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Commonly Encountered Problems in the Safety-Focused Design of Capital Projects

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Abstract

The design and construction of a new building is often a significant investment for capital projects. As a result, there are typically many competing design considerations, such as: land use, interconnectivity, access for operations personnel, building codes, personnel safety, cost, etc. To minimize the number of costly design iterations, it is vital that overall project goals for the building be firmly established, communicated, and implemented effectively. Unfortunately, many projects suffer from a misstep in one or more of these areas.

This paper details lessons learned from common building design complications encountered in the process industries, with a focus on personnel safety. The paper contains examples of common building design issues and suggests methods to avoid them. The paper discusses the safety-focused design requirements that are typically chosen for building projects as well as the potential impacts those requirements have on personnel safety and project cost.

Introduction

The design and construction of a new building is often a significant investment for capital projects. As a result, there are typically many competing interests in the design of the building. The availability of land, interconnectivity of infrastructure, accessibility for operations personnel, building codes, personnel safety, and cost may all need to be considered. A building designer may have difficulty arriving at a design with this many, often conflicting, priorities. This may lead to costly iterations in the design process, project delays, and a general level of frustration in the project group.

As with most large projects, clear goals and communication are essential to the successful design and construction of a new building. Unfortunately, it is not uncommon for building projects to suffer from a misstep at some point in this process. This paper details lessons learned from common building design complications encountered in the process industries, with a particular focus on personnel safety.

Building Intent

Probably the first question for the design team to ask the building owner is, "What is the intent of the new building design?" While many design teams will focus on and determine how the building is to house people, equipment, workspaces, or some combination thereof, it is important to dig deeper to help satisfy the safety-focused design requirements. This is especially important for mixed-use buildings that serve multiple functions.

A control room for example, may need to be relatively close to a unit for a variety of reasons. Given that process hazards are typically increased closer to a unit, this will typically result in more stringent safety-focused design requirements for the building and relatively increased project costs. This may be acceptable if the building has a small enough footprint and is seen as housing a necessary function. However, given the opportunity, the building owner may wish to add conference rooms, office space, or other building functionalities that may not be strictly necessary for control room operations. This increase in both footprint and occupancy of the building may significantly increase the cost of the project. Early on in the project, the designer may wish to question if some of these additional functions can be relocated to other less hazardous locations. If that is not an option, the project team should communicate with the building owner the potential cost impact that will arise with the added footprint of a building that already has an increased relative cost.

Similar consideration should be given if the building is to house equipment. The project team should determine if the building will be handling equipment critical to the safe operation or shutdown of the plant. If the equipment is deemed to be safety critical, the project may wish to look at redundant systems housed in various locations throughout the plant to mitigate against event escalation through the common cause failure of the loss of the planned new building. As detailed elsewhere,[1] the presence of wall-mounted equipment may impact the vulnerability of safety critical equipment. The project should consider whether additional distance between the wall and equipment, which may increase the building's footprint, is needed to allow for the movement of a wall during an explosion event. This additional building footprint may add cost, but could significantly improve the building response to blast and fire loads.

Once decided, changing the intent of a building may have serious implications for the project team. For example, a building housing neither personnel nor safety critical equipment may be designed to have a relatively poor response to most process hazards. If the project team later chooses to include occupancy in the building, they should do so acknowledging that substantial redesign work most likely will need to be accomplished to satisfy newly-introduced safety-focused design requirements and that initial cost estimates for the building are likely invalid.

Even after construction, the owner must ensure that the building intent is preserved. In the authors' experience, it is likely for a building that is not intended for occupancy (and was not designed with occupancy in mind) to become occupied. This is especially true if the building contains heating, air conditioning, seating (e.g., at equipment monitoring stations), or general space where meetings can be held. During project planning and design, project teams may want to assist plant operations in setting up controls to monitor and enforce the occupancy of the building once constructed and functional. Similarly, buildings requiring stand-off distance between housed equipment and exterior walls should be noted (e.g., exclusion zones indicated on the floor) and maintained throughout the service life of the building to ensure the building functions as intended.

During this "building intent" phase, it may also be prudent to begin considering the emergency response plan for an occupied building in the event of a toxic release. Designers should consider if occupants will be asked to shelter in place or evacuate from a building. They should also determine whether there is a need for a designated safe haven within the building or if storage of escape packs or other toxic mitigation equipment is needed. Consideration must also be given to the number of personnel that could be directed to utilize the building in the event of a toxic release.

Understanding the Hazards

Once the intent of the building has been established, the next phase for the designer is to understand the process hazards that may impact the building. If a facility siting study has previously been performed for the site, comprehensive process hazard information may be available for the potential building locations. The designer may run into difficulties however, if the building design is part of a larger plant expansion. New or modified processes may significantly alter the process hazard profile. In this instance, coordination between the building designer and the team handling the updated facility siting information is key.[2]

The American Petroleum Institute's Recommended Practice 752[3] is often considered to be the recommended good engineering practice for developing process hazard scenarios for building designs. Based on this document, analysts may determine their own study basis, but should use the maximum credible hazard scenarios in their study. As such, the project needs to have established the guidelines by which they will determine the maximum credible events. While previously a limitation on the process hazard release size to two-inch and smaller releases was common (in determining the maximum credible events), the authors have seen a significant shift in the industry to incorporate larger release sizes in their analyses and specific frequency calculations to determine the credibleness of a given release.

Consider Relocation

If the process hazards at a particular building location are significant, the design team should consider whether it is feasible to relocate the building or reduce its expected occupancy. Spacing buildings further from sources of hazards is an inherently safer method of protecting building occupants and equipment. In the same manner, reducing the occupancy of the building or limiting its function to only necessary tasks helps lower the risk to site populations.

However, these inherently safer designs may not be feasible. There may be minimal suitable land available for construction or operations may require that personnel be housed close to the hazards to improve time at tools. In addition, there may be a desire to tie new buildings into existing connections or attempt to reduce costs by limiting runs of telecommunications, power, and other utilities to a building. As detailed elsewhere,[4] a study of the feasibility of selecting both a building location and conceptual building design, while minimizing the risk to building occupants, can be conducted effectively given access to comprehensive process hazard information.

Developing a Design Basis

If a more suitable location cannot be found, then the design team can proceed to determine the basis of design for the building. Three common methods to determine a design basis are offered below.

Dynamic versus Static Design Loads

It should be noted that when developing the blast design of a building, a dynamic analysis should be performed rather than an equivalent static load analysis (sometimes referred to as an "equivalent wind" analysis approach). A static load design will typically cause a substantial increase to the material cost of the building, since damage to the structure is not considered nor accounted for in the analysis. It may also increase the instances of brittle failure modes controlling the response of the building. The combination results in a design that may be both less safe and more costly compared to a design based on dynamic blast loading. It has been noted in the literature[5] that the static load analysis method is not recommended for use in the design of buildings subject to time-varying blast loading.

Consequence Based

The maximum postulated blast load (overpressure and duration) is often adopted as the design basis for a blast resistant building. This technique has the advantage of ensuring that the blast risk to personnel and assets within the building is mitigated to the extent practicable (i.e., approaches zero). However, it is imperative that a sufficiently representative maximum load be determined. If only a small sampling of blast hazards is considered, the analyst may not identify the worst-case blast load. The analyst also runs the risk of selecting too stringent a design criteria and spending excessively to design to a scenario that has a very low probability of occurring. Attempting to dismiss blast hazards as non-credible without a proper frequency and risk assessment may leave significant uncertainty in the data. If blast hazards are significant, which is often the case when buildings are placed close to the process unit, it may not be feasible to design the building to the maximum postulated blast load.

Toxic hazards may also be difficult to design to the maximum consequence. Sheltering in place often depends on shutting down the HVAC system reliably as well as a relatively leak tight building. Evacuation depends on multiple human factors to be successful. It is therefore difficult to dismiss consequential scenarios as infeasible. Buildings with highly reliable detection and interlocked shut down and isolation systems for the HVAC may be able to drop the frequency of consequential events low enough to be viewed as non-credible, but these systems may be expensive to install and maintain.

Fire hazards on the other hand are typically designed with the maximum consequence in mind. Depending on the severity of the fire exposure, the removal of windows, presence of multiple exits away from the fire hazard, and other active and passive fire protection may offer enough protection even from the maximum fire cases.

Exceedance Curves

Frequency pressure curves are a common way to credit high blast loading events that are typically predicted to occur very infrequently, and provide a simple way to screen out low probability events. This design does have the benefit of often being more economical than designing the building to the maximum blast load and has a simpler analysis than the comprehensive risk based design. However, this data should be used with caution as a basis of design. Frequency pressure curves are often presented without reference to the duration of the blast load. At times, a long duration or the maximum duration may be chosen for the design load. At other times, the duration of the particular blast scenario at the design frequency is selected. In either approach, the analyst is entrusting luck to ensure that the selected design load satisfies the intent of the design. The amount of uncertainty in the input data makes it difficult to determine an optimized design that will minimize blast risk as well as cost.

Due to their dependence on duration to determine dosage and vulnerability, it is typically not recommended to use exceedance curves for toxic and fire hazards.

Comprehensive Risk Based Design

A comprehensive risk-based design considers both the duration of the blast wave as well as the ranges of building response, i.e., from a no damage response to potential building collapse, and scenario frequency when determining the blast design load. When using the comprehensive risk based design approach, the project adopts a tolerable risk criterion for the building, typically measured in significant injuries per year. The designer then determines the blast load(s) to design the building so that the risk remains below the established criterion. This comprehensive set of potential scenarios may be more analytically intensive to obtain and use, but it provides the foundation to create a balanced risk design that minimizes both risk and cost.

Another advantage is that the project team can measure the total risk to building occupants across all hazards. This allows the project team to address the hazards holistically and design a complete mitigation strategy based on one criterion instead of one for each hazard. One caveat to this design practice is that it is dependent on the occupancy of the building. Designers may wish to use conservative estimates of occupancy to provide some margin for occupancy fluctuation. Owners of the building will need to manage occupancy changes within the building to ensure that the risk tolerance criterion for the building continues to be met.

It is important to note that good-practice detailing should be incorporated in the building's design so that post-yield structural response and failure modes are controlled to maximize the response of the building to the postulated blast loads. In such a way, instances of brittle failure modes controlling the response of the building can be eliminated and sudden catastrophic failure post-yield can be avoided.

Maintaining a Design Criteria

During Design

As mentioned previously, it is important that a building's intent be clearly communicated. A site manager may want a building to serve a variety of needs in order to maximize operational efficiency. The designer must balance this request with the need to create an economic and safe design. Adequate communication in the early stages is imperative to mitigate surprises in later design phases.

Many large capital projects go through an optimization phase late in the detailed design phase. This often leads to cheaper alternatives being presented. For example, an off-the-shelf design may be recommended instead of the originally proposed designed solution for the building's hazard response and requirements of the safety-focused design. The designer must work with the optimization team to ensure that any proposed changes to the building design are managed and that risk to building occupants due to process hazards is not allowed to increase above tolerable levels.

This also holds true during construction, where small changes in the design implementation can have significant impacts. For example, a third-party designer might change the anchorage of blast resistant vendor products, e.g., doors and windows, from the structural components to the façade system to ease installation, thereby, nullifying the protection to occupants afforded by these products. Once again, having the designer involved at milestone review stages and implementing an effective management of change procedure is instrumental in reducing these types of last minute errors.

During Operations

One common issue that the authors have encountered during their careers is that many plant operators do not treat buildings as protective systems that must be inspected and maintained. This may mean that normal management of change procedures are not followed for changes to buildings. Alternatively, critical components such as HVAC louvers may not be maintained adequately. The authors have seen numerous HVAC shutdown systems that had reliable detection and interlocked systems, but were not maintained as safety systems so were prone to failure when tested. Changes in occupancy, intent, and structural integrity need to be managed like any other change.

Conclusion

A new building can be a significant investment for a facility. As shown, there are many potential pitfalls for the building design team given a number of competing project goals. While this paper discusses specific examples of a building design, the same arguments can be made for many other safety system design decisions. Quality communication and the sharing and review of project data are imperative to create designs that meet the project's design requirements while minimizing both risk and cost.

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