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Simulation of bomb residue deposition following the Oslo bombing July 22, 2011

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English summary

The objective of the present study is to simulate the dispersion and make an assessment on the shape and concentration of the deposition of particle residues originating from the improvised explosive device used on July 22, 2011, in Oslo. The results indicate that the bomb residue deposition concentration can be expected to be significantly higher on building surfaces than on the ground. Relatively large particle concentration levels are to be expected on the leeward side of buildings over which the particle cloud has passed. These findings provide valuable insight that can be used when determining the best positions to collect samples in e.g., forensic work. The method used in this study also provides information of the size and shape of the contaminated area, in addition to the variation of local concentration levels. This could be valuable information in conjunction with the aftermath of the use of e.g., dirty bombs.

Sammendrag

Målet med denne studien er å simulere spredning og avsetning av partikkelrester fra den improviserte eksplosivladningen som ble brukt 22. juli 2011 i Oslo, og å anslå omfanget av det forurensede området. Resultatene indikerer at konsentrasjonen av bomberester kan forventes å være betydelig høyere på bygningsoverflater enn på bakken. Relativt store partikkelkonsentrasjonsnivåer er å forvente på lesiden av bygninger. Disse funnene gir verdifull innsikt som kan brukes når man skal avgjøre de beste plasseringene å samle inn prøver i f.eks. etterforskingsøyemed. Simuleringsmetoden som ble brukt i denne studien gir også informasjon om størrelsen og formen på det forurensede området, i tillegg til variasjoner i lokale konsentrasjonsnivåer. Denne type informasjon er verdifull i forbindelse med vurderinger av omfang og konsekvenser ved bruk av f.eks. skitne bomber.

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Preface

Visualizations of the simulation presented in this report can be obtained by contacting the Protection Division at the Norwegian Defence Research Establishment.

1 Introduction

Particle residues from an explosion will be deposited on ground or on building structures, not only in the near field but also relatively far from the source. Information of the extent of the deposition area and expected particle concentrations within that, are helpful information both in terms of collecting particle residues from a forensic perspective and as an assessment of the extent of contamination in case of dirty bombs (containing chemical, biological, or radiological agents). The dispersion processes of particle residues following an explosion in built-up urban areas are governed by very complex physical mechanisms. The development of advanced modeling methodologies now makes it possible to numerically predict the aerial dispersion and subsequent deposition of particles in complex urban environments under different meteorological conditions. The objective of the present study is to simulate the dispersion and deposition of particle residues from the improvised explosive device used on July 22, 2011, in Oslo, and to estimate the extent of the contaminated area.

2 Modeling methodology

This study has utilized an approach to numerically simulate the wind field referred to as Large Eddy Simulations (LES). Dispersion and deposition of particles have been calculated using both a Eulerian and a Lagrangian framework. The details of these methods can be found in e.g., Fossum et al. (2012) and Wingstedt and Reif (2012), and is therefore not repeated here. The simulation covers an area of approximately 1000 x 1000 m^2, see Figure 2.1. It has for simplicity been assumed that the terrain is perfectly flat without green areas or vegetation. For the purpose of this study, the effect of these and other simplifications made to the building structures can be neglected. The particle cloud is simulated for the first 55 seconds after the explosion, focusing on the initial phase of the event when the shock front has past and the wind field is the dominating transport process. The dispersion of smoke caused by fires ignited directly or indirectly by the explosion is thus not considered her.

2.1 Meteorological conditions

The explosion took place at 15:25 on July 22, 2011. The meteorological conditions for this time period were obtained from the Norwegian Meteorological Institute and these are listed in Table 2.1. A wind speed of 7.7 m/s with direction 23 degrees was selected for the simulation.

Time	Wind speed	Wind direction
15:00	8.5 m/s	28°
16:00	7.2 m/s	18°

Table 2.1 Meteorological conditions in Oslo (Blindern) on July 22, 2011. No precipitation reported. Data obtained from www.eKlima.no

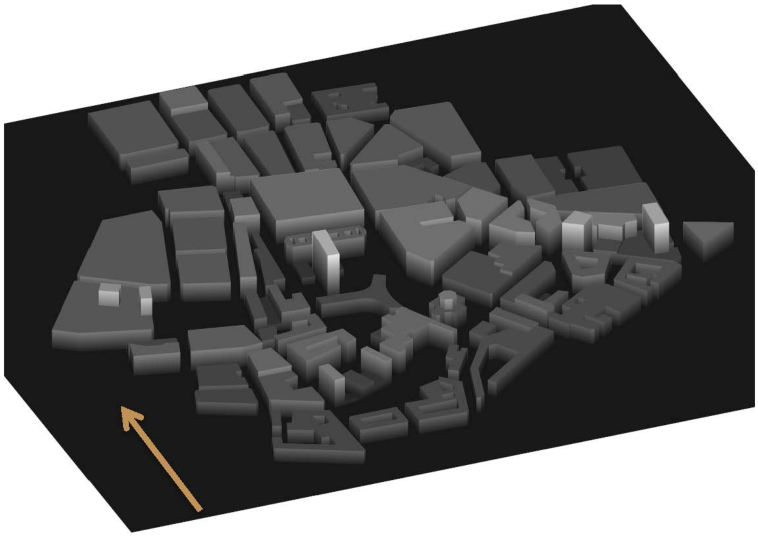


Figure 2.1 Schematic of simulation area. Wind direction is indicated by the arrow.

Effects of temperature and humidity have been neglected in the simulation. These parameters are generally important, particularly at low wind speeds. The wind speeds that day was however relatively high, especially on street level where wind velocities up to approximately 15 m/s locally could be observed in the simulations. It is therefore likely that the assumption of neglecting temperature and humidity effects only have minor influence on the results.

2.2 Post explosion conditions

The processes governing particle transport is generally driven by the atmospheric wind field. However, immediately following an explosion, a strong buoyant plume is created due to the high temperatures associated with the combustion processes taking place. The plume is characterized by a vertical draft that initially is stronger than the strength of the local wind field. Initially the plume effect therefore dominates the aerial transport of particles. However, the air is rapidly cooled and the plume strength weakens subsequently. The atmospherically driven wind field will therefore dominate the dispersion process shortly after the detonation. This is the instance in time when this simulation is started. In order to facilitate the plume effect without having to explicitly model the detonation process, the size of the initial particle cloud was estimated based on surveillance pictures. A short time after the explosion, the shape of the cloud appeared spherical with a radius of approximately 40 m, see Figure 2.2. It was assumed that atmospheric wind field was the dominating factor from thereon.

2.3 Particle characteristics

Bomb particle residues will mix with large amount of dust and smoke particles. These particles have a variety of sizes and shapes, as well as different physical properties (e.g., density). Generally, large (heavy) particles will deposit on the ground near to the detonation position, whereas

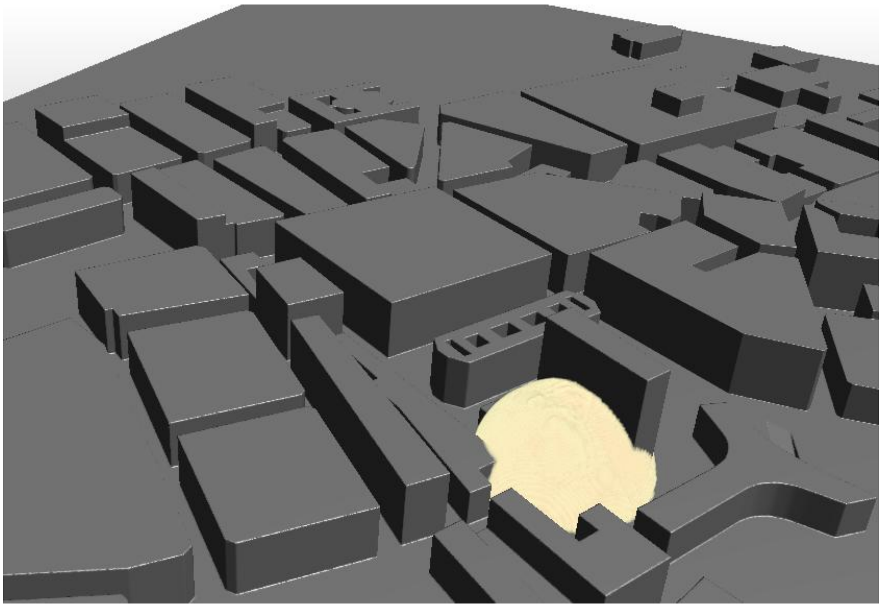


Figure 2.2 Initial spherically shaped particle cloud (radius 40 m).

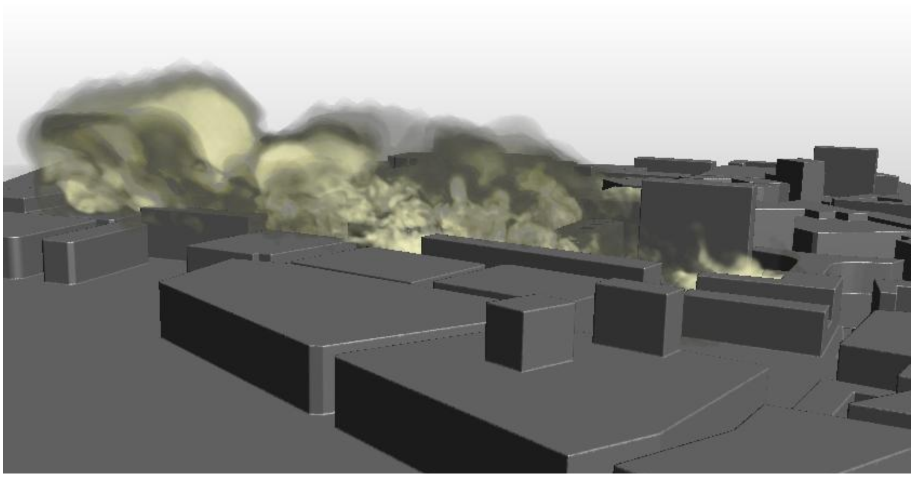
smaller particles tend to be transported by the wind field. The simulations in this study are based on the assumption that the particles of interest are small $(d < 20\mu\text{m})$ but with relatively high density $(\rho = 1000$ kg/m$^3)$. On the length scales considered in this study ($\mathcal{O}(10^2)$), the shape of the particles is believed to be of minor importance. For simplicity, only spherical particles have therefore been considered. The particle cloud is also assumed to be dilute, i.e., that there are no significant particle-particle interactions (collisions, agglomerations etc.) and that the particles' effect on the wind field is negligible.

3 Simulation results

The simulation results consist of information on how the particle cloud is evolving in time as it moves through the streets of Oslo. Figure 3.1 shows a photo of the particle cloud, taken seconds after the explosion (Dutton, 2011), and the result from the numerical simulation. It is difficult to compare these two, since they may not represent the exact same time, but there seems nevertheless to be a good agreement between the simulation result and the photograph.

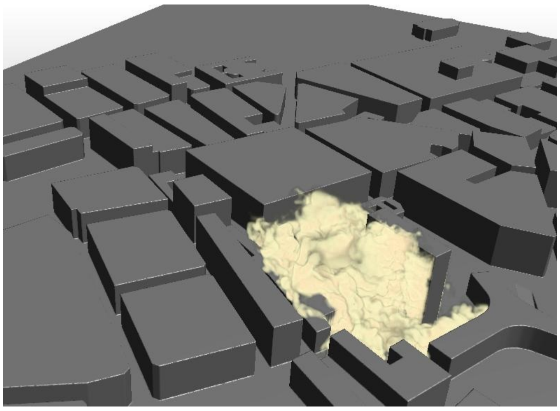
Figure 3.2 displays a series of images of the particle cloud obtained in the simulation at different times after the detonation. A significant portion of the cloud is transported vertically due to the wind updraft on the leeside of the high rise building caused by the atmosphere wind field (not the explosion itself). A notable characteristic of the cloud evolution is that it 'gets stuck' on the leeside of buildings, in what typically is referred to as the building wake. A portion of the cloud remains there over time whereas the rest is transported downwind. This results in a significant stretching of the cloud and a subsequent reduction of particle concentration. This particular feature is a general characteristic of dispersion and transport of gases and particles in built-up urban and industrial areas.

(a) Photo of the particle cloud taken a couple of seconds after the detonation.
http://news.blogs.cnn.com/2011/07/22/blast-rips-through-norways-capital-injuries-reported/

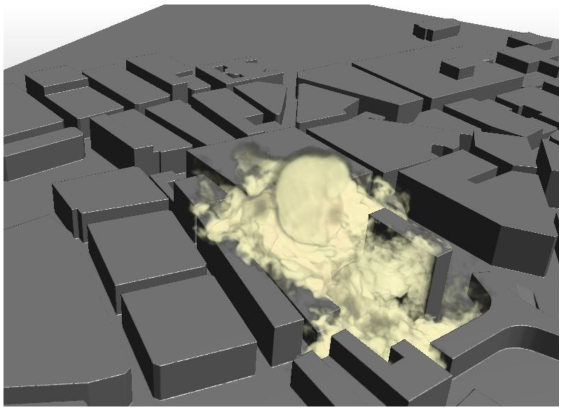


(b) Simulated particle cloud 55 seconds after the detonation

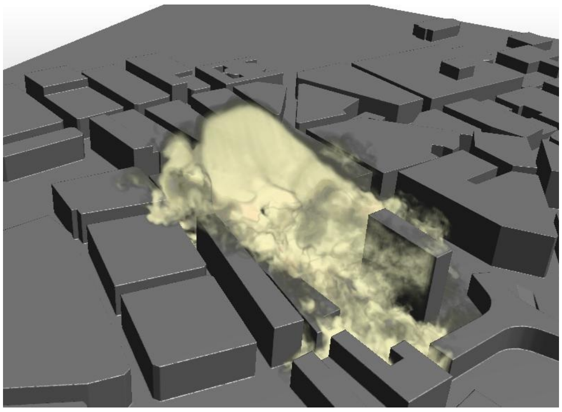
Figure 3.1 Comparison between picture of the smoke and the numerical simulation



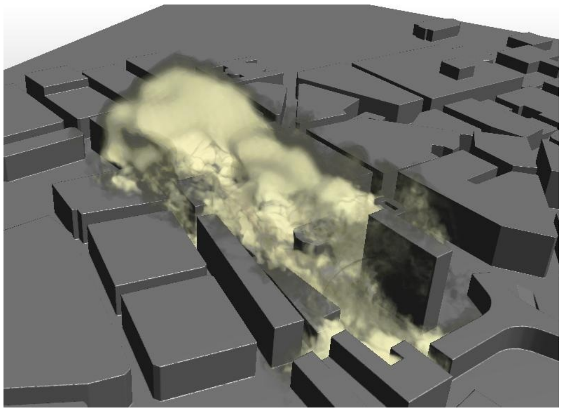
(a) $t = 10s$



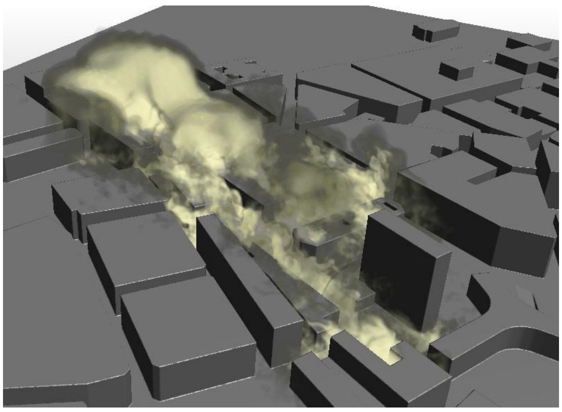
(b) $t = 20s$



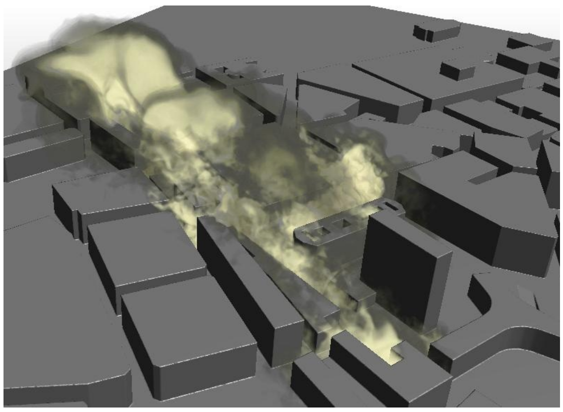
(c) $t = 30s$



(d) $t = 40s$



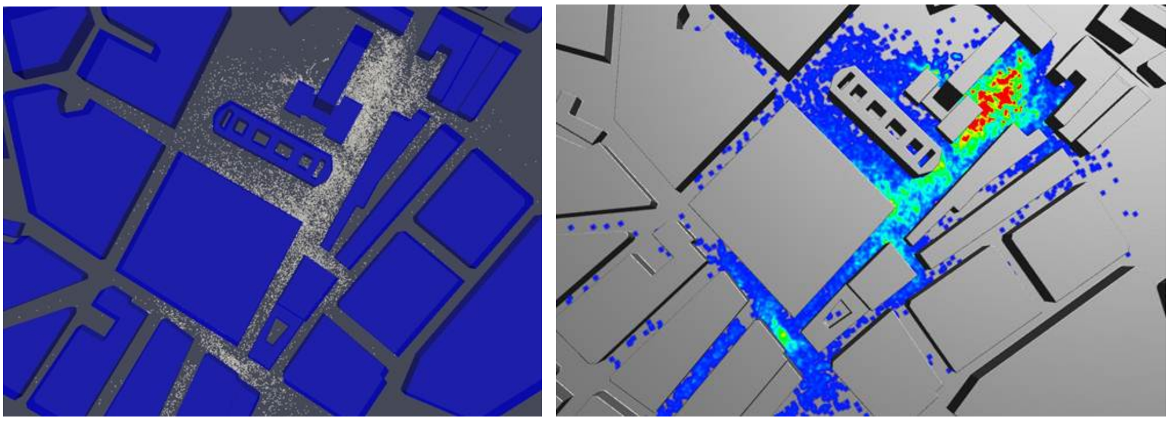
(e) $t = 50s$



(f) $t = 55s$

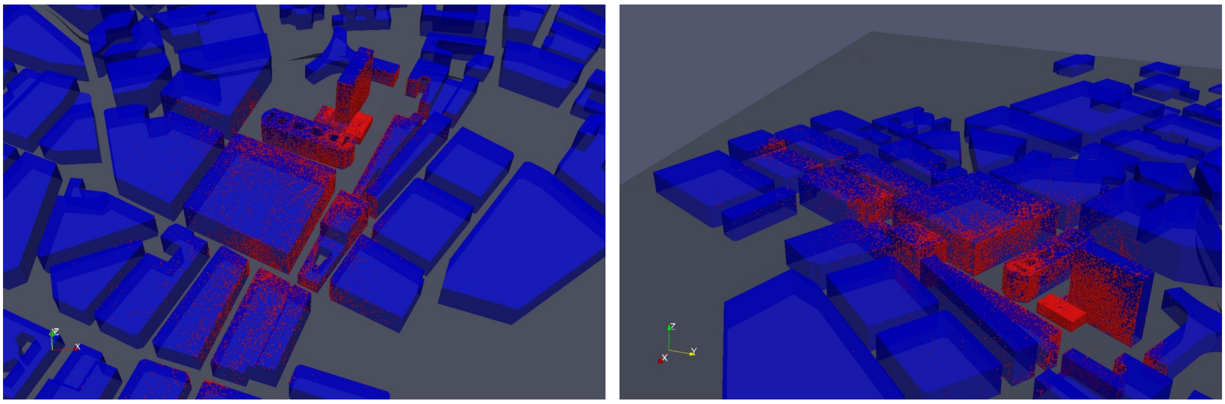
Figure 3.2 Simulated particle cloud at different times after the detonation.

A fraction of the airborne particles is deposited as time evolves. Figure 3.3 displays deposited particles on the ground. The concentration levels reduce with distance to the source. However, areas with locally high particle concentration are visible relatively far from the source.



(a) Deposited particles on the ground (b) Particle concentration on the ground

Figure 3.3 Bomb residue particles deposited on the ground in the vicinity of the location of detonation .



(a) View to the north (b) View to the southwest

Figure 3.4 Bomb residue particles deposited on buildings in the vicinity of the governmental area.

Figure 3.4 shows a corresponding image of deposited particles on building structure. By comparing with Figure 3.3, it is evident that the concentration of deposited particles on buildings is significantly higher than on the ground. It should be noted that there are relatively high concentrations of deposited particles on the leeside of buildings which the cloud has passed over. The simulations indicate that only approximately 5 % of the bomb residue particles emitted into the air by the explosion are deposited on the ground. The corresponding number for building surfaces is approximately 15 %.

4 Conclusion

Numerical simulations have been performed to predict the deposition patterns and concentration levels of bomb residue particle following the bombing in Oslo July 22, 2011. The choice of simulation method used in this study is dictated by the fact that the dispersion and transport of the particles in a complex urban area, such as in Oslo, depends directly on the details of the buildings and their positions relative to each other. The method used herein represents a generally applicable method to simulate the dispersion and transport of gases and aerosols in complex built-up areas.

The results indicate significant variability of particle concentration levels depending on position. This is expected due to the complexity of the area. Perhaps the most notable result indicates that the bomb residue deposition concentration can be expected to be significantly higher on building surfaces than on the ground. The effect of building wakes results in areas with large particle concentration levels on the leeward side of the building. These findings provide valuable insight that can be used when determining the best positions to collect samples in e.g., forensic work. The method used here also provides a realistic assessment of both the size and shape of contaminated areas and local concentration levels, in conjunction with the use of e.g., dirty bombs.

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