COST C26

Working Group 3: Impact and Explosion Resistance

COST Action C26

Urban habitat constructions under Catastrophic events

Prague (CZECH Republic)

30-31 March 2007

Chairmen: M. Byfield, G. De Matteis

Peak pressure in flats due to gas explosions

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Progressive collapse in case of gas explosion

"loss of load-carrying capacity of a relatively small portion of a structure due to an abnormal load which result in the failure of a major portion of the structure"

Ronan Point, London, 1968

The pressure peak was estimated 80 kN/m^2 → Collapse of a corner of the Building with precast load bearing wall.

Target:

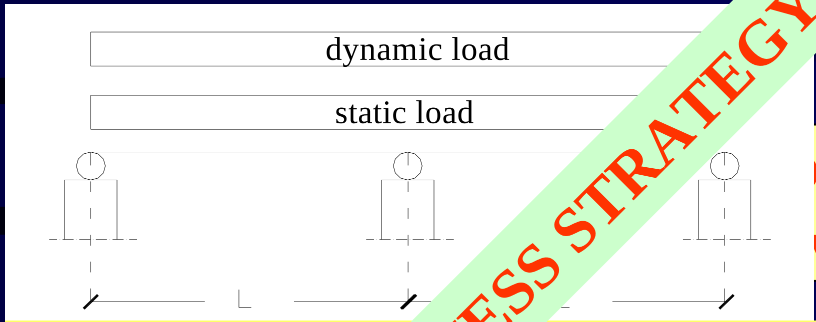
Reduction of the risk of progressive collapse

Main strategies:

1. ***Key element strategy***
2. ***Alternative load paths strategy***

Gas-Explosion Hazard and Progressive Collapse

I. Langone University of Chieti/Pescara "G. D'Annunzio", Italy

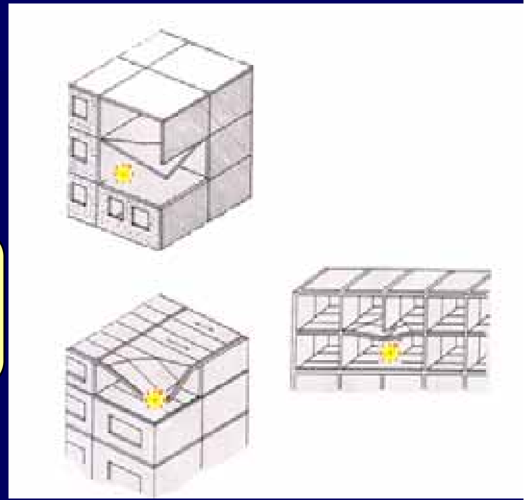


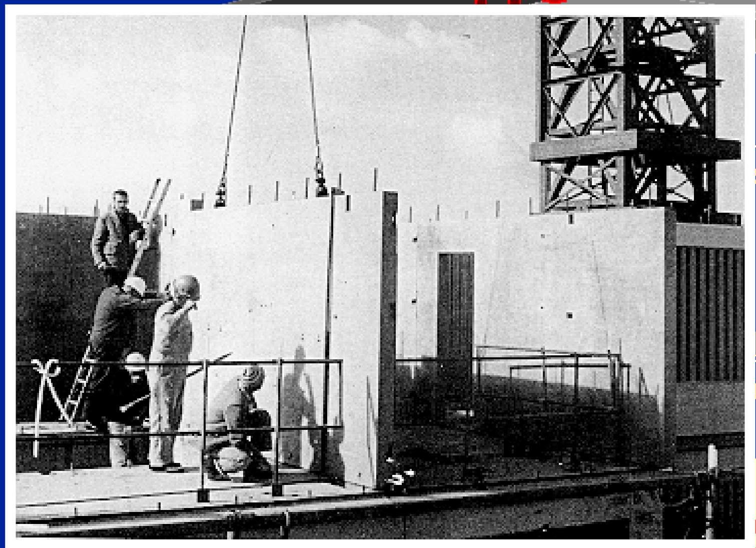
FLOOR SL… …LLAPSE

Multi-Stories B… …g with Pre-Cast Lo… …ring Wall

ROBUSTNESS STRATEGY

…sion Hazard and …ve Collapse Risk



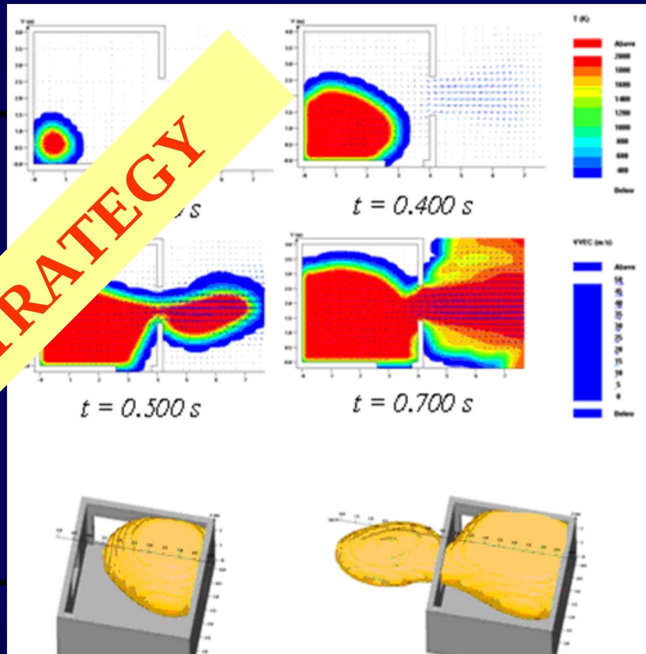


…ast floor slab

…l-slab …ectio…

RC ELEMENT WITH ST… CONNECTIONS

KEY ELEMENT STRATEGY



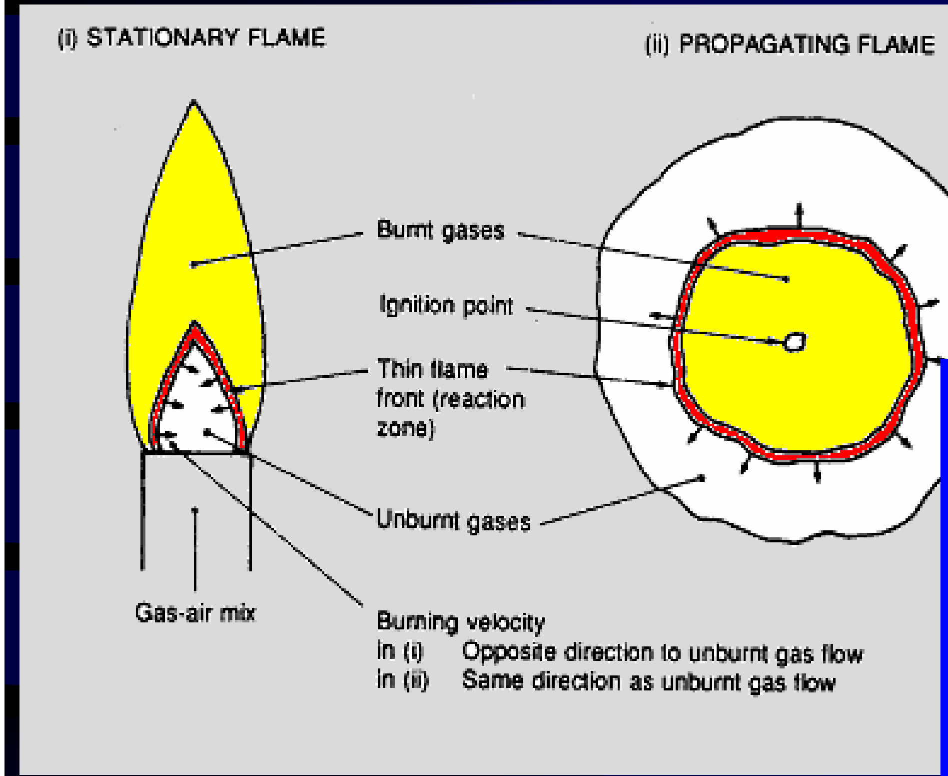
FLACS simulator

…mulas

…egies …b)

GAS EXPLOSION

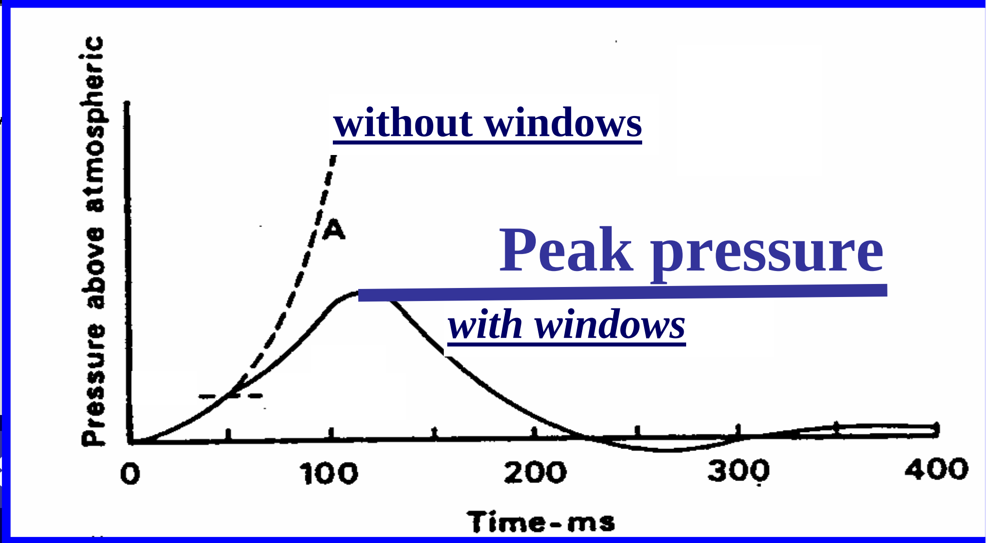
"Fast chemical reaction of gas in air; it happens at high temperatures and high pressure and having as a result the propagation of a pressure wave"



$C_5H_{12} + 8(O_2 + 3.76N_2) = 6H_2O + 5CO_2 + 30.0$

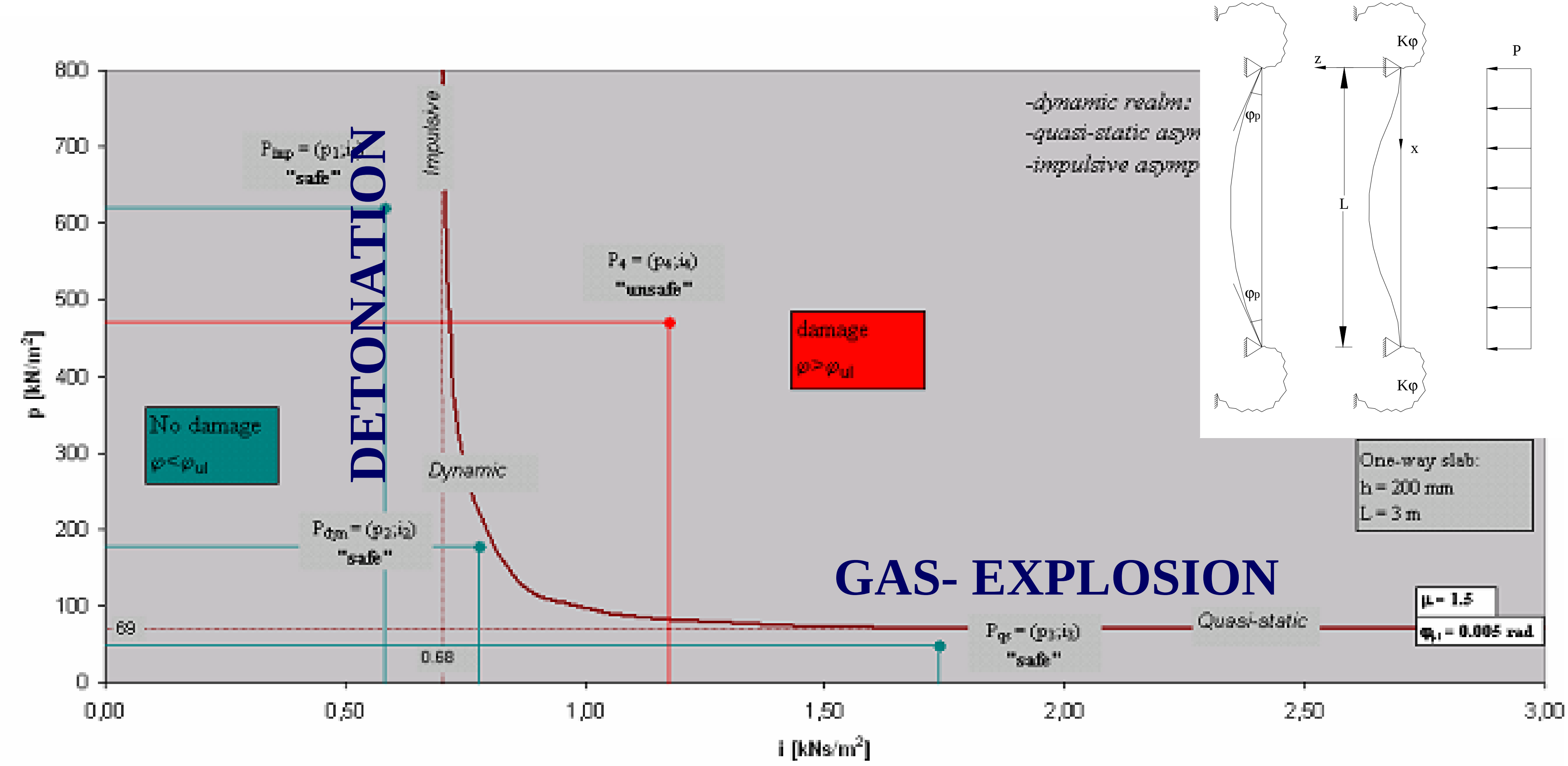
Pressure wave depends on :

- **Percent of gas in air**
- **Geometry of the compartment**
- **Largeness of the compartment**
- **Presence of openings**
- **Presence of wall of easy discouragement**



In case of "gas-explosions" only the peak pressure should be estimated (Quasi-static action) !!!

ENERGY BALANCE METHOD TO DEFINE THE CAPACITY OF THE KEY ELEMENT



THE KEY ELEMENT IS CHARACTARISED BY A "QUASI-STATIC RESPONSE"

External Work (WK):

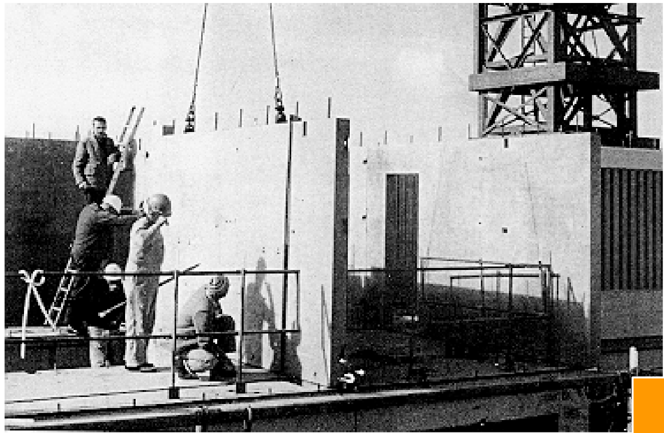
$$WK = \int_0^L p^* w(x) dx$$

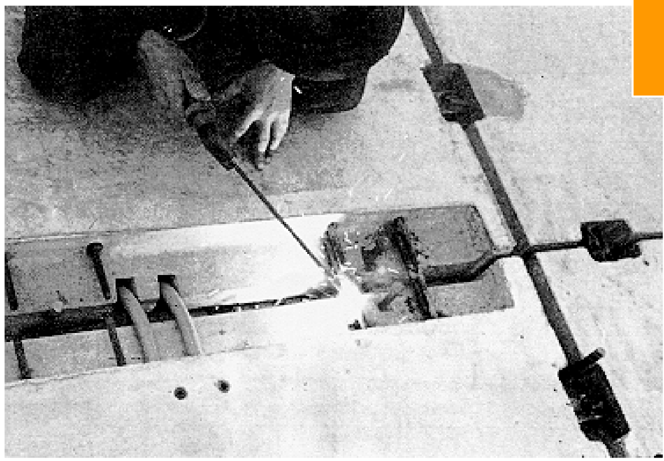
Strain Energy (SE):

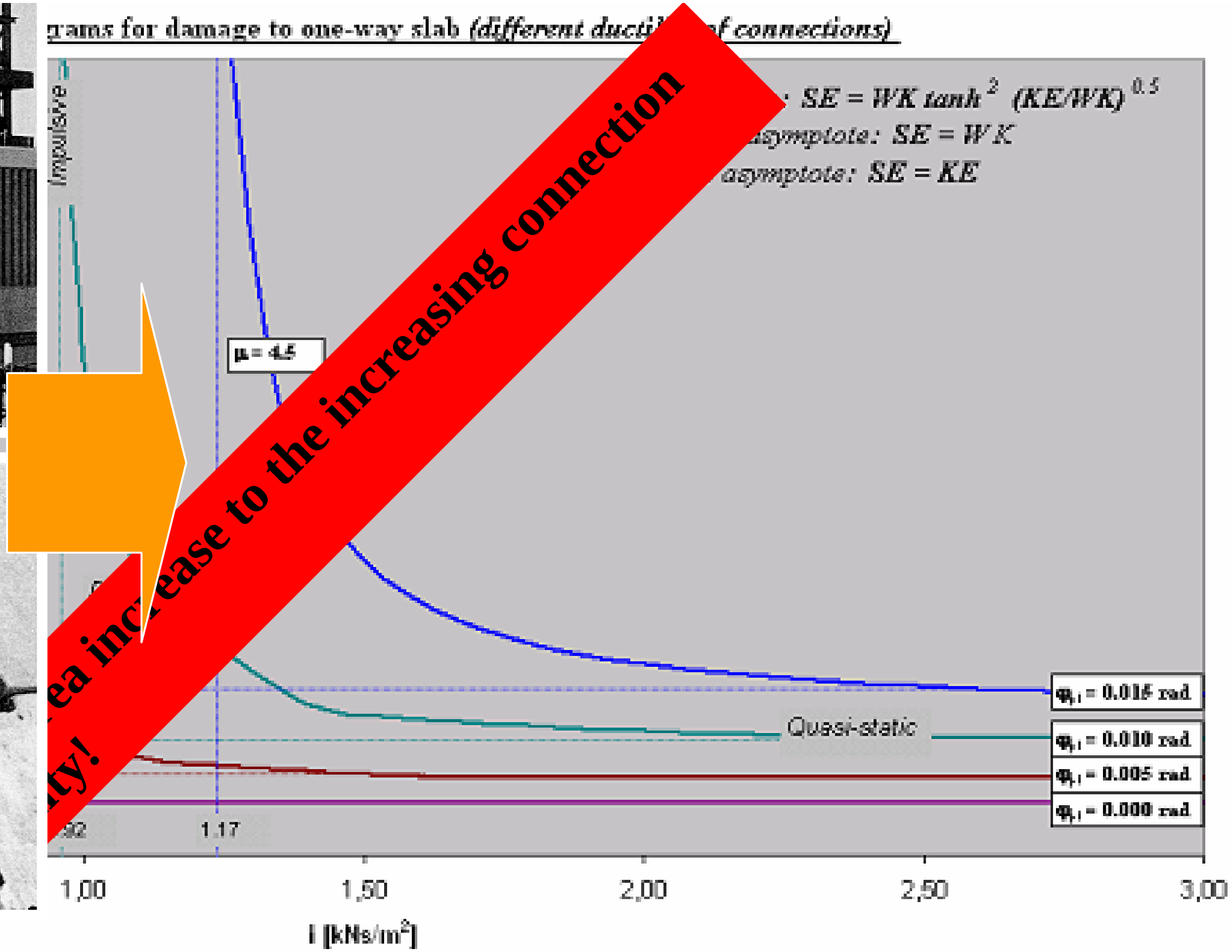
$$(SE)_s = \frac{1}{2}\frac{M_P^2}{k_\varphi} + \varphi_p M_p \qquad (SE)_b = \int_0^L \frac{M(x)^2}{2EI} dx = \frac{EI}{2}\int_0^L [w''(x)]^2 dx$$

$$SE = (SE)_b + 2 \cdot (SE)_s$$

ENERGY BALANCE METHOD TO DEFINE THE CAPACITY OF THE KEY ELEMENT



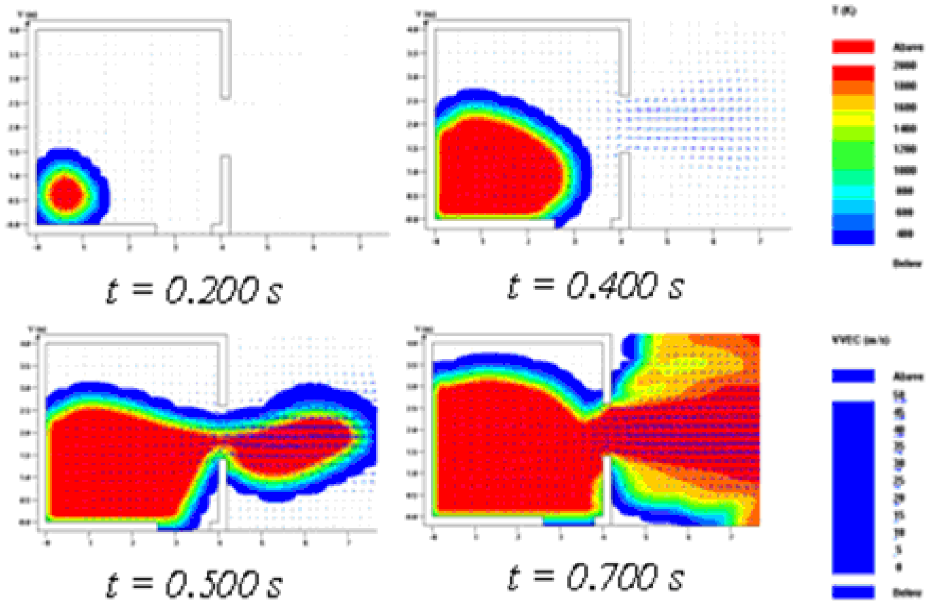




Precast Load Bearing Walls connected by means of Ductile Steel Elements

EMPIRICAL FORMULAS AND FLACS SIMULATION TO DEFINE THE DEMAND OF THE KEY ELEMENT

FLACS simulation:



Empirical formulas:

$$P_{\max} = 1.5 P_V + 77.7 S_L K$$

$$P_{\max} = P_V + S_L \left(\frac{4KW}{V^{1/3}} + 70K \right)$$

P_{max}, P_v = peak and vent pressure

V = volume of the compartment

$\frac{A_S}{A_V} \cong \frac{V^{2/3}}{A_V}$ = venting area

Empirical formulas should be used with particular care when irregular geometry is of concern, since the flame front can become turbulent, producing a significant increase of the blast peak pressure!

Empirical method

On the basis of experimental analysis, several empirical relationships have been proposed to estimate the peak pressure of the gas explosion.

Typical empirical relationships are based on the following main parameter:

$$P_{\max} = f\left(P_V, V, W, K, S_L\right)$$

Where:

P_{max} = peak pressure; P_v = vent pressure; V = volume of the compartment; W = Mass per unit area of the vent; S_L = velocity of the laminar flow; A_s = panels area; A_v = vent area and K is the ventilation ratio defined as the following:

$$K = \frac{A_S}{A_V} \cong \frac{V^{2/3}}{A_V}$$

Empirical method

STUDY CASE:

A "Common Kitchen" is analyzed, it being characterized by the following parameters:

V = 4 x 4 x 3 = 36 m^3, SL = 0.30 m/s, A_v = 1.2 x 1.5 = 1.8 m^2,
P_v = 20 mbar and W = 5 Kg/m^2.

The application of the empirical relationships provides the following estimation of the peak pressure (laminar flow):

$$P_{\max} = 1.5 P_V + 77.7 S_L K = 167 mbar$$

Rasbash

$$P_{\max} = P_V + S_L\left(\frac{4KW}{V^{1/3}} + 70K\right) = 154 mbar$$

Silvestrini et al.

$$P_{\max} = 3 + \frac{P_V}{2} + \frac{0.04}{\left(\frac{A_v}{V}\right)^2} = 20\frac{kN}{m^2} \cong 200 mbar$$

Eurocode 1, Part 1-7: Accidental actions

Using Rasbash and Silvestrini et al. relationships the results are quite in line with the one provided by Eurocode 1

Computational Fluid Dynamics (CFD) Modeling

Computational fluid dynamics (CFD) modeling is a general term used to describe the analysis of systems involving fluid flow, heat transfer and associated phenomena (chemical reactions) by computer based numerical methods.

They are represented as a set of equations in terms of density ρ [Kg/m^3], pressure P [N/m^2], velocity v [m/s], temperature [°C], internal energy per unit mass N [J/Kg] and total energy per unit mass:

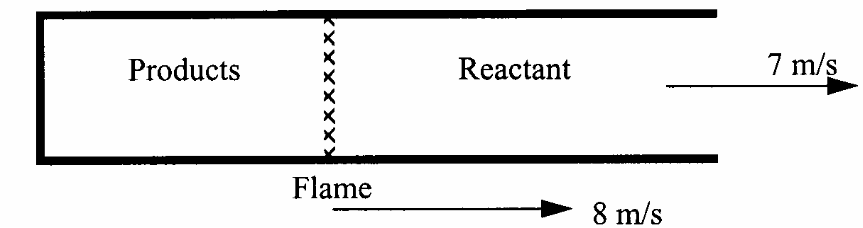
$E = N + 1/2\, v^2$ [J/Kg]

CFD codes are widely used for simulation of gas explosion in complex geometries but competent combustion modeling is needed for reliable simulations. The purpose of a combustion model, like gas explosions, is to localize the reaction zone and convert reactants to products similar to those a real flame produces during an explosion.

Computational Fluid Dynamics (CFD) Modeling

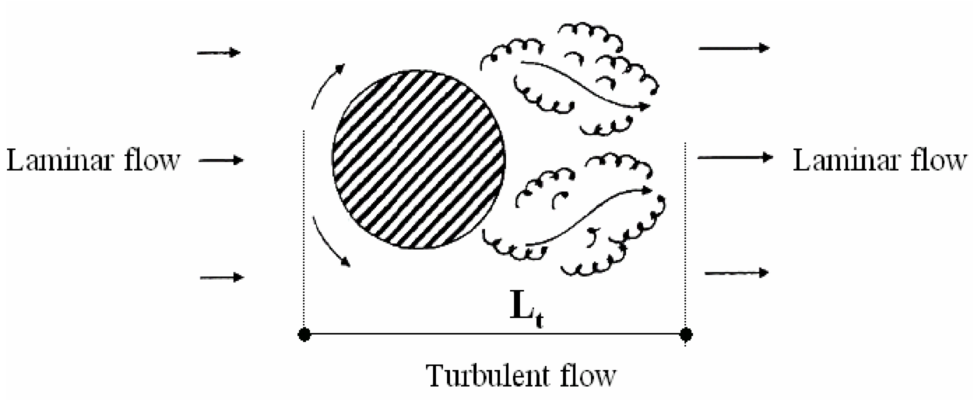
The combustion processes are better described by dividing the combustion in two models (as in FLACS code):

- flame model
- burning velocity model



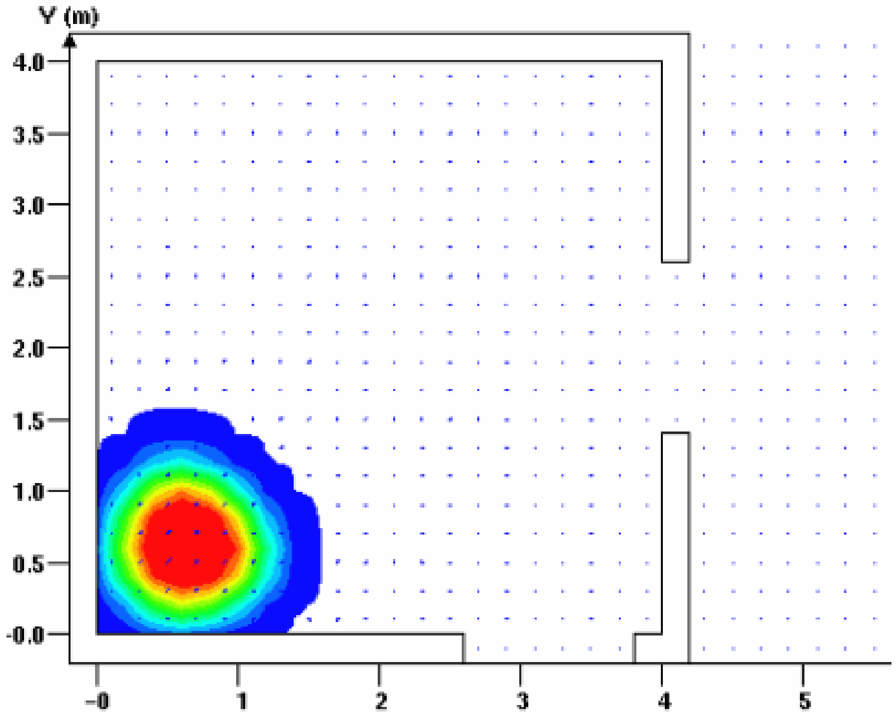
Flame model should move the reaction zone through reactants with the flame speed specified by the burning velocity model. Functions describing thickness, curvature and burning direction of the flame should be used in the model.

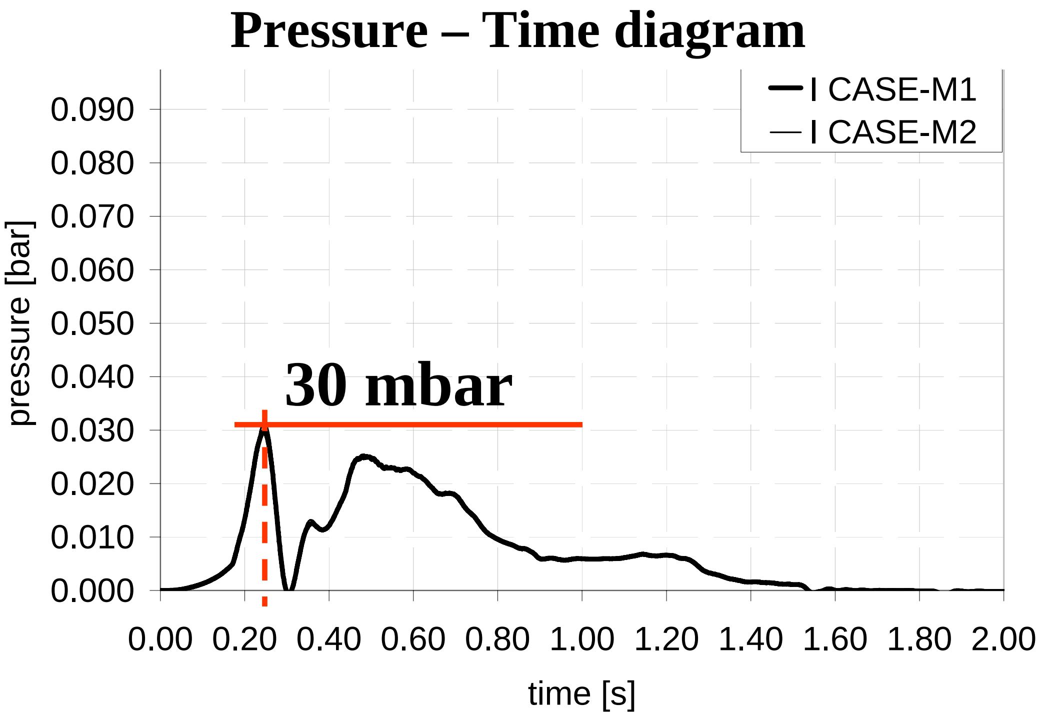
The turbolence are taken into account by CFD modeling!



FLACS SIMULATION

I case (regular compartment): regular room with window as venting



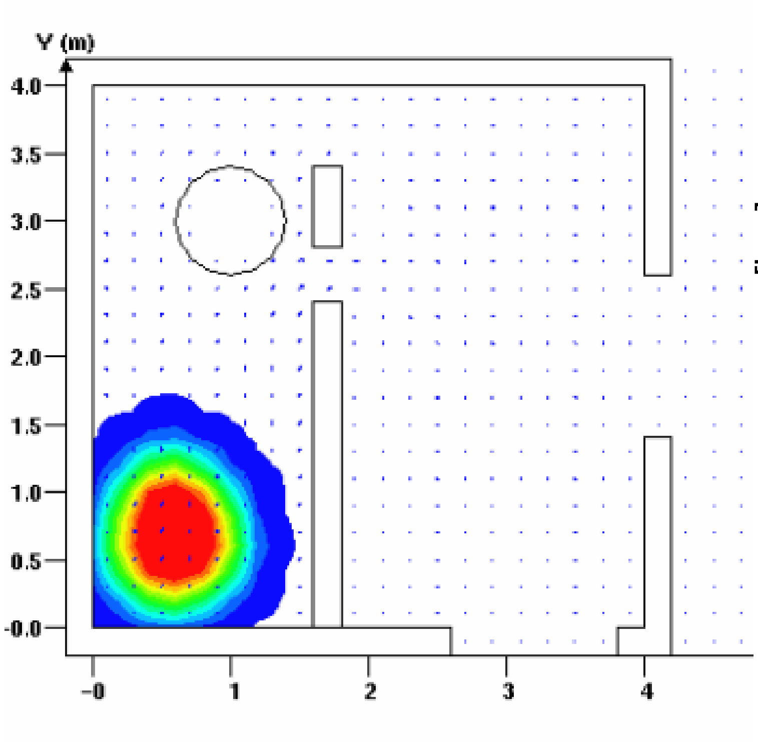


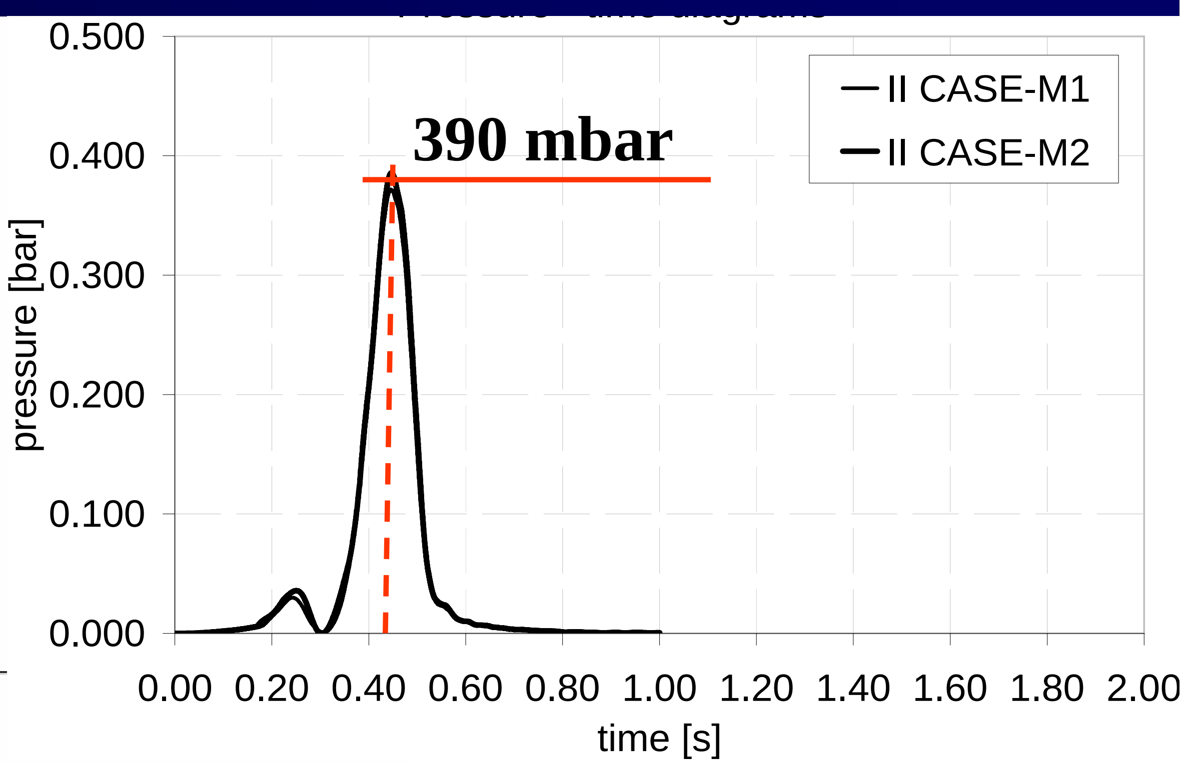
Regular volume (4 x 4 x 3 = 36 m^3), with window (1.2 x 1.5 = 1.8 m^2), supposed filled with air at ignition time.

The peak pressure, reached at the rise time 0.25 s corresponds to 30 mbar.

FLACS SIMULATION

II case (irregular compartment): irregular room with window as venting

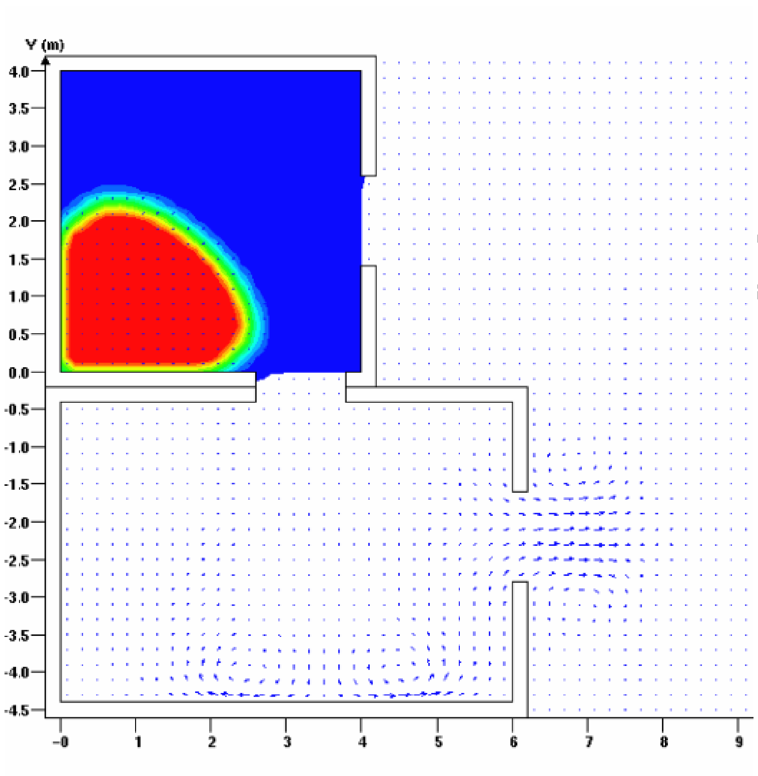


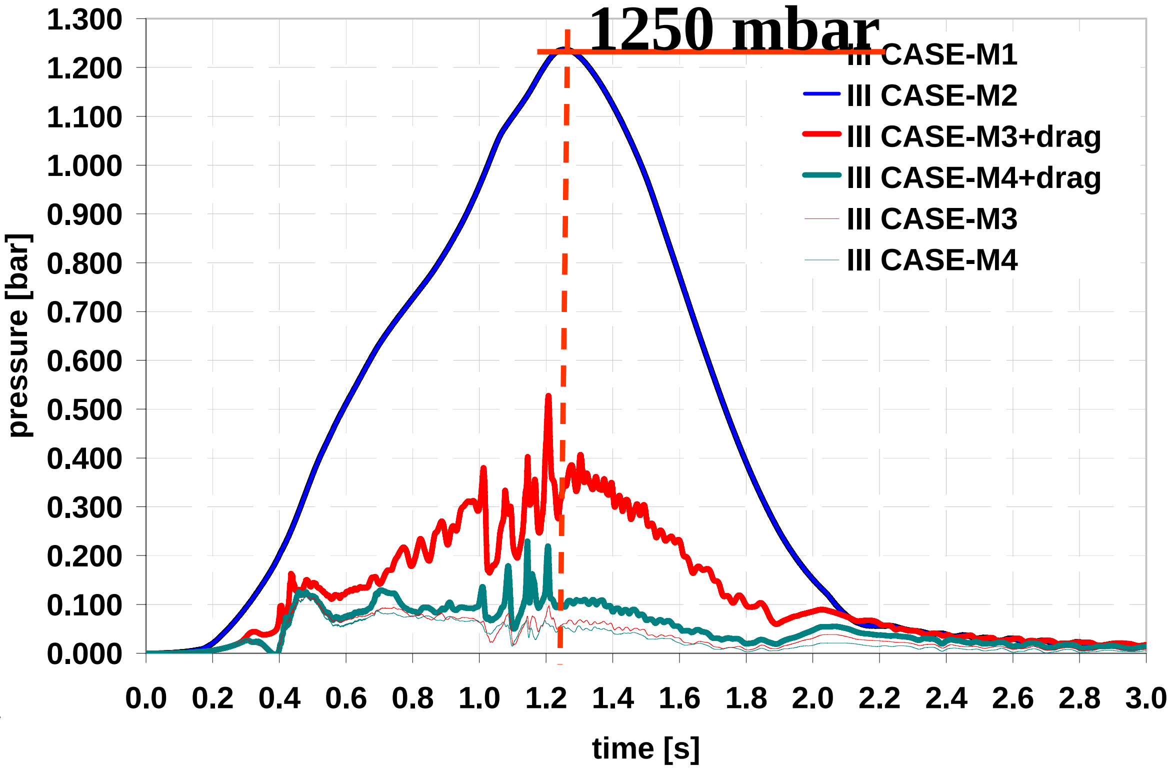


In case of irregular compartment, the combustion flow becomes turbulent and the peak pressure reaches the value of about 390 mbar at a rise time equal to 0.45 s

FLACS SIMULATION

III case (irregular compartment): regular room linked to another one with window as venting





In such a severe condition the peak pressure reaches the value of about 1250 mbar, at a rise time 1.30 s.

CONCLUSIONS

•Firstly, key elements (precast walls) can be designed by estimation of the peak pressure due to the gas explosion.

•Secondly, empirical relationships can be used to estimate the peak pressure in a regular compartment (combustion laminar flow). Otherwise, in complex compartment the CFD modeling is advisable.

•Then, more realistic compartments with turbulence are represented by the second simulation (II Case). In such a case the peak pressure increases to 390 mbar (CFD modeling).

•Next, in the case of severe conditions of turbulence and domino effects (III Case) the peak pressure can reaches a value of 1250 mbar (CFD modeling)

•Finally, computational fluid dynamic modeling should be used in case of High Consequences of Failure – Consequences Classes 3 (Eurocode 1, Actions on Structures, Part 1-7: General actions – Accidental actions)