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Discussions on Applying Numerical Simulation Results in Disaster Management: Beirut Explosion 2020 as an Example

M.L. Ivanov[1] and W.K. Chow[2*]
[1]Academy of the Ministry of Interior, Sofia, Bulgaria
[2]Department of Building Environment and Energy Engineering, The Hong Kong Polytechnic University, Hong Kong, China
[*]Corresponding author: wan-ki.chow@polyu.edu.hk

Abstract

Results predicted from numerical simulations in fire and explosions are valuable for disaster management. Fluid flow and thermal behaviors predicted can be integrated with geospatial data to give important results in two- or three-dimensional maps. An explosion occurred on 4 August 2020 with blast devastating a large part of Beirut. Blast waves were simulated by finite difference or finite element models. Points to note in applying such numerical simulation results for disaster management and similar explosion hazards such as keeping numerous fuel tanks in residential areas were discussed in this paper.

Keywords: Disaster management; Fuel storage tanks in downtown; Explosion studies; Numerical simulations; Computational Fluid Dynamics (CFD).

1. Introduction

There are many explosion [1-5] occurred in dense urban areas before. Similar hazards can occur in downtown storing huge amount of petroleum and gas field [6]. Results predicted from numerical simulations in fire and explosions [1-3] are valuable for hazard assessment and disaster management. The predicted fluid flow and thermal behaviors can be integrated with graphical software for easier decision-making, particularly by the firefighting authority. An explosion occurred on 4 August 2020 with blast devastating a large part of Beirut. There are many works on numerical heat transfer and fluid flow simulations to study the blast wave with a three-dimensional finite difference or finite element model [4] or sensor observations [5]. Computational Fluid Dynamics (CFD) packages [7-9] are always used in simulations. Fluid interactions with building surfaces can be included by an appropriate technique with geospatial data [4] applied for disaster management. Results are useful in disaster management on fire and explosion [10-21]. Similar hazards can occur in downtown storing huge amount of petroleum and gas fuel tank [6] such as Tsing Yi Island in Hong Kong.

2. Observations

CFD has been used [1, 22, 23] in fire hazard assessment in Performance-Based Design (PBD) since late 1970s. Most of the CFD fire and explosion models are not properly validated with systematic large-scale fire tests for big construction projects in the Asia-Oceania (AO) regions. Criticisms on using CFD in fire and explosion simulations are:

- Three-dimensional phenomena make the simulations harder and slower.
- Aerodynamics and temperature fields induced by fire and explosion in open or very large spaces are very unstable.
- Three-dimensionality and instability of the aerodynamics are difficult to archive and sometimes not discussed in detail.
- Ability of studying the turbulent fire flow for big halls with irregular shapes is doubtful.
- Uncertainty in studying the turbulent exchange flow across free openings such as windows and doors.

Three groups of parameters would affect the accuracy of predictions:

- Physical models parameters such as the empirical coefficients describing turbulent fluid flow either through Reynolds-averaged Navier-Stokes (RANS) equations [24] or Large Eddy Simulation (LES) [25]. Many of those flow empirical coefficients are determined from wind tunnel experiments. Tuning up the coefficients in building fire and explosion simulations is always challenged as a curve-fitting exercise.
- Numerical spatial and temporal discretization parameters, and convergence criteria. Thermal plumes experiments [26] can give some hints.
- Parameters on physical systems such as the free boundary condition of a building. There are no rules in determining such parameters. For example, the extension length of the computing domain outside an opening to get ambient pressure is decided from experience.

3. Points to Note

It is a good opportunity to try using big explosions like the Beirut blast as case studies for large-scale urban blast simulations. Taking the numerical simulations of explosion [8, 9] as an example, the following points should be noted in the study:

- Boundary and initial conditions including coordinates of the building locations would affect results. Some parameters such as local wind speed (varying for the Beirut explosion from 20 km/h to 24 km/h with mainly Southwest direction [27]) and turbulence are difficult to determine. Results of the simulated blast wave propagation of the explosion might be different from the real incident if different parameters are selected.

- Pressure distributions should be studied with appropriate turbulent parameters and presented in detail.

- Important results of interest to disaster management should be compared with those estimated from simpler analytical studies [28] with appropriate parameters.

- Although the complex geometrical of the structural parts has no simplified algorithms deduced from experimental empirical data, some simpler online calculators should be used for comparing with the numerical simulation.

- Simple equations are useful in case studies as demonstrated before [28]. An online available free tool UN SaferGuard tool named Kingery-Bulmash Blast Parameter Calculator [29-31] is applied to compare with simulation model in ref. [4] on overpressure at 300 m, 500 m, 750 m and 1000 m away from the explosion center, ΔP_{300}, ΔP_{500}, ΔP_{750} and ΔP_{1000} (see Table 1).

  In Table 1, it can be observed that the results matched reasonably well with those estimated by the above paper for both cases for ideal conditions and with Urban Blast Simulation [4] under the same initial conditions of 1.1 kilotons of TNT.

Table 1. Comparing numerical simulation with simple expressions

Approach		**ΔP_{300} /kPa**	**ΔP_{500} /kPa**	**ΔP_{750} /kPa**	**ΔP_{1000} /kPa**
Paper [4]	Ideal	124	46	24	15
	Urban Blast Simulation	125	46	23	11
Kingery-Bulmash Blast Parameter Calculator [29-31]		124	46	24	16

4. Recommendations

There is no doubt that CFD predictions should be evaluated properly with technical guidance [32] supported by in-depth research. CFD predictions on the following [2, 33] are observed:

- Only the velocity vector patterns and temperature distribution are shown in the hazard assessment report, but not the air pressure and turbulence parameters.
- Grid sensitivity criteria are only determined from studying temperature and velocity, but not pressure or turbulence parameters.
- Predicted results are not always justified by systematic experiments with heat release rates measured by oxygen consumption calorimetry.

Consequently, the following should be added in CFD report:

- Discussion on grid selection and grid-independent results. For example, note that in studying fire and explosion inside a large airport terminal, a 10-m grid means that velocity and temperature are the same within 10 m.
- The convergence and stability criteria for turbulent parameters should be discussed.
- The external boundary conditions on flow variables must be presented clearly. The extension of free boundaries should be stated.
- The prediction and presentation in the three groups on velocity-temperature, pressure and turbulent parameters [34] should be evaluated.
- Checking CFD predictions to give details of exchange flow and neutral pressure planes for vertical openings.
- Multi-directional flow across horizontal ceiling vent [35, 36] to watch.
- Experimental verification using data from full-scale burning tests.
- In-situ field tests to evaluate the system performance such as atrium hot smoke test [37-42].

5. Conclusions

There are potential risks in many places, such as keeping gas stations and even fuel tanks in urban areas such as those in Hong Kong. Disaster management plan should be drafted in advance. Different numerical simulations had been applied to study the consequences of a blast event in a large-scale urban environment, from structural damage of the buildings to human casualties and critical infrastructure resilience.

The explosion in the Port of Beirut in Lebanon on 4 August 2020 was disastrous due to storing large amount of explosive materials, causing considerable damage to surrounding structures and lots of human lives. Whether such event is suitable for assessing the proposed numerical simulations in a widely exposed (by the blast wave) urban zone should be justified.

Following the exact case study, some recommendations for reducing the probability of ammonium nitrate accidents with big losses are: keeping factories for producing ammonium nitrate and related materials as well as warehouses for storage of these materials must be out of urban area; considering the replacement of ammonium nitrate with an alternative material, a plant fertilizer which is not explosive; putting ammonium nitrate storage in concrete buildings with no other combustible or toxic goods; and requiring sprinklers in production and storage spaces.

An immediate need is to work out appropriate disaster management scheme for usage, storage and transportation of chemicals with fire and explosion risk in urban areas and checking the implementation of the normative documents. Experts and safety personnel in vulnerability assessment and planning of the disaster management strategy are recommended to consider carefully whether to use simple calculators or complicated numerical simulations. Computer packages can be used for simulating the effects of explosions in urban environments in terms of structural damage. However, results must be justified with simple analytical expressions on macroscopic parameters or physical modeling, scale or full-scale experiments.

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