high hazard for the large and small truck bombs for the unretrofitted Pentagon.

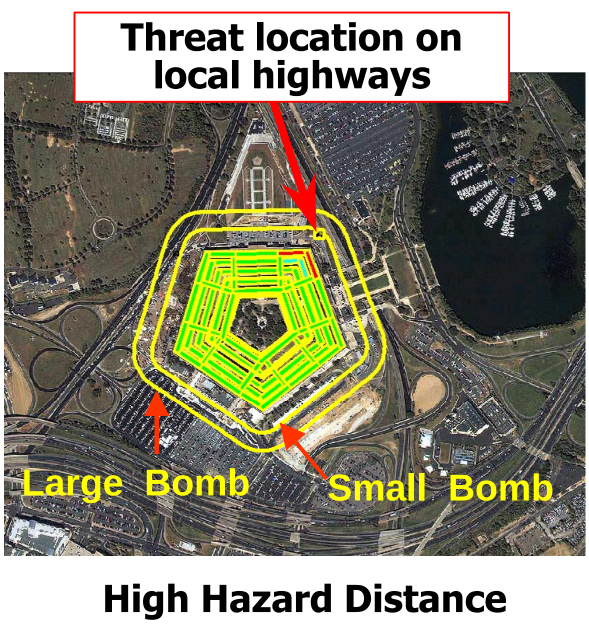


Figure 9. Stand-offs to prevent high hazard for the large and small truck bombs for the current Pentagon retrofits.