CFD for risk analysis in urban environment - Tilburg city case study -

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Harmo 15 conference, May 6-9th 2013, Madrid
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Introduction

Why this study?

- RBM-II is standard method for calculating risks of transport in the Netherlands (RBM = Risk Calculation Methodology)
- RBM-II:
  - is uniform & fast
  - gives only a rough estimate and no detailed information

- Pilot-study to show added value of CFD for risk calculations
RBM-II

- Standard method for risk analysis for road, rail and water transport of hazardous materials
- Types of substances:
  - A  flammable gas (propane)
  - B2 toxic gas (ammonia)
  - B3 very toxic gas (chlorine)
  - C3 very flammable liquid (pentane)
  - D3 toxic liquid (acrylonitrile)
  - D4 very toxic liquid (acrolein)
- Scenarios: large leak (g+l), small leak (g+l), BLEVE (g)
- Standard atmospheric conditions, probability based on meteorological data
RBM-II (continued)

› 2 types of risks:
  
  › Individual risk (*plaatsgebonden risico*, PR)
  › Societal risk (*groepsrisico*, GR)
RBM-II (continued): Individual Risk

- Individual risk (*plaatsgebonden risico*, PR)
  - Probability for 1 unprotected person 24 hours present at a certain location to die as a consequence of the transport
  - Represented as iso-risk contours on a map
  - Fatality Probability should be below $10^{-6}$ per year (threshold)
- Societal risk (*groepsrisico*, GR)
RBM-II (continued)

- Individual risk (*plaatsgebonden risico*, PR)
- Societal risk (*groepsrisico*, GR)
  - Cumulative probability per year that at a certain number of people die as a consequence of the transport
  - Represented as an fN-curve: frequency of a number of casualties
  - Population density is important here
  - fN curve should be below guide value (10: $10^{-4}$, 100: $10^{-6}$, etc), more fatalities should have lower frequency
Jet release
Tilburg: train station zone
Scenario definition in RBM-II

- Substance B2: ammonia
  - Transported as liquid
  - 2-phase release
  - (semi-)continuous release
  - D5 atmospheric stability class

<table>
<thead>
<tr>
<th>Storage</th>
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<tbody>
<tr>
<td>Volume</td>
<td>89 m³</td>
</tr>
<tr>
<td>Mass</td>
<td>50 000 kg</td>
</tr>
<tr>
<td>Pressure</td>
<td>616 257 N/m²</td>
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<tr>
<td>Temperature</td>
<td>282 K</td>
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<table>
<thead>
<tr>
<th>Release</th>
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<tbody>
<tr>
<td>Diameter</td>
<td>0.075 m</td>
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<tr>
<td>Duration</td>
<td>667 s</td>
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<tr>
<td>Mass flow</td>
<td>75.01 kg/s</td>
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<tr>
<td>Rain out fraction</td>
<td>0.6859</td>
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<tr>
<td>Source strength</td>
<td>23.56 kg/s</td>
</tr>
<tr>
<td>Vapour mass fraction</td>
<td>0.4364</td>
</tr>
</tbody>
</table>
Results RBM-II

- All scenarios have standard cloud dimensions
- Lethality is based on concentration and duration of exposure
- For the current scenario:

<table>
<thead>
<tr>
<th>Lethality (%)</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Off-set (m)</th>
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<tr>
<td>1</td>
<td>453</td>
<td>99</td>
<td>0</td>
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<tr>
<td>10</td>
<td>340</td>
<td>75</td>
<td>0</td>
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<tr>
<td>25</td>
<td>281</td>
<td>62</td>
<td>0</td>
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<tr>
<td>50</td>
<td>211</td>
<td>45</td>
<td>0</td>
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<tr>
<td>75</td>
<td>174</td>
<td>37</td>
<td>0</td>
</tr>
<tr>
<td>90</td>
<td>135</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>99</td>
<td>75</td>
<td>16</td>
<td>0</td>
</tr>
</tbody>
</table>
Scenario definition in CFD

- Continuous release
- 2-phase release: mass flow rate & vapour mass fraction identical to RBM-II:
  - 23.56 kg/s
  - 0.4364 [-]
- Diameter: 45 cm for a square source
- Droplet size: 75 µm
- D5 atmospheric boundary layer
Tilburg: CFD-domain

1000mx1000m X300m
Full scale
9.1 $10^6$ cells
Tet-mesh with prism inflation layer (5 cells)
Results CFD

1% lethality

1 $10^{-7}$ mass fraction

Close to source: influence of building is clearly visible
Results CFD – lethality contours at 1m height
Comparison RBM-II and CFD: cloud dimensions

<table>
<thead>
<tr>
<th>Lethality (%)</th>
<th>RBM-II</th>
<th>CFD</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Length (m)</td>
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<tr>
<td>1</td>
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</table>

- RBM-II: longer and wider cloud, no off-set
- CFD: shorter and narrower cloud, small off-set, effects of buildings clearly visible
Comparison RBM-II and CFD: fN-curves

For a single scenario fN-curves are different: curve obtained from CFD results is below RBM-II curve: CFD results in lower risk

After adding all other scenarios (RBM-II calculations) no difference is observed in fN-curves
Dense gas release
Dense Gas Release
Wind tunnel model

Source

Train station
Qualitative comparison CFD and wind tunnel

Global dispersion pattern is comparable:

- Upwind dispersion due to dense gas behaviour
- Effect of buildings
Calculated CO$_2$ concentration
Quantitative comparison

11 measurements (out of 16) are within a factor of 2
Plume width and upwind dispersion are calculated correctly

- Measurement time in wind tunnel too short to obtain steady state
  (sensors 14 +15)
- Sensor locations have high gradients
Conclusions

- CFD and RBM-II give different effect distances for the jet release:
  - length from CFD is half of length from RBM-II
  - Width from CFD is 2/3 of width from RBM-II
- No difference in total societal risk – only 1 scenario studied

- Good agreement between CFD and wind tunnel is found for dense gas release in built environment

- When buildings or measures are expected to significantly influence dispersion CFD is best choice for calculating effect distances