Damages Mitigation in Confined Work Environments Exposed to Explosion Hazard

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The presence on its territory of a large number of work environments having explosion hazard forced the European Community to promulgate the ATEX Directive to specifically deal with this issue. In Italy the correspondent regulation has been inserted into a legislative framework that asks the employer for the workplace occupational safety & health risk assessment, the consequence estimation for the credible accidents and the intervents both on the productive process itself to make it safer and on the buildings/structures to mitigate the damages. Various Authorities, each one with its role and responsibility, have to verify the application of ATEX Directive.

1. Introduction

Explosions occurring in confined work environments are the cause of significant damages to both people and structures. This mostly due to the fact that these environments have been, obviously, designed for actions different from those generated by an explosion.

In spite of the violence of the phenomenon it appears to be possible reducing, even greatly, the explosion effects with some intervention that aren't excessively onerous.

This paper presents the analysis path of a theoretic accident that, taking into account all the intervents on the productive process, proposes how to determine:

- the overpressure in confined environments due to combustible chemicals explosions;
- the mechanical resistance degree of the housing in which the explosion could take place;
- which targets located in the surroundings should be protected.

It’s advisable to highlight that the reference to the combustible chemicals explosions, basis of the paper, does not limit the results universality given by the adoption of such proposed methodology.

Let’s suppose that it is preliminarily possible to determine with suitable calculation theories and simplification assumptions on the mechanical behavior, the damages on a specific building/structure.

In order to get these results it’s reasonable to adopt an impulsive-type dynamic analysis. This method has general validity and it could be applied for the analysis of explosions in both confined and unconfined environments, for buildings made of various materials (concrete, steel, masonry, prefabricated modules, etc.), for bunkerized structures or facilities having common openings (windows, doors, etc.).

This method also introduces several simplification assumptions that are coherent with the probability based part of the traditional risk assessment, but it does not give up a certain refinement degree that allows to provide for less intrusive interventions (more acceptable from the economic point of view) to revamp the existing structures with acceptable costs. From the impulsive nature of these phenomena the correct evaluation of the credible damages and the mitigation measures comes from the comparison between the dynamic characteristics of the building and of the explosion; the exam of these properties, in particular, should focus on both the global behavior (of the entire building) and the behavior of the various mechanical subsystems (windows and doors frames, prefabricated panels, walls, floors, etc.). To identify this systems, a great role is played by the sensitivity of the structural engineer, since it’s important to identify in a correct way all the constraints among them.

From the analysis a path rises that, taking into account a credible accident scenario referred to a specific building in a specific context, allows the theoretic identification of the damages coming from the accident.

It becomes then possible to protect the building/facility with the damages mitigation in order to be able to manage an explosion with a precise prevention strategy. The result is achieved by iteration: first the explosion damages scenario is defined on the building “as is”, then the same scenario simulation is conducted taking into account some “possible” and “available” protections, and in the same way until the needed performance is reached.

2. Approach

As anticipated in the introduction to reach the objective the approach should be iterative: the identified risk, connected with the manufacturing processes, indicates an intervention for the structures protection. Considering these measures it is important to verify the impact they have on the work environment configuration and assure that they do not rise any other hazards there. If this last requirement is not met different interventions should be evaluated by the analyst and the stakeholders, towards the safest conditions. In the following diagram (modified from a similar performance based approach applied to fire safety), the logic scheme has been summarized.

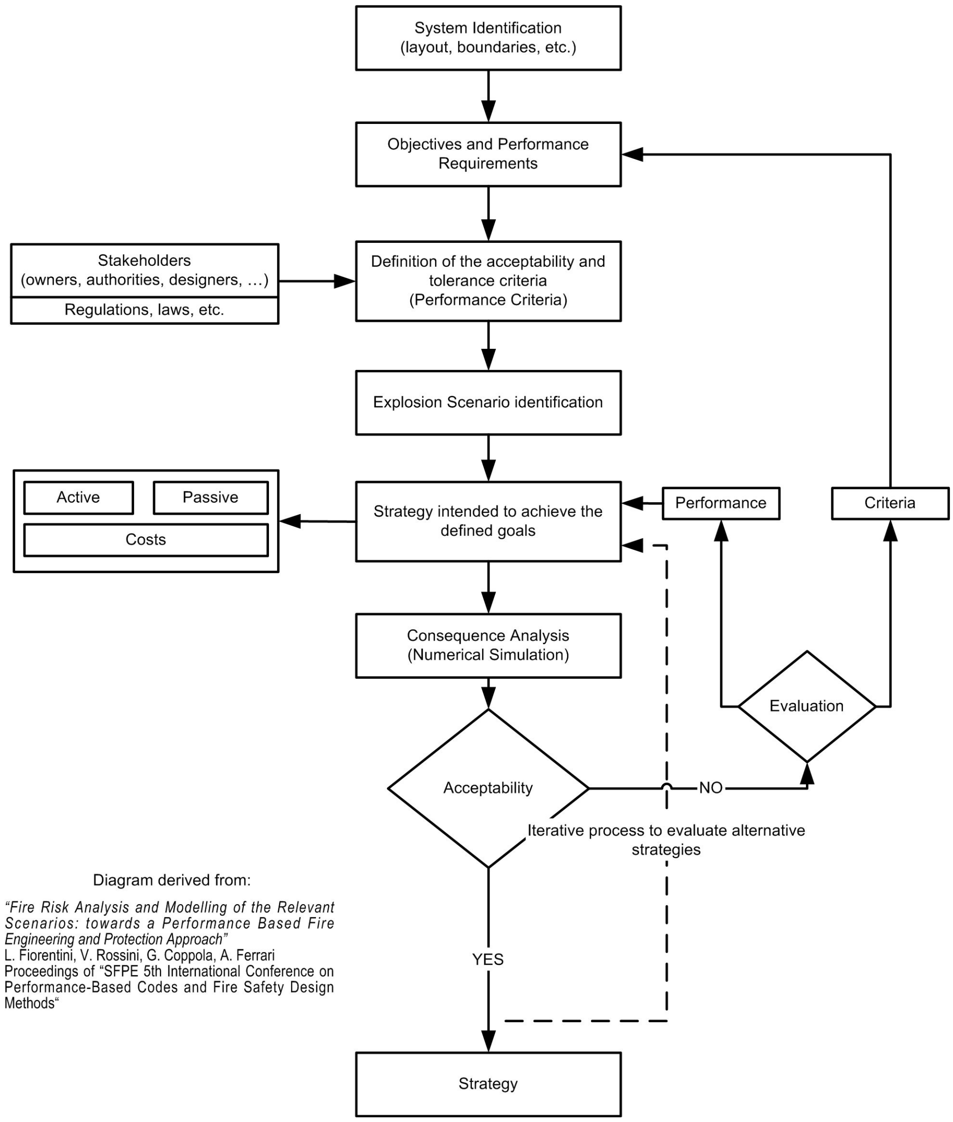

Figure 1. Approach

Figure 2. presents a manufacturing company typical layout composed essentially by a work environment (A), a locker-room for the personnel (B) and some offices (C). Car parking lot (E) is requested by the land use planning regulation. The explosion hazard is given by a mixture of methane.

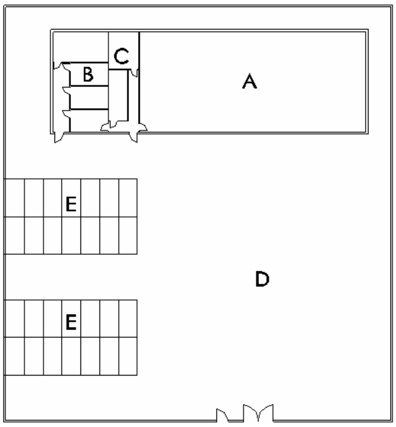

Figure 2. Case study layout

The proposed case study should not be considered realistic by the reader: the example is an excuse to underline how prevention and mitigation interventions are the final step of the analysis process in which the analyst should consider all the constraints of the specific situation, considering also the interactions and interferences with the manufacturing processes and the company budget.

Generally speaking, in order to characterize the action coming from the explosion it is sufficient to define a diagram of the overpressure versus time. To achieve this goal, as a first approximation, it is possible to quantify the maximum overpressure and make an hypothesis regarding a decay law.

For this particular point, many references are available, while, for the overpressure maximum value determination, in the cases where the explosion is due to a combustion process, Boyle law can be successfully applied (overpressure is function of the burned gases volume increase).

$$\Delta P \quad V = P_o \Delta V \qquad (1)$$

This equation could be also presented in the following form:

$$\Delta P = P_o (\Delta V / V) \qquad (2)$$

where P_o is the atmospheric pressure, ΔV is the volume variation connected with the combustion phenomenon and V represents the original volume where the explosion takes place. With reference to the case study, considering the following elements: maximum value 0.1 bar, positive phase duration 200 msec. and decay law described by a second order polynomial we obtain the graph in Figure 3.

The explosion effects on a building can be correctly evaluated only if the dynamic characteristics of the building itself are known. Applying the overpressure maximum value as a static stress the resulting actions could be under or over estimated. In the case study we will consider a static load of 0.15 bar on walls, doors and windows and a 0.4 bar load on roof and structure.

In these conditions it is likely that, due to the explosion, we have several ruptures, in the following order: windows, doors and walls.

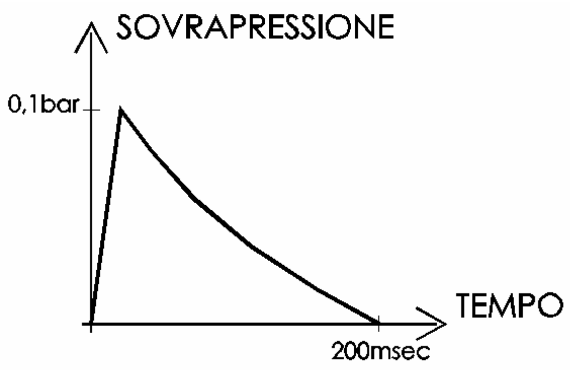

Figure 3. Overpressure versus time diagram

It is not probable that the roof caves in and we can exclude that the main structure collapses. These results give a precise knowledge about the presumable damages and their occurrence sequence. Thanks to this the analyst is able to elaborate and intervention strategy aimed both to minimize the explosion consequences and optimize the expenses.

Our case study suggests several different strategies, that, in order of effectiveness, are:

- partial containment of the explosion allowing the vent in areas usually not occupied by people;
- containment of the explosion in the main building without internal compartments;
- containment of the effects in compartments without vent in adjacent compartments or external areas.

In case roof is not interested by serious damages, to act the aforementioned strategies, the interventions could be limited to walls, doors and windows, in order to make these elements resistant. Several technologies are available to achieve this objective: walls in reinforced concrete, metallic framed walls and prefabricated walls are common solutions. Each one has to be evaluated against the specific situation, taking into account execution problems and costs. In this sense it is not possible to define the strategy before an in-depth analysis of the case study. In the following figures (n. 4, 5, 6) several strategies have been applied to the case study. In particular in Figure 4 the anti explosion septum has been lengthened on the courtyard since with an intervention limited to the walls the explosion could still reach the cars in the parking lot, and these furthermore could lead to a domino effect. A further protection is then applied according to the iterative process.
A single step methodology could not have taken into account this specific situation. All the strategies have to be evaluated against the specific situation and the requirements.

These considerations apply to passive barriers.

To manage the explosion hazard it is important to consider also active prevention systems (alarms, fire suppression systems, emergency valves, block systems, etc.). These systems could be easily controlled by electronic switchboards and distributed control systems. All the active and passive measures should also be verified against the emergency management plan where all the scenarios (taking into account the effects of the explosion themselves) have been considered and the emergency procedures have been clearly defined.

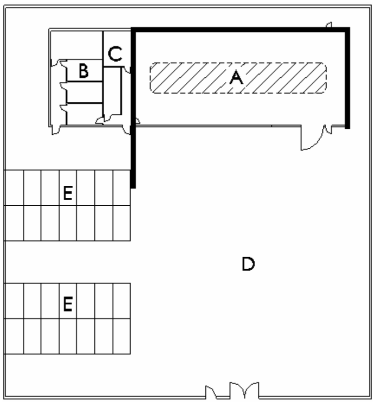

Figure 3. Case study: Strategy 1.

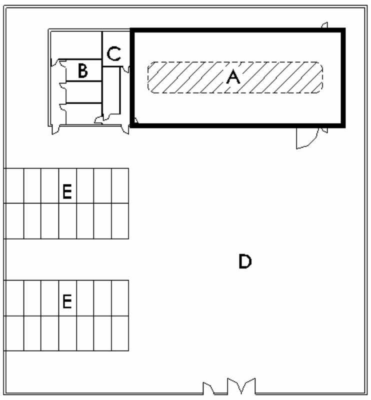

Figure 4. Case study: Strategy 2.

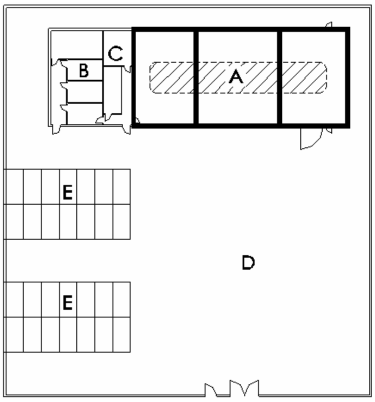

Figure 5. Case study: Strategy 3.

References

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