# Factsheet:
# Modelling of explosion loading

B.J. Leira

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# Background/Introduction

- According to the Memorandum of Understanding, the Activity 4 of COST TU0601 concerns the engineering modelling of relevant exposures.
- The task includes the modelling and assessment of the probabilistic characteristics of extreme exposure events in the first place.
- In addition one needs information on other (normal) loads and structural properties as they determine to a large extent the effect of the event.

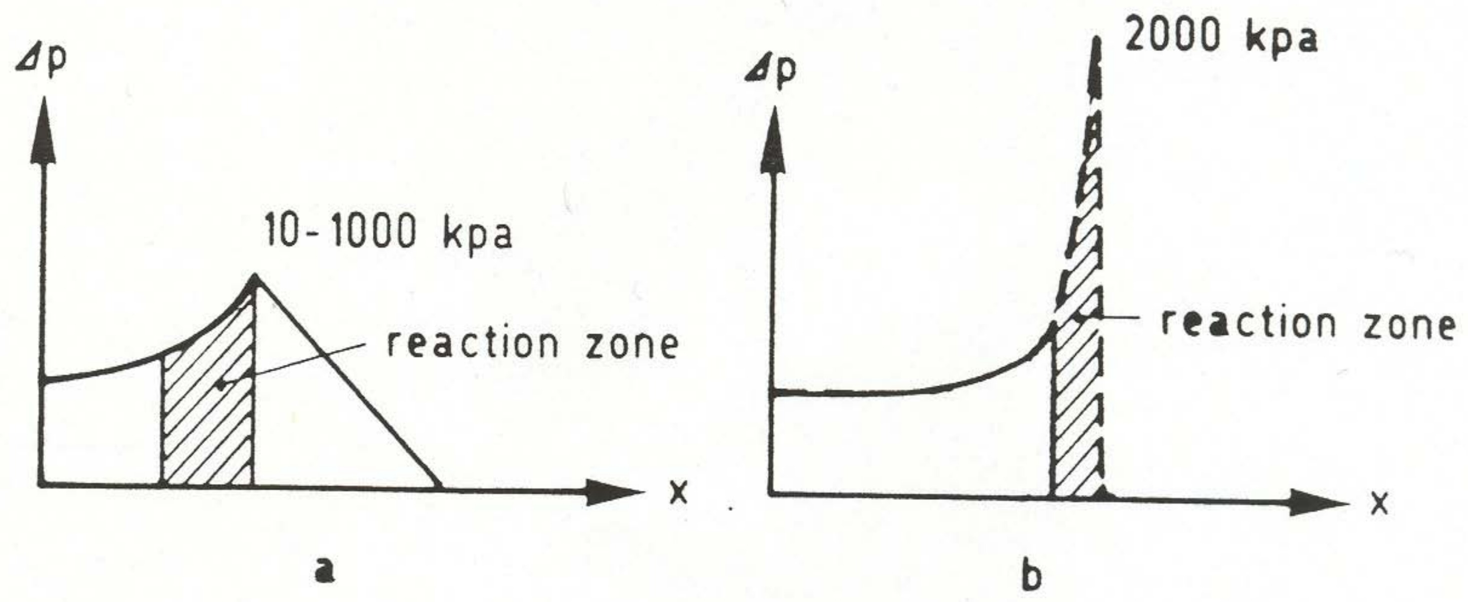
# Problem statement / Key issues

- Explosions account for a substantial number of accidental actions in buildings.
- For adequate design a model for in particular internal gas or dust explosions is wanted.
- However, literature from a structural perspective is scarce as well as the number of interested experts. The note is an attempt to bring together some material.

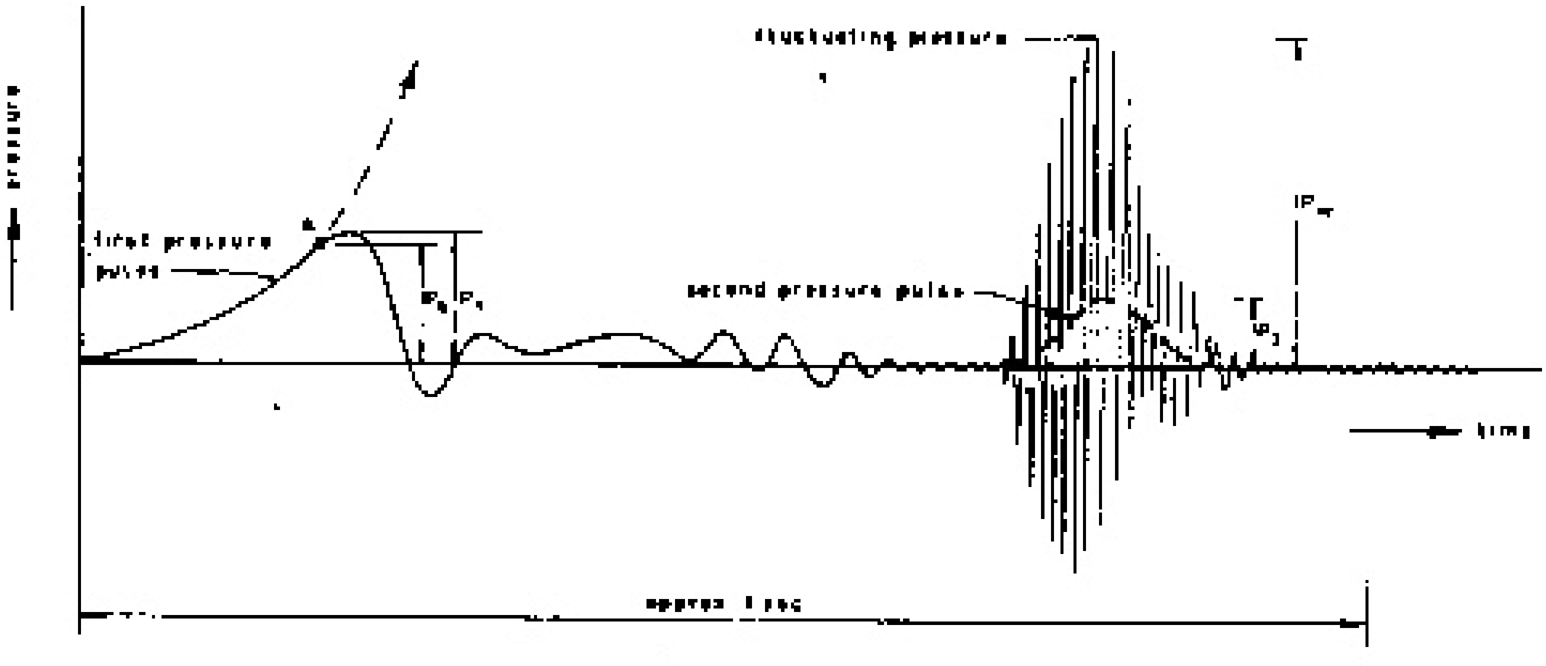
# Methodology

- Description of phenomenon
  - Detonation
  - Deflagration
  - Pressure/time variation
- Methods for prediction of loads due to internal explosions
  - Empirical and codified models
  - Phenomenological models
  - CFD-models
- Statistics
- Probability of exceedance curves

# Deflagration(left)/detonation(right)



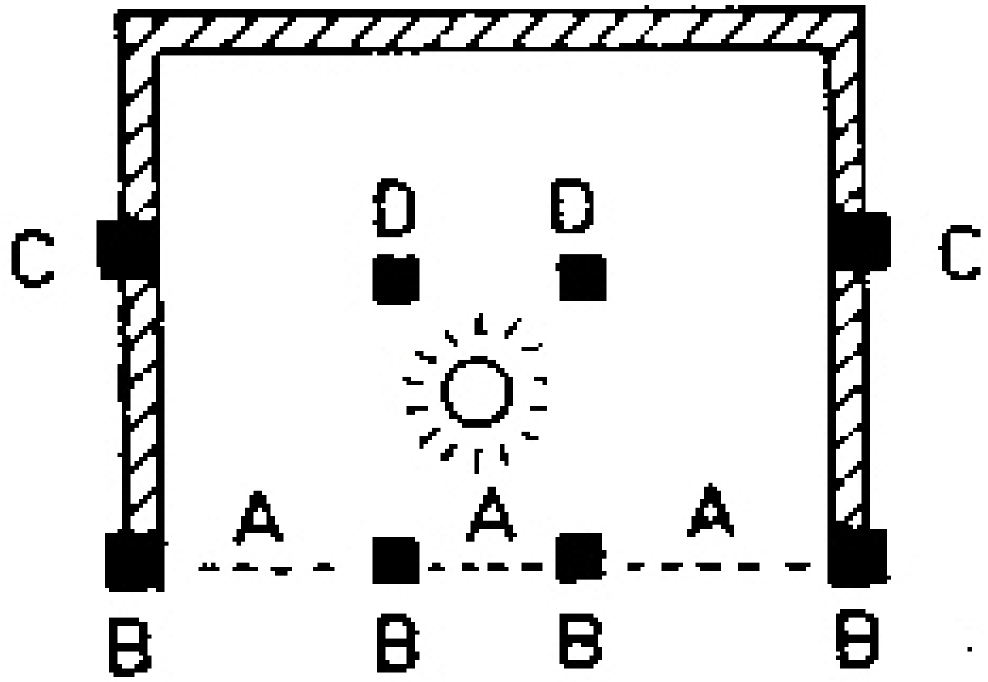
# Pressure-time variation



# Empirical and codified models
(further described in Annex A)

- Eurocode model
- Cubbage and Simmonds
- Rasbash et al
- NFPA-1
- NFPA-2
- Based on concept of a vent coefficient K: $K = \frac{A_s}{A_v}$

# Configuration-dependent loading



# Phenomenological models

- Based on 1D considerations
- Trying to model some of the physics involved in the process
- Input will be a rough geometry model
- For each submodule, the blocking effect will have to be estimated
- High uncertainty should be expected for such applications
- Such models can be considered just as CFD-models with a very coarse (poor) grid resolution
- Computed pressures will be the average over a large volume
- No local pressure peaks will be picked up
- Validation of these models will generally be through comparison of simulation results with experiments

# CFD models

- Attempt to resolve the physics numerically by dividing space into small boxes (control volumes)
- Implements models for various phenomena like fluid flow and turbulence
- In each cell, all variables are assumed constant in one time step, and are based on the flow balance and fluxes
- For explosions, additional models will have to be incorporated compared to a standard CFD-model, as flame propagation and combustion will have to be modelled
- For each time step, equations for the following are solved for:
  - Mass balance (continuity)
  - Impulses
  - Entalpy
  - Turbulence
  - Fuel transport and mixture fraction.

# CFD models, contd.

- If only blast pressures in the far field are to be assessed, simplified models may be used
- Special purpose CFD-models, like FLACS, EXSIM and Auto Reagas have a greater potential to perform well. (Developed by people doing experimental and theoretical work within gas explosions)
- Still, significant differences will be seen between the models, both with regard to applicability and validity
- Geometries can be either defined by hand or imported from CAD systems

# Limitations of CFD models:

- Available computation power limiting the numerical resolution that can practically be used
- Accuracy of numerical models
- The underlying empirical sub models for
  - Reaction zone
  - Turbulence generation
  - Turbulence length scale
  - Turbulent combustion

# Observations related to application of different types of models:

- The phenomenological code SCOPE and 'simple' CFD codes FLACS, AutoReaGas, and EXSIM are in widespread use
- Phenomenological and CFD methods generally give fairly good accuracy (within an factor of two) so these models yield solutions that are approximately correct
- The limitations associated with empirical and phenomenological methods (simplified physics and relatively crude representation of geometry) can only be overcome through additional calibration
- It is recommended to develop 'advanced' CFD codes that will allow fully realistic combustion models and resolution of all obstacles
- However  it is likely to be many years before such tools are available. (This is primarily due to the large computational expense of this type of model)



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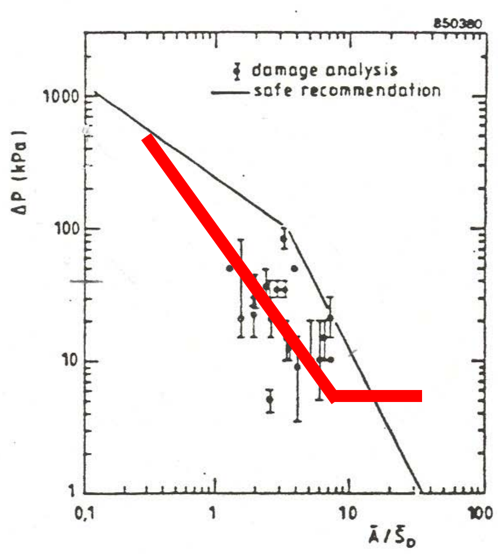
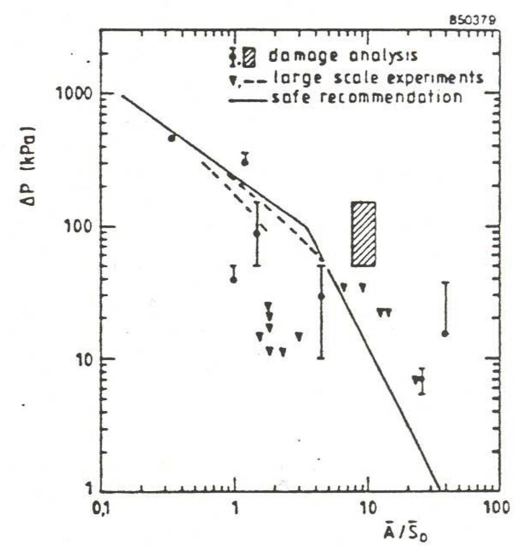
# Statistics/Probabilistic modelling:

- As a function of time the ***occurrence of an explosion*** can be considered as a Poisson process
- The next step is to model the ***magnitude of the explosion***, conditional upon occurrence
- For internal explosions the maximum pressure can be taken as the maximum of the "breaking pressure" and the "vent controlled pressure”

# Statistics/Probabilistic modelling:

- The "vent control pressure" as observed in practice can be estimated from Figure 3(The Eurocode line may be considered as an average and the coefficient of variation is about 0,7)



# Statistics/Probabilistic modelling:

- The magnitude of the overpressure, depend on many factors and data parameters, deterministic and random (see Annex A)
- Some of them are common with the probabilistic model of the fuel concentration, while others are not
- Depending on the desired accuracy of probabilistic model, random parameters can be represented by random variables, random processes (in time) and random fields (in space and time)

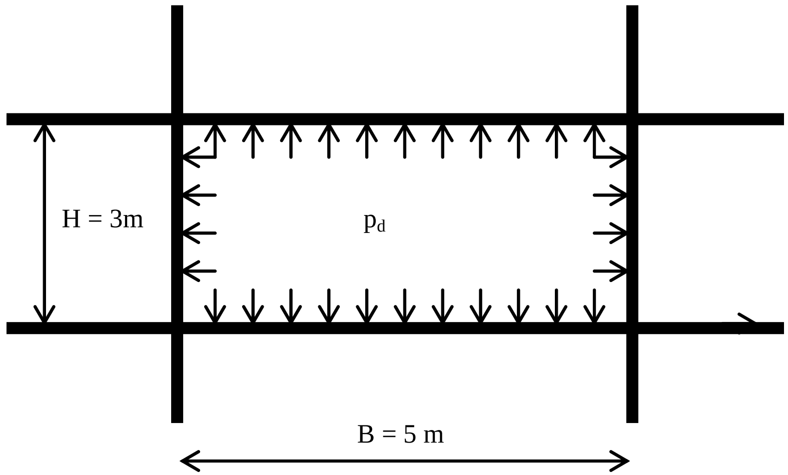
# Statistics/Probabilistic modelling:

- Four natural sub-algorithms for calculation of explosion loads:
  - Estimation of probability model for fuel concentration due to gas dispersion at one leak area
  - Estimation of the probability distribution function for ignition events
  - Estimation of the probability distribution function for ignition events
  - Estimation of gas explosion overpressure for a given homogeneous cloud made of flammable fuel-air mixture

# Probability of exceedance curves:

- 3D-surfaces plotting probability of exceeding both a pressure level and an impulse level can be useful for a simplistic structural assessment.
- When numerical methods are applied, other model uncertainty factors will clearly be relevant as compared to the analytical approach (i.e. simplified empirical models)
- For quantification of the model uncertainty related to numerical models, it is referred to some recent publications

# Example / Illustration / Case studies




| | | |
|---|---|---|
| V | Volume | 180 $m^3$ |
| As | Area of side of enclosure | 200 $m^2$ |
| Av/V | Vent area parameter | 0.01 - 0.20 $m^{-1}$ |
| pv | Vent breaking pressure | 3 $kN/m^2$ |
| So | Burning velocity | 0.45 m/s |
| W | Mass density of vent material | 20 $kg/m^2$ |

# Comparison of empirical models

| | | | Av/V [m-1] | Av [m2] | K | EN | cubbage | rasbash | nfpa |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | kN/m2 | kN/m2 | kN/m2 | kN/m2 |
| | | | 0,01 | 1,60 | 125,00 | 404,50 | 89,49 | 534,11 | 3125,00 |
| V | 160 | m3 | 0,02 | 3,20 | 62,50 | 104,50 | 44,86 | 269,42 | 781,25 |
| As | 200 | m2 | 0,03 | 4,80 | 41,67 | 48,94 | 29,99 | 181,20 | 347,22 |
| pv | 3 | kN/m2 | 0,04 | 6,40 | 31,25 | 29,50 | 22,55 | 137,08 | 195,31 |
| So | 0,45 | m/s | 0,05 | 8,00 | 25,00 | 20,50 | 18,08 | 110,61 | 125,00 |
| W | 20 | kg/m2 | 0,06 | 9,60 | 20,83 | 15,61 | 15,11 | 92,97 | 86,81 |
| | | | 0,07 | 11,20 | 17,86 | 12,66 | 12,98 | 80,36 | 63,78 |
| | | | 0,08 | 12,80 | 15,63 | 10,75 | 11,39 | 70,91 | 48,83 |
| | | | 0,09 | 14,40 | 13,89 | 9,44 | 10,15 | 63,56 | 38,58 |
| | | | 0,10 | 16,00 | 12,50 | 8,50 | 9,16 | 57,67 | 31,25 |
| | | | 0,11 | 17,60 | 11,36 | 7,81 | 8,35 | 52,86 | 25,83 |
| | | | 0,12 | 19,20 | 10,42 | 7,28 | 7,67 | 48,85 | 21,70 |
| | | | 0,13 | 20,80 | 9,62 | 6,87 | 7,10 | 45,46 | 18,49 |
| | | | 0,14 | 22,40 | 8,93 | 6,54 | 6,61 | 42,55 | 15,94 |
| | | | 0,15 | 24,00 | 8,33 | 6,28 | 6,18 | 40,03 | 13,89 |
| | | | 0,16 | 25,60 | 7,81 | 6,06 | 5,81 | 37,82 | 12,21 |
| | | | 0,17 | 27,20 | 7,35 | 5,88 | 5,48 | 35,88 | 10,81 |
| | | | 0,18 | 28,80 | 6,94 | 5,73 | 5,19 | 34,15 | 9,65 |
| | | | 0,19 | 30,40 | 6,58 | 5,61 | 4,93 | 32,60 | 8,66 |
| | | | 0,20 | 32,00 | 6,25 | 5,50 | 4,70 | 31,20 | 7,81 |
| | | | 0,21 | 33,60 | 5,95 | 5,41 | 4,48 | 29,94 | 7,09 |
| | | | 0,22 | 35,20 | 5,68 | 5,33 | 4,29 | 28,80 | 6,46 |
| | | | 0,23 | 36,80 | 5,43 | 5,26 | 4,11 | 27,75 | 5,91 |
| | | | 0,24 | 38,40 | 5,21 | 5,19 | 3,95 | 26,79 | 5,43 |
| | | | 0,25 | 40,00 | 5,00 | 5,14 | 3,80 | 25,91 | 5,00 |



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# Annex A: Description of models

*(1) Eurocode EN 1991-1-7*

*(2) Cubbage and Simmonds*

*(3) Rasbash et al*

*(4) NFPA 68, Guide for Venting of Deflagrations, 2002 Edition for low strength buildings*

*(5) NFPA 68, Guide for Venting of Deflagrations, 2002 Edition for high strength buildings*

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# Annex B: Table CFD parameters

| Deterministic factors | Random factors |
|---|---|
| type of problem: e.g. gas explosion in vessels, gas explosion in buildings / off- shore modules, gas explosion in uncon- fined process areas | position of leakage points. (They can be even deterministic with different proba- bilities of gas dispersion events.) |
| shape and sizes of structure / processing area | flow rate of gas/liquid |
| shape, location and sizes of equipment | wind direction and velocity |
| type of fuel and oxidiser | air exchange rate due to natural ventila- tion [and forced ventilation |
| size, location and type of explosion vent area | ignition source: strength and position |
| mitigation system | time to ignition: time delay after gas has been released |
| minimum ignition energy as a function of fuel concentration | temperature field |
| autoignition temperature | |
| flammability limits (in terms of fuel-air concentration) as a function of tempera ture | |
| stoichiometric composition, which gives usually the highest explosion pressure | |

# Additional items, not completed

| Limitations |
| --- |
| xx |

| Recommendations |
| --- |
| xx |

| Outlook to further research |
| --- |
| xx |

- Accuracy vs. Computation time
- Various types of models can be applied for different purposes
- Further work on more comprehensive CFD models
- Continuous need for calibration of models by experimental results
- Further work on probabilistic modelling



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