Assessing and Minimizing Threats to Buildings

Mohammed Ettouney, Ph.D., P.E.,

Principal
Weidlinger Associates
375 Hudson Street, New York, NY 10014

Abstract

This paper discusses security of buildings due to blast effects. Planning, hazard definitions are presented first. It is shown that there are three integrated phases in how buildings are affected to blast effects: outside the building envelope, the building envelope itself, and inside the building envelope. Each of these phases is discussed. Different mitigating strategies are presented.

1 PLANNING

Planning to reduce blast hazards for buildings involves several steps: the definition of the hazard, H , site considerations, building envelope considerations, structural and non-structural considerations. A successful planning would optimize all of those considerations, so as to minimize the harmful effects on the building and its inhabitants, while minimizing the financial costs. If we assume that the different building and site categories that affect blast hazard are B_i , and that the respective representative costs are C_i . In the planning stage, the relative costs of each mitigating solution should be estimated. The total mitigation cost for a given hazard, H is

$$C_H = \sum_i C_i \ B_i \tag{1}$$

A careful balance of different mitigating solution should result in the minimum cost for the project.

1.1 New Buildings

In new buildings, the site conditions (setback outside the building envelope) represent an easy way to reduce the blast hazard to the building: larger distances quickly reduce harmful blast pressures. This, in turn, result in smaller costs of building mitigating measures. Thus, one of the most important planning issues is: how much setback vs. how much building mitigating measure? In urban area, where setback choices are limited, the emphasis would be on building mitigation measures. In suburban or rural areas, the setbacks are utilized more in securing the building.

In addition to the balance between setbacks and building mitigation measures as a whole, a balance of those building mitigation measure themselves is needed. The building envelope decisions represent a challenging task of balancing. Also, the interior of the building needs to be investigated and the optimum decisions must be made.

1.2 Existing Buildings

Existing buildings represent a far more difficult task. The building site is usually difficult to change. This is particularly true in urban areas, where social and cultural factors limit the introduction of sizable setback, if any. Thus most of the mitigating measures is delegated to the building envelope, and the interiors of the building. In numerous situations, the existing building envelopes and the interior of the buildings were not designed for blast mitigation in mind, resulting in limiting choices for the professionals. A careful application of equation 1 is needed most for existing building. The professionals (engineers and architects) must work closely with building officials and inhabitants to define as many creative, and inexpensive, mitigating solutions as possible. This is done usually by setting a list of all available mitigating methods, and their effectiveness. Then a process of prioritization is performed by all parties. This will ensure that the available funds are spent efficiently.

2 HAZARDS

Figure 1 shows the hazards-Building interaction. The initiation event is the blast event. The main components in the blast event are the distance (standoff, R, ft.) and the weight of the bomb, W, pounds, usually measured in an equivalent TNT weight. The detonation of a bomb with an equivalent TNT weight of W at a distance of R, ft. would cause a blast pressure time history as shown in figure 2. Such a time history can be idealized as a triangular wave form, with maximum amplitude of p, psi, and total duration of t_d, milliseconds. The short duration of the blast wave form have a major implication: it excite many higher modes in the structure, the building envelope and the non-structural components. The very high pressure amplitude p has an equally profound implication: it results, in general, in a nonlinear behavior of all of those systems.

The design values of p and W is governed by several standards. The choice of the applicable standard is usually done by the building owner. Sometime, the design professional and the building occupant participate in making this decision. For more details on the blast pressure properties, the reader is referred to the works of Mays and Smith, 1995.

After the blast pressure arrives to the building, it will affect both the building envelope and the building structural system, see figure 1. The hazards that are generated by the building envelope are the shards and fragmentation of the building envelope components.

The hazards that are generated by the structural system are the potential of progressive collapse; progressive collapse of structures is not discussed in this paper.

Finally, figure 1 shows the next level of hazards; the interior building components (generally referred to as non-structural components). Two categories fall under the interior components: interior architectural systems and mechanical/electrical and plumbing systems (including elevators). In the case of failure of either structural or building envelope, the internal building systems can fail. The hazard from such a failure can be either direct, e.g., interior partition harming occupants, or indirect. An indirect hazard can be a loss of functionality of a life support system, such as an elevator, of electric transformer.

In assessing different mitigating measures for any building, the flow of hazards throughout the building, as represented in figure 1, should be carefully considered. This includes all the hazards sources as well as the interdependence of these hazards. It should be mentioned that the structural progressive failure phenomenon is out of scope of this paper, for further information, the reader might want to refer to the publication by the Research Council on Performance of Structures (1972) or The work that was edited by R.B. Malla (1993).

3 OUTSIDE THE BUILDING ENVELOPE (SITE CONSIDERATIONS)

Site considerations in hazard reductions are affected by such parameters as availability of surrounding land, topography and type of available landscaping. The availability of land is perhaps the most important parameter. In urban areas, no, or limited land is available for use to increase, or control, the setback around the building. In suburban or rural areas, the land is more readily available, so larger setbacks around the building can be utilized in the overall planning stage.

The topography of the site can play a major factor in hazard reduction. Existence, of topographical features such as hills, lakes, rivers, nearby roadway systems can all have positive or negative effects on desired building protection. In general, there are no pre-set rules to govern this issue. It is a case-dependent issue, and must be handled accordingly.

The landscaping of the site around the building can be designed (for new buildings), or changed (for existing buildings) to improve the security of the building. Some desired features would be fountains, pools and moats. Use of thick shrubs and / or trees can help in acting as barriers for vehicles; however, it can act as hiding places.

When landscaping features can’t be used in a particular site, it can be compliments or replaced by a set of barriers. The main purpose of the barriers is to prevent vehicles from coming close to the building. The barriers can have many shape and forms. They can be heavy planters, steel of concrete bollards, etc. In addition to the system of barriers, a system of gates might also be needed for complete protection of the site.

The barriers must be designed to meet specific demands, namely weight and speed of vehicle. There are several standards for barrier designs; the reader is referred to some of those standards for more information. It should be noted that there are situations that the type of soil or the type of construction will result in a case-specific barrier design. An example of such a situation is the existence of retaining wall. To anchor a standard bollard on top of an existing wall, without retrofitting the retaining wall would result in an unconservative/unsafe situation.

There are several standard designs of gates that the professionals can use to compliment the design of a secure site. Some gates are manually operated, while others are automatic. The designers should coordinate the appropriate choice of the gate type and location with the building owners and occupants.

4 BUILDING ENVELOPE

Building envelope is one of the exposed systems in the building (the other is the structural systems). The building envelope, as shown in figure 1, is affected directly by blast pressures. If not designed properly, it can harm either the occupants, or the other major components, inside the building. During the Oklahoma City Bombing, numerous human losses were encountered because of the failures of different building envelopes. See the report of ASCE, 1996 for further details.

Building envelope can be constructed of metals, cement-based materials, and/or glass. Curtainwalls and cladding can be part, or whole of the building envelope. For secure building envelope, it should be designed to transmit the postulated blast pressures safely into the supporting structural system.

In designing building envelopes, it should be remembered that different hazards affect building envelope; including seismic, wind, as well as blast hazards. There are some similarities between seismic and blast hazards such as both hazards tend to exert dynamic forces on the system, thus causing it to dislodge from its anchors. Mitigation methods for the harmful effects of earthquake hazards are well documented. The common seismic design for building envelope components is based on estimating a seismic design force, $F_p = a_p\ m_p$, where m_p is the mass of the system under consideration and a_p is an adequate acceleration value. The system under consideration is then anchored to the main structure so that the anchoring mechanism can resist the force F_p. In addition, qualitative seismic detailing might be needed to ensure that the building envelope components do not sway or fall during an earthquake.

Applying the above methodology to blast condition is problematic. First, the design seismic force, F_p, is based on an assumed seismic acceleration, a_p. Effective blast force on a particular nonstructural system depends on the expected blast pressure that will affect the system. Second, the qualitative seismic detailing for anchoring building envelope components to the building are all base on expected seismic deformation modes. Blast deformation modes can be different from the seismic ones; in many cases they are the opposite. Blast-specific approach to the design and detailing of building envelope components to mitigate blast conditions is needed.

There are several important considerations that are needed in a blast-specific design for building envelope:

Considerations of dynamic effects: As was discussed above, the short duration of blast events would excite high frequency modes. Since many of the components of building envelope have frequencies that are within the blast pressure range, their dynamic responses should be accounted for in the design.

Rate effects on Strength and ultimate strains: IT is well known that high loading rates increases the strength of materials. However, these same high loading rates decreases the ultimate strains of materials. This phenomenon should be included in the design.

Balanced Design: Since the building envelope is usually constructed from several components that are made of different materials, it is important to ensure that the load path throughout all the components and the jointing between these components is strong and ductile enough for the postulated blast load. Any weak link can render the whole building assembly unsafe.

Glazing: Shattering of glass is a particularly worrisome occurrence during a blast event. During different terrorist acts, the shattering of glass was the major cause of human fatalities and injuries. The lack of ductile behavior and the large coefficient of variation in design parameter make it essential that glass design be addressed properly.

Anchoring to Structural systems: Good design of building envelope is not complete without appropriate anchoring to the supporting structural systems. If there is any potential of interaction between the building envelope and the supporting structural system, it should be accounted for in the design.

Un-Reinforced masonry (URM) bearing walls: In many building the URM is used extensively in the building envelope. URM is not ductile systems, and is fairly weak in the transverse direction. Some retrofit measures should be employed for existing buildings that have URMs. For new construction, some form of reinforcement should be used in exterior masonry walls.

A safe and secure building envelope will result from following the above rules. For more information about curtainwall design and behavior, refer to the work by Zhou, 2002.

5 INSIDE THE ENVELOPE

Figure 1 shows the two categories of systems inside the building envelope. They are the Architectural Systems (AS), and the Mechanical, Electrical and Plumping (MEP) systems. The architectural systems include, but not limited to interior partitions and walls, ceilings, light fixtures, furniture and elevated floors, if any. MEPs include generators, transformers, elevators, chillers, etc.

The safe design for blast effects include appropriate anchoring, hardened enclosures and simply installing important MEPs always from harm's way. For example, it is prudent to locate generators, and other essential equipments, deep inside the building, rather than near the outside. Another subtle, but important consideration is the possible harmful effects that seismic considerations might have on blast considerations. For example, whenever a seismic restraint (snubber) or seismic (or noise) isolation system is placed with a heavy machinery (or even a light weight clean room) the effectiveness of any of those measures should be considered during blast event. In particular, the differences in the operational frequency ranges for different hazards must be studies, see figure 3.

6 CONCLUSIONS

The different aspects of safety of buildings during a blast event were discussed above (not including the structural systems). The flow of hazards from the source all the way to the inside the buildings were illustrated. The change of the type of hazard, from blast pressures to flying glass shards to the disabling of important equipments was highlighted. In addition, different mitigation options for each of the stages were mentioned.

Secure and safe buildings require early planning as well as integral mitigating strategy, as highlighted by equation1. Without such an integral approach, the result will not be cost effective. Worst yet, it may not end up in a safe building.

7 REFERENCES

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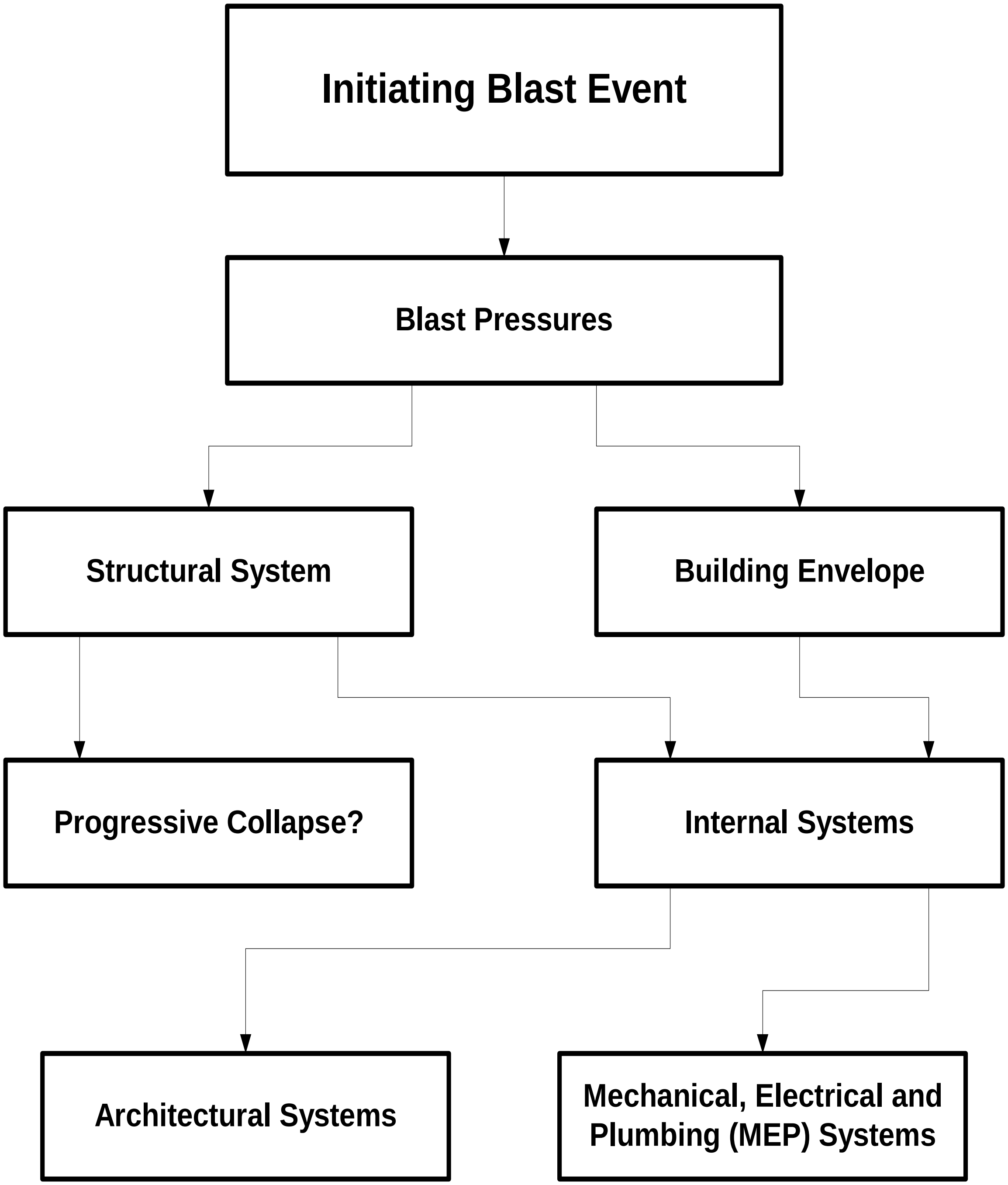

Figure 1 – Different Hazards Resulting From a Blast Event

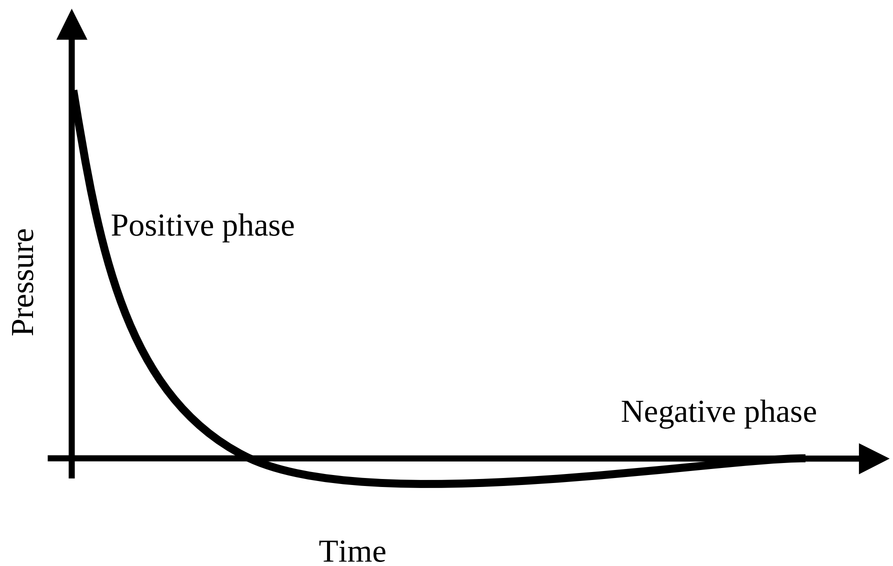

Figure 2 – Typical Blast Pressure Wave Form

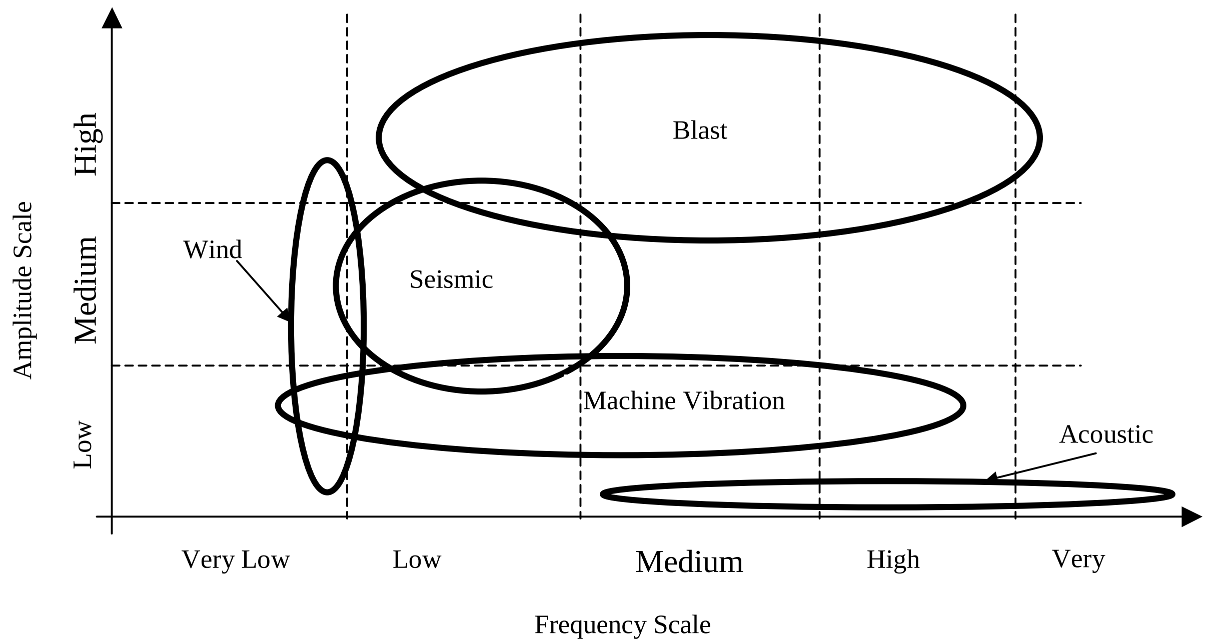

Figure 3 – Qualitative Frequency-Amplitude distribution for different Hazards