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Blast resistant modular buildings for the petroleum and chemical processing industries

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Abstract

There exists a need for blast resistant yet portable buildings to protect personnel temporarily assigned duties within explosively hazardous areas. Blast resistant portable buildings (BRPBs) are a valuable asset for protection of temporarily assigned personnel involved in activities located near portential explosion sites.

- Portable.
- Stackable and modular.
- Blast designed and ductile.

Several companies have designed products to meet this need. Blast resistant portable buildings are the size of a typical office trailer; however, they may be installed in a variety of configurations and floor plans. The buildings are similar in design and construction to steel shipping containers but they are larger in scale, are much stronger, and are intended to be occupied within hazardous areas.

Typical siting issues for modular buildings involve blast related requirements, process related requirements and conventional loading requirements. Examples of these requirements include:

- Sliding and overturning during blast response.
- Positive pressure and forced ventilation requirements.
- Seismic and wind loading.

This paper describes blast performance, structural siting issues, and presents different applications of blast resistant modular buildings that have been installed at various facilities.

Keywords: Blast; Building; Industry

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1. Background

Blast resistant structures are essential for protecting personnel from building generated hazards when they are working in explosively hazardous areas. Blast resistant buildings are typically permanent structures constructed of pre-cast, cast-in-place concrete, or are steel clad steel frame. However, there is also a need for structures to be temporarily placed in areas with the potential for blast overpressure. To meet this need, several companies have had blast resistant modular, or portable, structures engineered. These buildings, similar to that shown in Fig. 1, are currently in use throughout the petroleum and chemical processing industries. The blast resistant portable buildings (BRPBs) are typically 40 ft in length, 10–15 ft in width, and are approximately 10 ft tall. The buildings are similar in design and construction to steel shipping containers but they are larger in scale and more robust.

BRPBs were engineered to meet an existing need within the petroleum industry. During construction projects or turnaround operations at a petroleum or chemical plant it is necessary to provide temporary structures, such as trailers, to employees and contractors so that they may have shelter closer to the area they are working in. Refineries and chemical plants have the potential to release clouds of flammable vapor that if ignited may produce explosive loads. The solution to protecting personnel temporarily assigned duties within these hazardous areas is the BRPB.

This report describes the performance characteristics of BRPBs and issues associated with siting. In addition, several applications of BRPB installations are provided.

2. Performance characteristics

Performance characteristics of BRPBs are a function of a variety of factors. Blast clearing effects and interaction between structural components are the two most predominant performance characteristics of the buildings.

Fig. 1. Representative blast resistant portable structure.

2.1. Applied blast loading

Blast resistant modular buildings are typically designed for loads that do not include effects such as clearing and wrap around load relief of frames. This is due to their modularity. The buildings can be stacked and placed in a number of configurations that may change the nature of the blast loads on the building. However, the effects of clearing and wrap around loading on a single module can be significant [1]. The blastward wall can fully clear in approximately 25 ms. Significant reduction in impulse can be realized for long duration loads. For example, an 8 psi free-field loading for a duration of 200 ms would place a reflected load upon the blastward wall of 20 psi and 1900 psi ms of applied impulse. Clearing effects reduce the applied impulse to 950 psi ms. This example is illustrated below in Fig. 2. In addition the blast applies load to the roof and backside of the structure. A blast trace applied to the roof is presented in Figs. 3 and 4 shows a typical rear wall loading. It is noteworthy that the applied blast loads are positive pressures on all surfaces.

2.2. Structural response to blast loading

BRPBs are currently manufactured in such a manner that they respond to blast loading utilizing a variety of response modes. For example, individual components such as the wall panel, roof deck, and roof joists will exhibit deformations relative to their supports. However, each of the six exterior surfaces can act as a diaphragm and the entire module may also act as a box girder. This variety of load transfer mechanisms coupled with the application of loading on the building result in a system that performs well when subjected to blast loading.

3. Technical siting issues

Several issues must be considered when siting temporary buildings within a facility. These include: level of blast hazard, potential presence of toxic gases, desired proximity to the

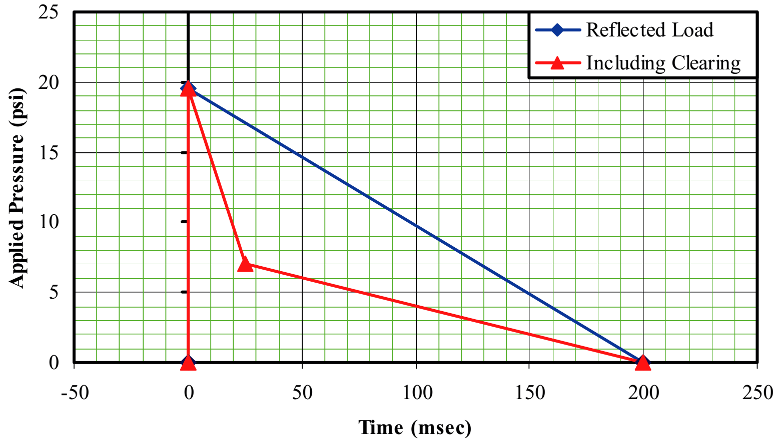

Fig. 2. Effects of clearing on reflected wall load.

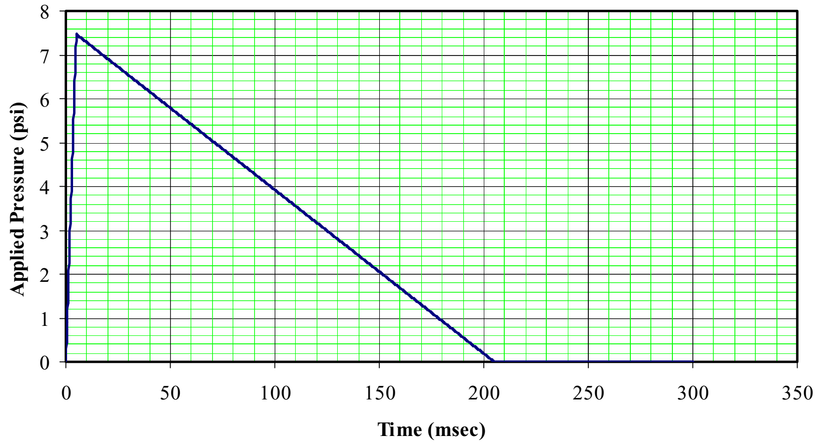

Fig. 3. Roof load for 8 psi free-field 200 ms blast.

process unit, applicable building codes, and the desired level of protection. Consideration of these variables will define the blast design level of the building, the ventilation requirements, electrical classification, and foundation requirements.

3.1. Foundation requirements

Blast resistant modular buildings may be anchored to a foundation for environmental loading and building code compliance. However, a conventional structural connection to the foundation may not be sufficient to restrain the module during response to blast loading. In some applications, the foundation connection may even be relatively insignificant. Therefore, it is necessary to assess the magnitude of sliding and tipping response of a BRPB when

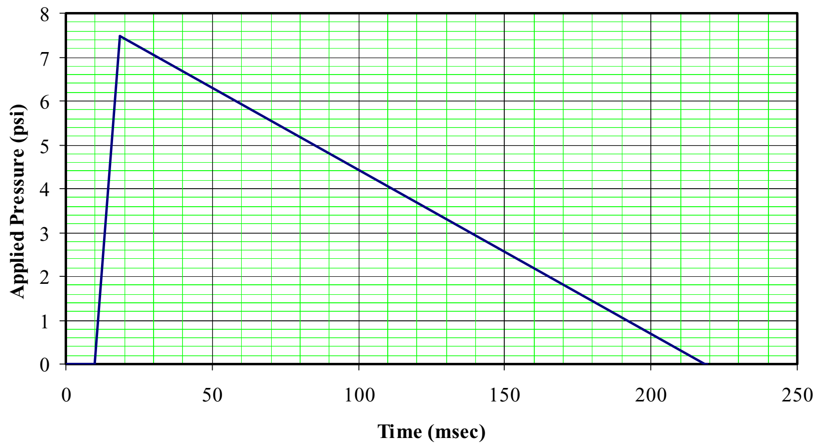

Fig. 4. Back wall load for 8 psi free-field 200 ms blast.

Table 1
BRPB sliding response, effects of roof loading

Roof loading	Total translation (in.)	Peak velocity (in./s)	Time to peak velocity (ms)
Included	3.1	31	22
Excluded	26	109	24

subjected to blast loads. The most significant variable in this determination is whether blast loading will be applied to the underside of the building. If blast is able to load the underside of the module it will negate the stabilizing benefit of the blast load on the roof. Table 1 and Fig. 5 detail the effect inclusion of roof loading has on the predicted sliding response of an unrestrained BRPB. Preventing blast load from loading the underside of a BRPB will significantly limit the global response of the structure after failure of the connections to the foundation. If the BPRB is sited such that blast may reach the underside of the structure, the benefit of roof loading should not be considered unless measures are taken to prevent blast from loading the underside. If the BRPB is subjected to blast loading underneath the building, it is recommended that it be tied down in a manner consistent with the magnitude of the blast hazard.

3.2. Blast design level

Blast resistant portable buildings are available in a variety of configurations and blast capacities. However, issues associated with a particular site and personnel requirements will dictate the blast capacity and performance of the modular building. For instance, it is always preferable to move personnel out of a hazardous area or to eliminate the hazard

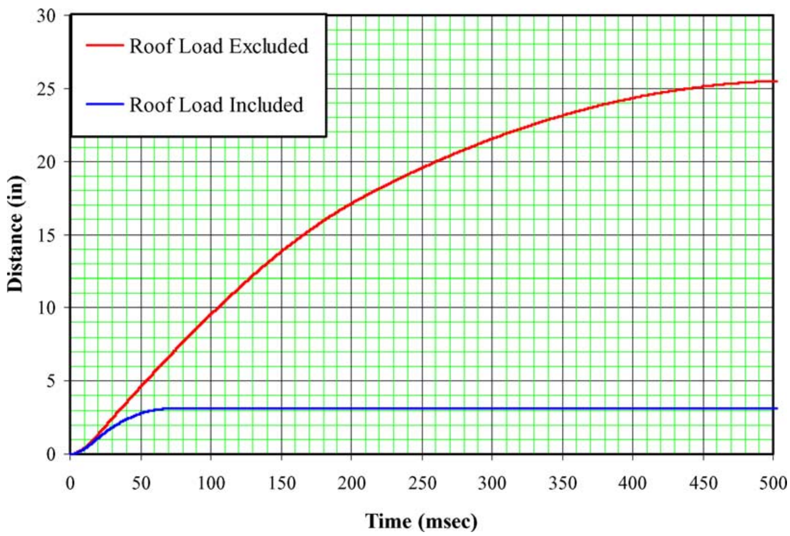

Fig. 5. BRPB sliding response, comparison of effects of roof loading.

rather than to subject people to risk [2]. However, if the siting variables and operation requirements dictate that people be located close to explosive hazards then the following items should be taken into consideration:

- Place structure in as low a blast overpressure contour as possible.
- Orient narrow end of building towards hazard.
- Determine foundation performance requirements for blast (base on neutral risk).

Placing a temporary building in as low a blast overpressure area as possible is the first and most obvious goal. Proper orientation of the building to the hazard can also help to minimize the risk exposure of the personnel within the building. The last aspect of determining the blast load requirement for the building is a function of neutral risk. The purpose of the blast design is to make the personnel within the building as safe as those outside of the structure. This way the building does not increase the overall hazard to the worker. An individual inside a BRPB in the 4–5 psi free-field blast contour and heavy damage to the building can expect to be thrown to the floor and have ceiling tiles and drywall fall on them. In comparison, a worker in the open in the same blast environment may experience burst eardrums and temporary hearing loss as well as being thrown to the ground [3]. In order to achieve neutral risk, an understanding of the hazards associated to personnel located in the open and the corresponding risks to building occupants and different structural damage levels need to be considered.

3.3. Positive pressure and forced ventilation

Blast resistant modular buildings are all steel structures that are fully seam welded. Therefore, they are very air tight and proper forced air ventilation is important. However, the tightness of the buildings allows for positive pressurization and may easily be converted to safe-havens by utilizing emergency to seal the buildings in case of toxic release.

3.4. Conventional loading requirements

Depending on the location of a particular process plant, building code and conventional loading requirements for a BRPB installation may vary. Seismic areas on the west coast, high wind zones along the gulf, and heavy snow loads in Canada and the northeast all place unique requirements on the installation of buildings. Working with the local building department to insure that portable buildings, conventional and blast resistant, are installed to code is important. Some regions even have special requirements in the electrical code that are important to communicate to the BRPB vendor.

4. Applications of blast resistant portable buildings

Blast resistant portable buildings have been in industry for some time now and they have been installed in a variety of configurations. Examples include single modules as shown in

Fig. 6. Stacked complex of BRPBs.

Fig. 1, "double-wide" modules, stacked complexes as shown in Fig. 6, and muti-module buildings enclosing thousands of square feet of floor space. The buildings may also be purchased or leased.

5. Conclusions

Blast resistant portable buildings play an important role in protecting personnel in explosively hazardous workplaces. In order to achieve to proper level of protection and building performance several technical siting issues must be considered. Examples of these requirements include:

- Sliding and overturning during blast response.
- Positive pressure and forced ventilation requirements.
- Conventional loading requirements.

Blast resistant buildings must be designed and sited such that the appropriate level of protection is provided to workers in hazardous areas. Addressing the siting issues discussed in this report and selection of the appropriate performance criteria for blast resistant temporary buildings can greatly reduce the risk to employees in temporary buildings.

References

[1] B.F. Harrison, Analysis of blast resistant modular structures, in: Proceedings of the 29th DoD Explosive Safety Seminar, Department of Defense Explosives Safety Board, Session 7A, 2000.
[2] Scott W. Ostrowski, ExxonMobil Baton Rouge chemical complex's approach to facility siting of temporary buildings, in: Proceedings of the Environmental Health Safety Seminar, Texas Chemical Council, Session II, PSM/RMP, 2001.
[3] Departments of the Army, the Navy, and the Air Force, Structure to Resist the Effects of Accidental Explosions, Department of the Army Technical Manual TM 5-1300, Department of the Navy Publication NAVFAC P-397, Department of the Air Force Manual AFM 88-22, Revision 1, November 1990.