CFD modeling for urban blast simulation

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Abstract: *In this paper we present a Computational Fluid Dynamics (CFD) simulations for the case of natural gas explosion in urban area. Blast simulations aid in the development of effective mitigation strategies. By understanding how blast waves propagate through an urban environment, authorities can implement measures such as barriers, protective shields, strategies for firefighting strategy or evacuation plans to minimize damage and casualties. Accurate simulations provide insights into the potential impact of a blast on surrounding infrastructure and populations. This information is crucial for emergency response planning, helping authorities to allocate resources and respond effectively to minimize the consequences of an explosion.*

Key Words: *gas explosion, CFD modelling, blast simulation*

1. INTRODUCTION

Every year natural gas-related accidents such as Texas City (CSB, 2007), Buncefield (Buncefield Investigation Report) and Danvers (CSB Investigation Report, 2007) affect people's lives. The blast waves from vapor cloud explosions cause severe damage to buildings and produce victims. In case of gas auto station placed in urban areas there is a need to assess the risk of the worst case scenario: the explosion of the quantity of gas stored. This allows solutions to be found, such as optimal distance to habited buildings or the design of protective walls. Blast simulation in urban environments, particularly using Computational Fluid Dynamics (CFD), is crucial for assessing building damage and enhancing the understanding of the effects of explosions. Blast simulations help in evaluating the vulnerability of buildings and structures to explosive events, providing essential information for security and safety assessments. Understanding the potential damage allows authorities to implement preventive measures and design structures to better withstand blasts, ultimately improving public safety.

Engineers and architects can use blast simulations to optimize the design of protection of sites such as GPL stations buildings and infrastructure to resist the effects of explosions.

Identifying weak points and vulnerabilities allows for the incorporation of blast-resistant features into new constructions, reducing the risk of catastrophic failure. Blast simulations aid in the development of effective mitigation strategies. By understanding how blast waves propagate through an urban environment, authorities can implement measures such as barriers, protective shields, strategies for firefighting strategy or evacuation plans to minimize damage and casualties [1]. Accurate simulations provide insights into the potential impact of a blast on surrounding infrastructure and populations. This information is crucial for emergency response planning, helping authorities to allocate resources and respond effectively to minimize the consequences of an explosion. In many regions, there are regulations and standards related to blast resistance in urban areas, especially for critical infrastructure like government buildings, airports, and power plants. Blast simulations help ensure compliance with these regulations [2].

Urban geometry plays a critical role in blast simulation in towns and has a significant impact on the propagation of blast waves, the distribution of pressure, and the resulting damage to structures [3], [4]. The layout of buildings and streets in urban areas affects the reflection and refraction of blast waves. Tall buildings can reflect and focus blast energy, potentially amplifying the impact in certain areas, while street layouts may influence the direction of blast waves. The height and density of buildings impact the interaction of blast waves with the built environment. Tall buildings can shield or amplify the effects of explosions, while the density of structures influences the extent to which blast energy is absorbed or transmitted. Street canyons formed by tall buildings on either side can create complex airflow patterns, influencing how blast waves propagate [5], [6]. These canyon effects can lead to increased pressure in certain areas and affect the overall damage pattern.

Urban geometry influences the reflection and amplification of blast waves [7]. Understanding how buildings reflect and amplify the energy can help in identifying areas of higher risk and implementing measures to mitigate the impact on structures and inhabitant. Tall buildings may create shadowing effects, protecting certain areas from the direct impact of blast waves. This knowledge is valuable for urban planning and designing structures that take advantage of natural protection offered by the surrounding environment [8]. The town urban geometry influences the propagation of blast waves and the resulting damage. Understanding these aspects is essential for designing blast-resistant structures, implementing effective mitigation strategies, and enhancing overall urban resilience.

As seen in Table [9], computing overpressure levels enables us to assess building damage. The building's walls or structure might collapse due to the shock wave overpressures. Nevertheless, the collateral harm caused by the debris creates further damages. The fact that the blast wave causes injury to people due to tissue rupture caused by overpressure is crucial. The harm to the lungs is the most severe (Table 2).

Table 1- Shock wave effect on structure [9]

Damage	**Overpressure (ΔP)**	
	Bar	**psi**
Glass breakage	0,01-0,015	0,15-0,22
Minimal damage to buildings	0,035-0,075	0,52-1,12
Damage to metal panels	0,075-0,125	1,12-1,87
Failure of wooden panels (buildings)	0,075-0,15	1,12-2,25
Failure in brick walls	0,125-0,2	1,87-3
Rupture of refinery tanks	0,125-0,2	3-4,5
Damage to buildings (metallic structures)	0,2-0,3	4,5-7,5
Damage to concrete structures	0,3-0,5	6,0-9,0
Probable total destruction of most buildings	0,7-0,8	10,5-12

Table 2- Shock eave effect on human [9]

Damage	Overpressure (ΔP)	
	Bar	psi
Tolerable (does not cause damage)	up to 0,0001	up to0,0015
Fall	0,07-0,1	1,05-1,5
Eardrum rupture	0,35-1,0	5,25-15
Lungs injury	2,0-5,0	30-75
Lethal	7,0-15,0	105-225

The arrangement of buildings affects local airflow patterns, which in turn influence how blast waves disperse. Understanding these patterns is crucial for predicting the distribution of the blast effects and implementing measures to improve building resilience.

Accurate representation of urban geometry in simulations enhances the overall accuracy of blast predictions [10], [11], [12]. Models that consider the specific layout and characteristics of a town or city provide more realistic and reliable results.

2. METHODOLOGY

When conducting Computational Fluid Dynamics (CFD) simulations for blast scenarios in urban environments, several parameters are crucial for obtaining accurate and meaningful results. In this research we consider several CFD parameters.

Grid resolution is critical for capturing the details of the urban geometry and accurately representing the blast wave propagation. Finer grids provide better resolution but that implies more computational resources. We used 100 mm dimensions to define the fluid volume. We used real 3D dimensions.

The time step size determines how often the simulation calculates the changes in fluid dynamics. A smaller time step size is essential for capturing rapid changes during the blast wave, ensuring accurate representation of the dynamic behavior, but translates into high computational time.

Choosing an appropriate turbulence model is crucial for capturing the turbulent flow resulting from the explosion. We used the model Reynolds-Averaged Navier-Stokes (RANS) as is the most suitable for our case.

Concerning the detonation model we assumed modeling the release of energy during the blast. No information is available concerning the gas volume and type of gas, as the accident occurred when two type of gasses were combined.

This location was used to combine cheaper gas to be sold as superior quality GPL. The calculation of gas tank explosions, often expressed in terms of TNT equivalent, involves assessing the potential energy release from the combustion of a specified quantity of gas and comparing it to the energy released by an equivalent amount of TNT.

This method is commonly used to provide a standardized measure for the destructive power of explosions. Accurate material properties of both the explosive and the structures in the urban environment are essential.

This includes density, viscosity, and other relevant properties for the fluid dynamics simulation, as well as material properties for the structural response.

In some blast scenarios, the interaction of the blast wave with various phases (air, debris, dust) needs to be considered. To simplify the model we consider only the gas phase. Accurate representation of urban geometry, including buildings and terrain features, is crucial. The geometry should be finely resolved in the simulation to capture the interactions between blast waves and structures.

The key element is using GIS information if available lidar data. Lidar data allows quite precise 3D representation of the buildings, though is subjected to error depending on material building.

This means, that if a building has specific materials, such as metallic sheet, a good estimate of the 3D model will result.

In case the buildings top roofs are composed of materials such as bitumen cardboard, the error is even in meters, if the satellite is used. Public information concerning 3D building models can be found in Google Earth.

Various software such as Autodesk Infraworks allows importing data from Google Earth, if available. In our case, there is no 3D models for the area. This is the reason we need to estimate 3D modeling.

Figure 1 presents the accident in Crevedia, Romania, that occurred due to illegal gas transfer between tanks [13].

These investigations may involve examining the circumstances that led to the explosion, the type and quantity /amount of gas involved, however there is no publicly available information, and we consequently have estimated this scenario.

Given the complexity and potential consequences of gas explosions, it is advisable to involve experts in the field, such as chemical engineers, safety specialists, or explosion investigators, to ensure accurate calculations and assessments.

The calculation may vary based on the specifics of the gas involved, the nature of the incident, and any unique characteristics of the environment. Additionally, the TNT equivalent method provides a simplified measure and is just one aspect of a comprehensive analysis of gas explosions.

Figure 2 depicts the image of the area taken from Google Earth [14] and imported in Autodesk Inventor to reproduce the simplified 3D model of the buildings. In Figure 3 is presented the pressure distribution on different buildings.

We notice that building 1 which is out of metallic composite is totally destroyed after explosion, while the others made of bricks and concrete will not collapse. The present simulation only considered the wave pressure not the flame simulation effects.

Fig. 1- Aerial image of the fire and explosions in Crevedia, Romania [13]

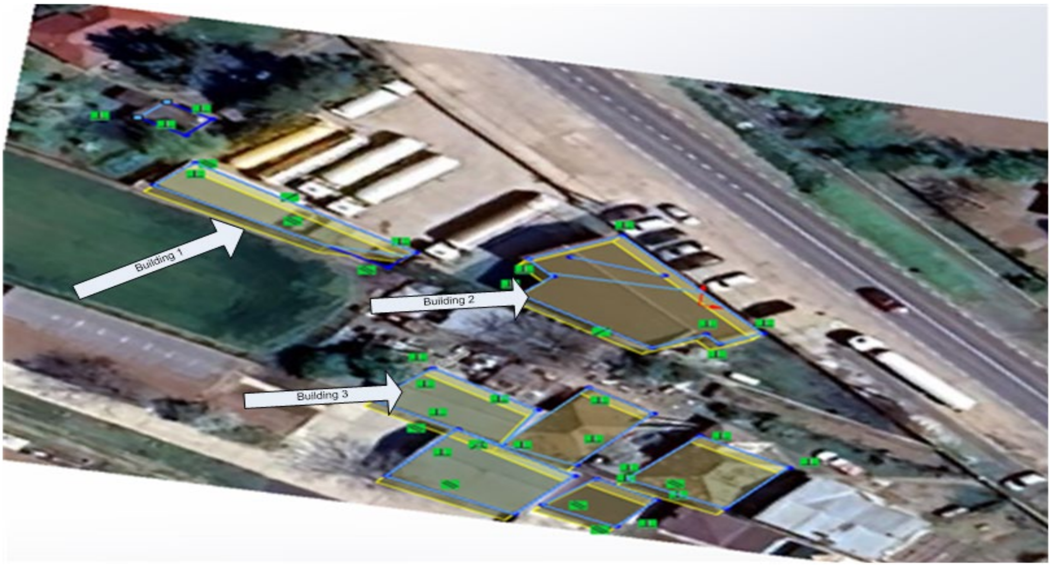

Fig. 2- Google Earth image to estimate 3D model of building [14]

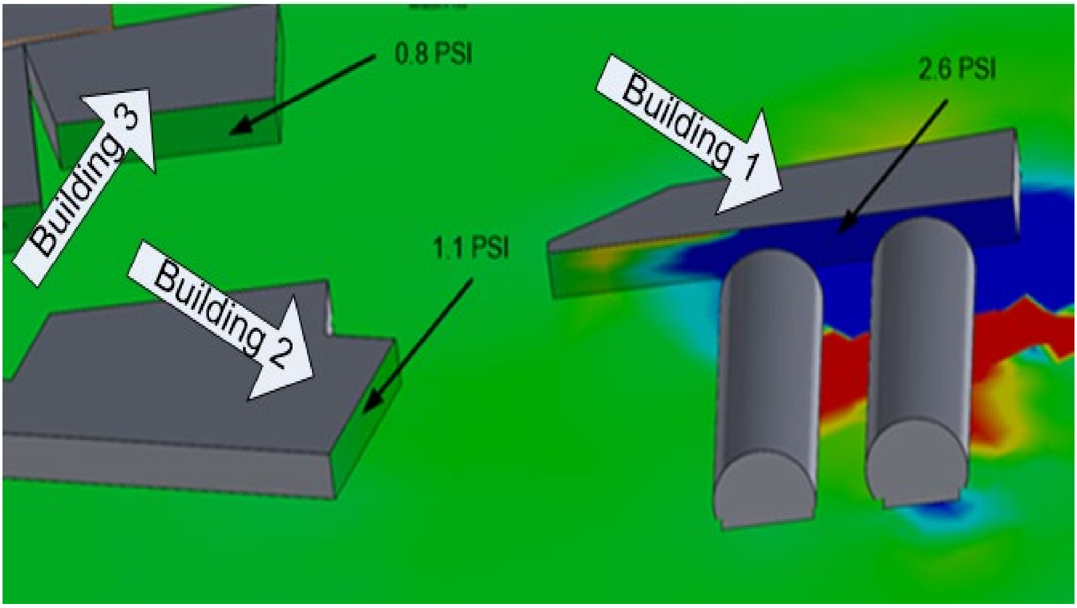

Fig. 3- Modeling of pressure distribution on buildings walls

Our approach parsing the following steps, define the explosion source, as a volume of gas expanding with a certain speed. Quantity of gas was estimated as 50% loading of the tank. For specific incidents like GPL gas explosions, detailed investigations and analyses are typically conducted by experts in the field.

The CFD simulation in Autodesk CFD shows different wave pressure. The results confirmed the destruction in real case. Building 1 (Figure 2) is destroyed as is made of steel sheet composite while Building 2 and Building 3 did not collapse being constructed of bricks and reinforced concrete columns with rebar. Engineers and architects might /could use blast simulations to mitigate the effects of explosions and to protect buildings near GPL stations from the effects of explosions.

A separating wall was the solution to avoid destruction in this case. Simulations of fire propagation will complete a study that will provide the information needed to identify solutions to avoid the destructions of buildings.

3. CONCLUSIONS

Modeling the response of materials to blast loading requires appropriate constitutive models. This includes the modeling of materials such as concrete, glass, and steel under high-pressure and high-strain rate conditions.

Adaptive meshing techniques can help refine the grid in areas of interest, providing higher resolution where needed and optimizing computational resources.

Validation against experimental data could not be assessed in this research because of the lack of accurate information on the volume of gas, the exact wind speed in the area, and therefore, the gas plume may have different volume and heights.

In this research we estimate the gas volume and location. Identifying weak points and vulnerabilities of gas stations and deposit allows for the incorporation of blast-resistant features into new constructions, reducing the risk of catastrophic failure.

Blast simulations help develop effective mitigation strategies. By understanding how blast waves propagate through an urban environment, authorities can implement measures such as barriers, protective shields, fire-fighting strategies or evacuation plans to minimize damage and casualties.

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