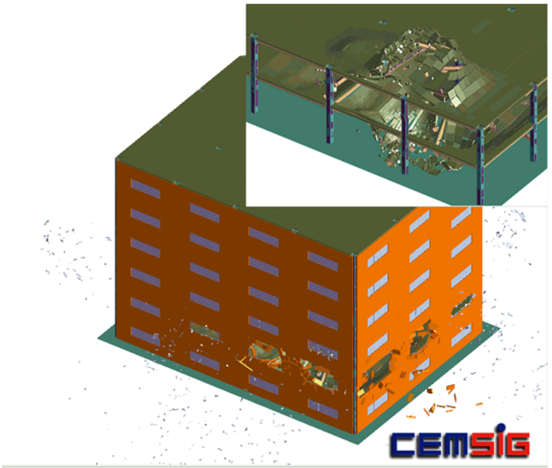
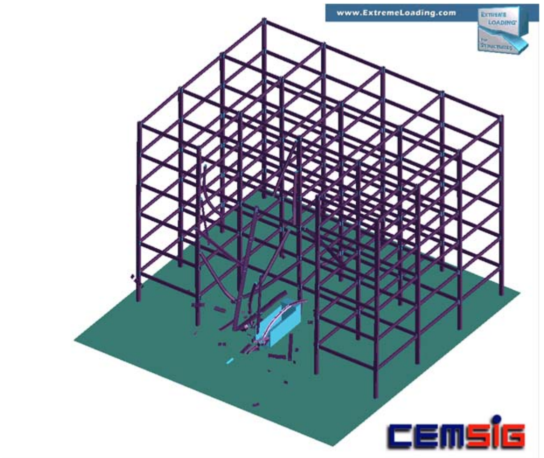
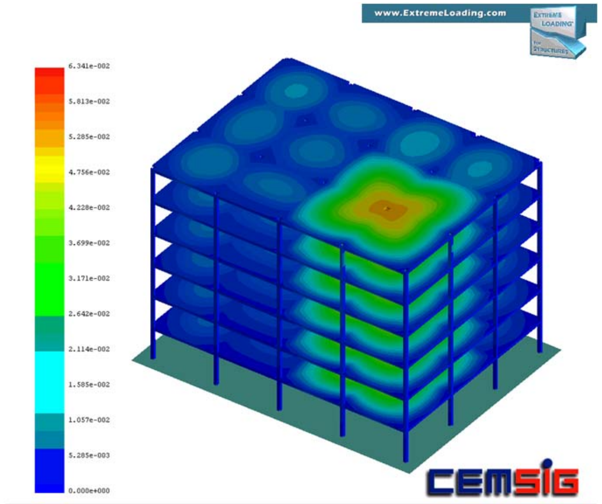
Explosion and blast resistance







Florea Dinu

Lecture 12: 07/04/2014

European Erasmus Mundus Master Course

Sustainable Constructions

under Natural Hazards and Catastrophic Events

520121-1-2011-1-CZ-ERA MUNDUS-EMMC

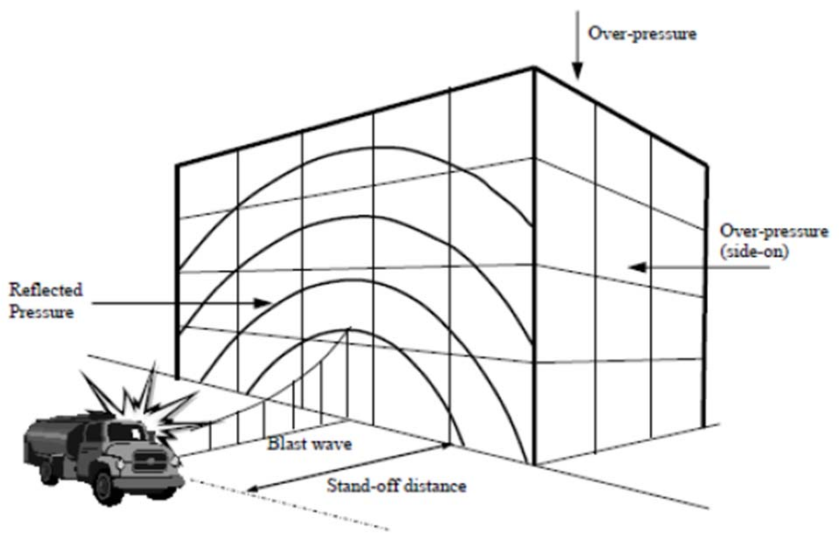
Universitatea Politehnica Timişoara

Main Text and Reference Materials :

1.Chopra, Anil. – Structural Dynamics
2.Krauthammer, T. – Modern Protective Structures, CRC Press, 2008
3.Smith, P. D. and Hetherington, J. G., "Blast and ballistic loading of structures."
4.Baker, W. E., et al., "Explosion Hazards and Evaluation."
5. Donald O. Dusenberry, Handbook for blast-resistant design of buildings

Introduction

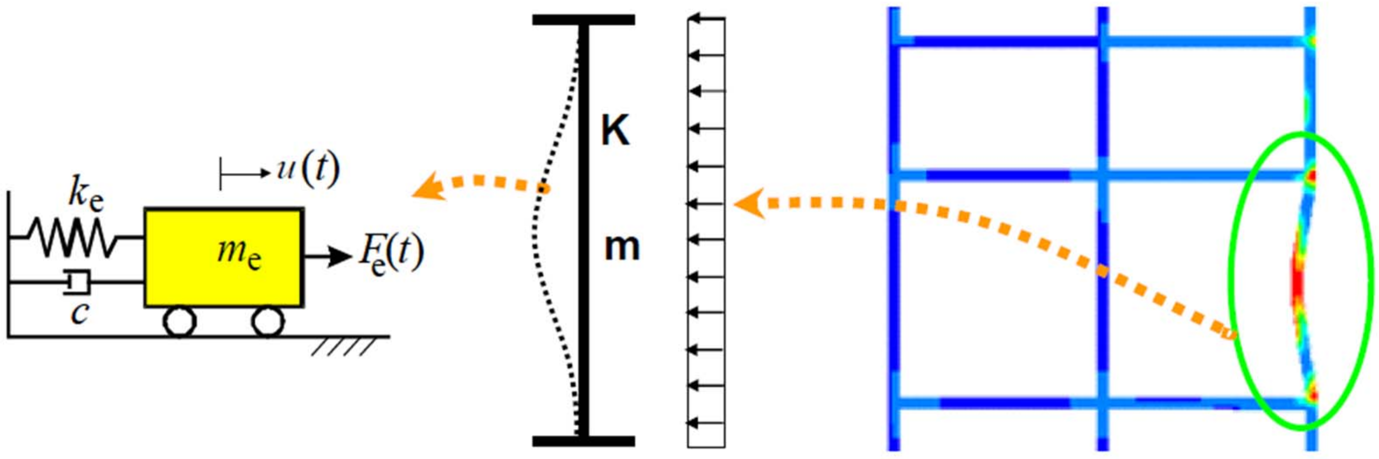
- Increased attention after the explosion that demolished the Alfred P. Murrah Federal Building in Oklahoma City in 1995
- Vulnerability of buildings, bridges, tunnels, and utilities in the midst of numerous recognized international social and political instabilities expanded the interest for explosion and blast resistant design
- Engineers need training and information so that they can provide designs that effectively enhance a building’s response to explosions



Blast loads on a building

Classification of dynamic loads on structures

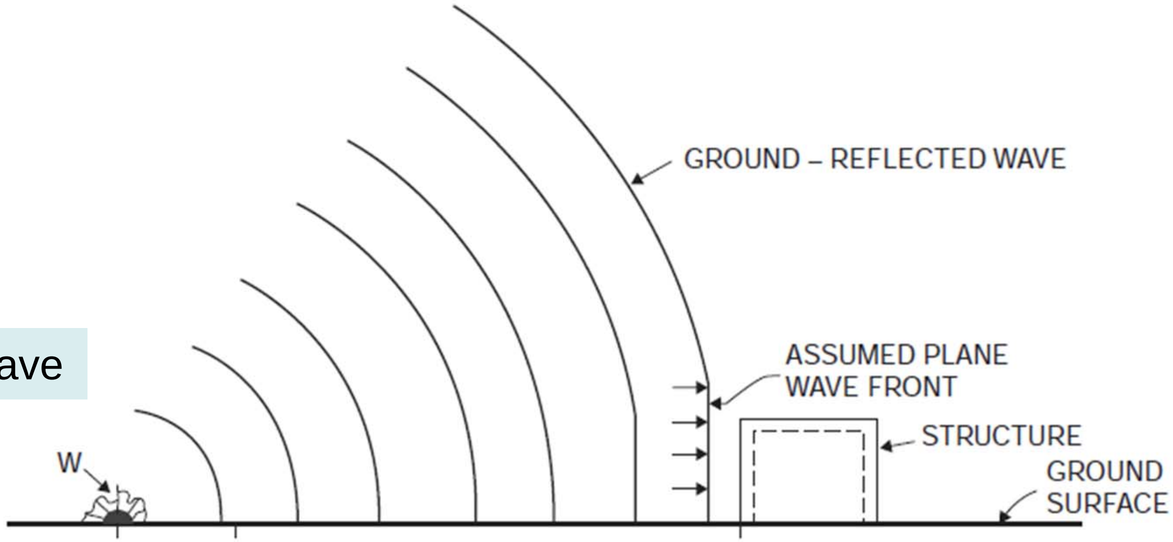
- Lower frequency dynamic loading: wind, current, earthquake ground motions – frequency up to a few Hertz
- Medium to high frequency dynamic loading: construction vibration; blast-induced ground excitation – Frequency order of 10's ~ 100's Hz
- Shock and impact loading, e.g. due to blast – pulse duration in the order of milliseconds



Blast phenomena

- Blast is a pressure disturbance caused by the sudden release of energy:
  - detonation of an explosive
  - flammable materials mixed with air can form vapor clouds that when ignited can cause very large blasts
  - bursting pressure vessel from which compressed air expands
  - rapid phase transition of a liquid to a gas
- The loads resulting from a blast are created by the rapid expansion of the energetic material, creating a pressure disturbance or blast wave radiating away from the explosion source, as shown in figure

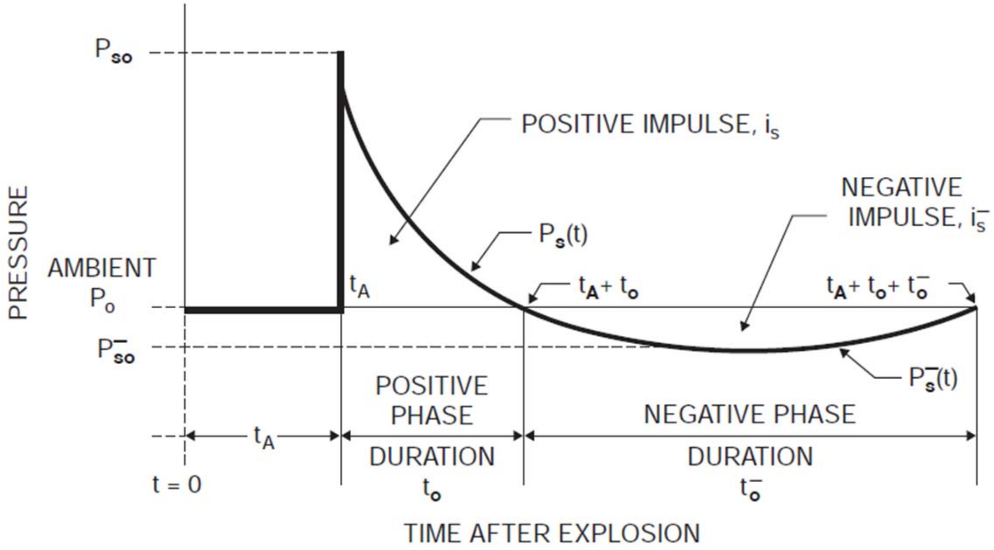
Propagating Blast Wave



Blast pressure

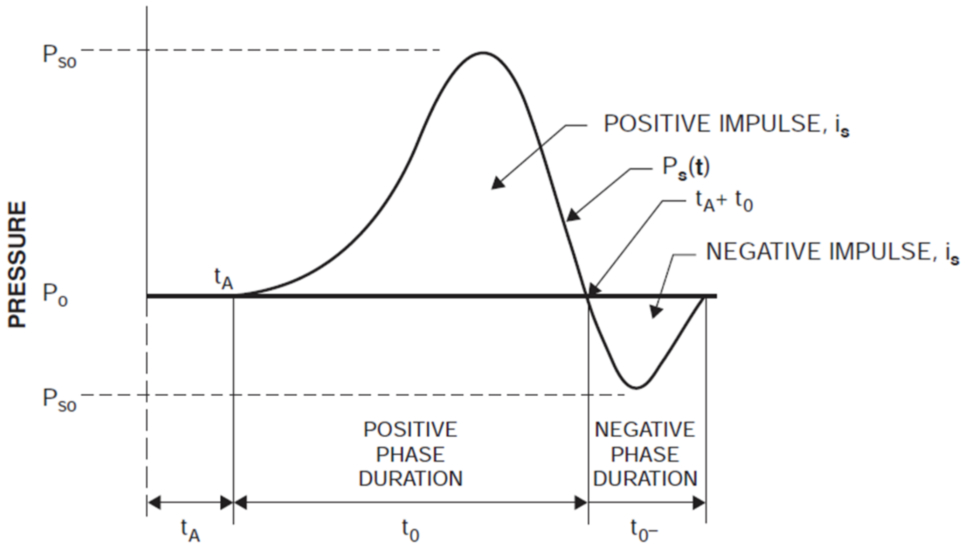
- Shock waves :
  - are high-pressure blast waves that travel at a velocity faster than the speed of sound.
  - shock waves are characterized by an instantaneous increase in pressure followed by a rapid decay.
- Pressure waves:
  - are lower amplitude and travel below the speed of sound.
  - are characterized by a more gradual increase in pressure than a shock wave, with a decay of pressure much slower than a shock wave
- In most cases, shock waves have a greater potential for damage and injury than pressure waves.

Shock Wave from Detonation



In a detonation, the reaction front propagates supersonically, usually many times faster than the speed of sound

Pressure Wave from Deflagration



A deflagration is an oxidation reaction that propagates at a rate less than the speed of sound in the unreacted material

- Explosive materials (solid materials, combustible gases) can be broadly categorized based on their state:
  a. High explosives (intended to produce detonation): e.g. TNT
  b. Propellants and pyrotechnics (also known as low explosives) - do not typically detonate (e.g. black powder)
  c. Vapor cloud explosions (overpressures produced by vapor cloud explosions are substantially lower than those produced by high explosive)
- Energy output and standoff distance are key to accurately determining blast loads acting on a structure.

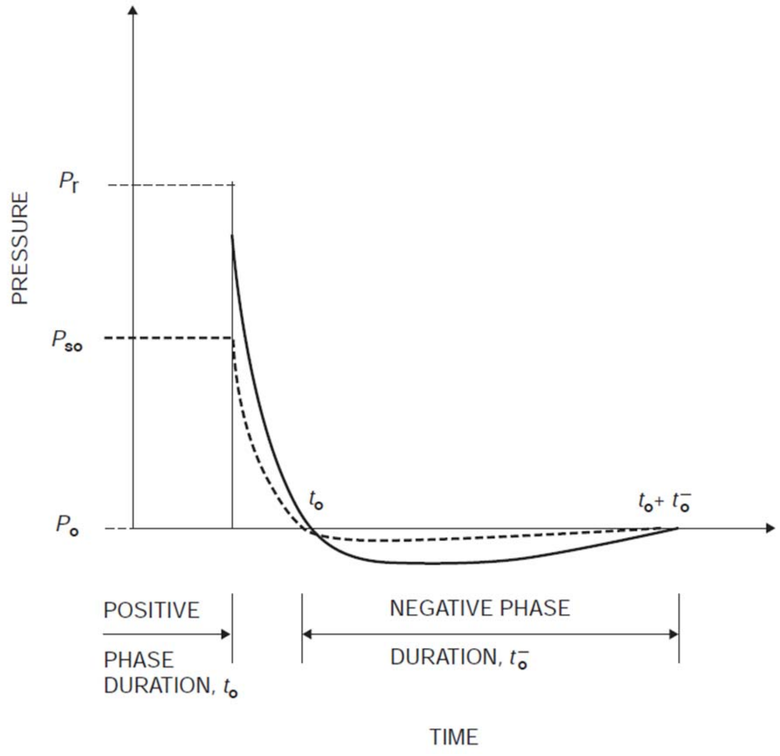
a)

b)

c)

Characteristics of blast waves

- Key parameters of a blast load are presented in the figure
- Blast pressures, load duration, impulse, shock wave velocity, arrival times, and other blast parameters are frequently presented in scaled form - the most common form of scaling is called "cube root scaling" - blast parameters are scaled by the cube root of the explosion energy
- Prediction of blast parameters – very important for calculation of the loads imposed to the structure



P_o = Ambient pressure
P_{so} = Peak positive side-on overpressure
P_{so}^- = Peak negative side-on overpressure
$P_s(t)$ = Time varying positive overpressure
$P_s^-(t)$ = Time varying negative overpressure
P_r = Peak reflecte overpressure
I_s = Positive-phase-specifi impulse, the integration of the positive phase pressure-time history
i_s^- = Negative-phase-specifi impulse, the integration of the negative phase pressure-time history
t_a = Time of arrival
t_o = Positive phase duration
t_o^- = Negative phase duration

High Explosives

- Blast parameter curves typically plot air-blast parameters versus scaled distance (for both air-burst and surface-burst configurations) (e.g. Hopkinson-Cranz, or cube root, scaling method)
- The scaled distance is obtained by dividing the standoff distance from the charge to the point of interest by the cube root of the charge weight
- For explosives, this takes the form of:

$$Z = R/W^{1/3}$$

where:
Z = scaled distance (ft/lb$^{1/3}$)
R = standoff distance (ft)
W = explosives weight (lb)

1 pound = 0.45 kg
1 ft = 0.30 m

Example: Oklahoma City Bombing.

- event equivalent to the detonation of 4,000 lbs of TNT at essentially the ground surface.
- If a location of interest is 100 ft away, the scaled distance is

$$Z = 100/(4000)^{1/3} = 6.30 \text{ ft/lb}^{1/3}$$

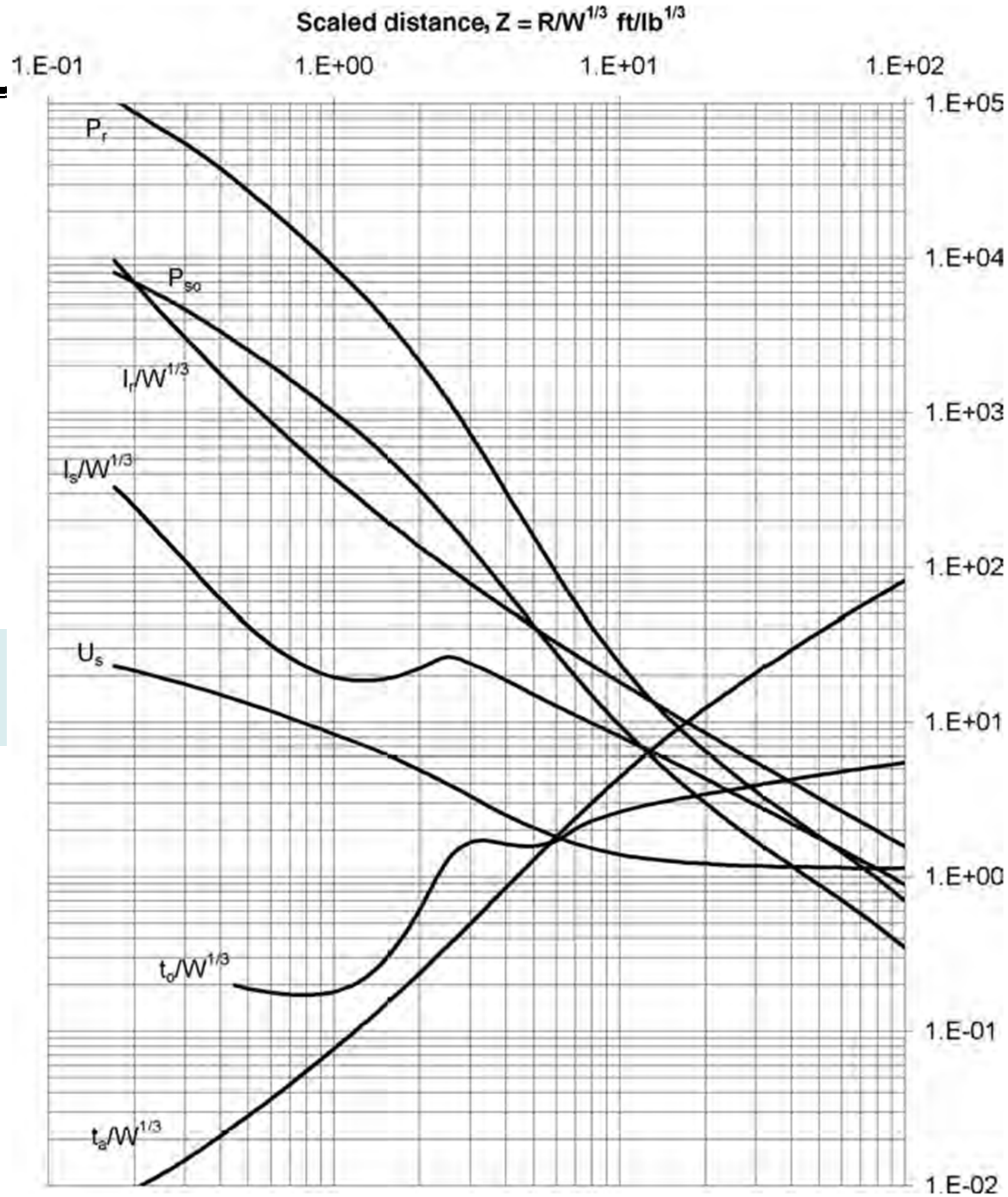
- We have an incident pressure of P_o = 24.9 psi and a reflected pressure of Pr = 79.5 psi at this scaled range (see diagram plotted on the next slide)
- The scaled positive phase duration is:

$$t_o/W^{1/3} = 1.77 \text{ msec/lb}^{1/3}$$

- The positive phase duration is:

$$t_o = 1.77 \times (4000)^{1/3} = 28.1 \text{ msec}$$

Blast Parameters for TNT Surface Bursts

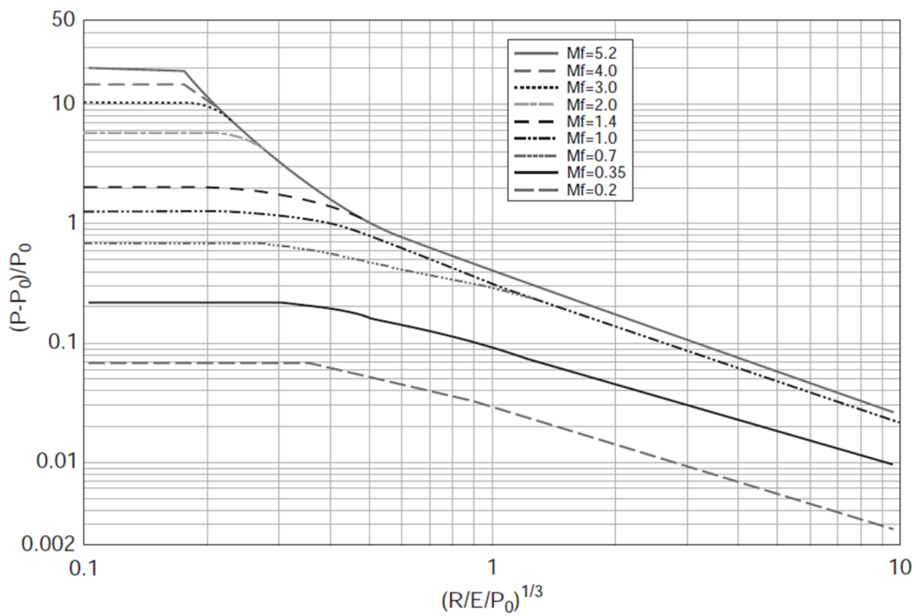


Vapor Cloud Explosions

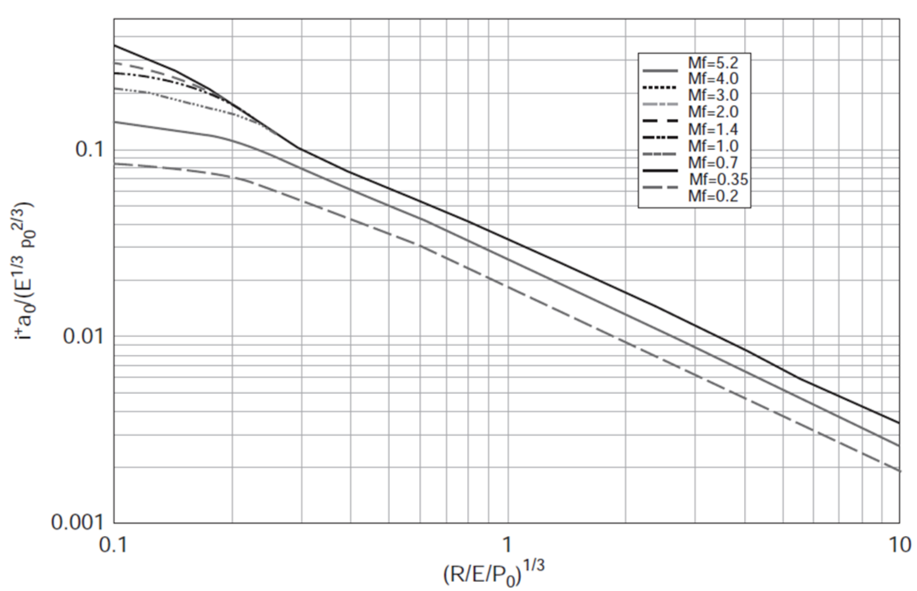
- Prediction of blast loads for vapor cloud explosions can be more complex than loads for high explosive detonations:
    - It is necessary to develop the release scenario for the flammable material
    - simplified methods consisting of graphs (blast curves) of pressure and impulse, or of duration versus scaled standoff
    - more complex using computational fluid dynamics (CFD) modeling

Blast curves method

- The scaled standoff is computed by using distance from the center of the explosion to the point of interest and the energy content of the confined/congested flammable mass
- Scaled pressure and impulse values are read from blast charts containing flam speed curves
- The two most commonly used methods are the Baker-Strehlow-Tang (BST) and TNO Multi-energy Method (MEM)



Peak Pressure for Vapor Cloud Explosions—BST



Impulse for Vapor Cloud Explosions—BST

$R_{bar} = R(p_o/E)^{1/3}$

where:

R_{bar} = scaled distance
R = standoff distance
p_o = ambient pressure
E = heat of detonation

→ $P_{bar} = (P/p_o)$
$i_{bar} = i\ a_o/(E\ p_o)^{1/3}$ → P, i → t_0

P_{bar} = scaled pressure
i_{bar} = scaled impulse
a_o = ambient sound velocity

$t_o = 2i/P$
t_0 is the equivalent triangular duration

Blast loading

- Empirical method consists of equations, graphs, tables, and figures that allow to determine the principal loading of a blast wave on a building or a similar structure.
- Softwares has also been developed to automate calculations based on this same source information.
- More comprehensive methods, such as computational fluid dynamics (CFD), require specialized software, operator training (is potentially time consuming)
- Most data are based on plain rectangular target structures located in open terrain.
- Explosions are assumed to be either an air blast or surface blast.
- There are three blast loading situations:
    - a blast wave interaction with a rectangular structure of finit size - the structure is blast-loaded on all sides (a significant lateral force applied to the structure)
    - a blast wave interacting with a relatively small structure, such as a vehicle, that is effectively engulfed with blast pressure acting on all sides of the structure at once
    - a blast wave acting on a relatively large structure, such as a large office building, where the magnitude of the blast wave varies significantly across the surfaces of the structure. Some surfaces of these structures may see little if any external blast loading

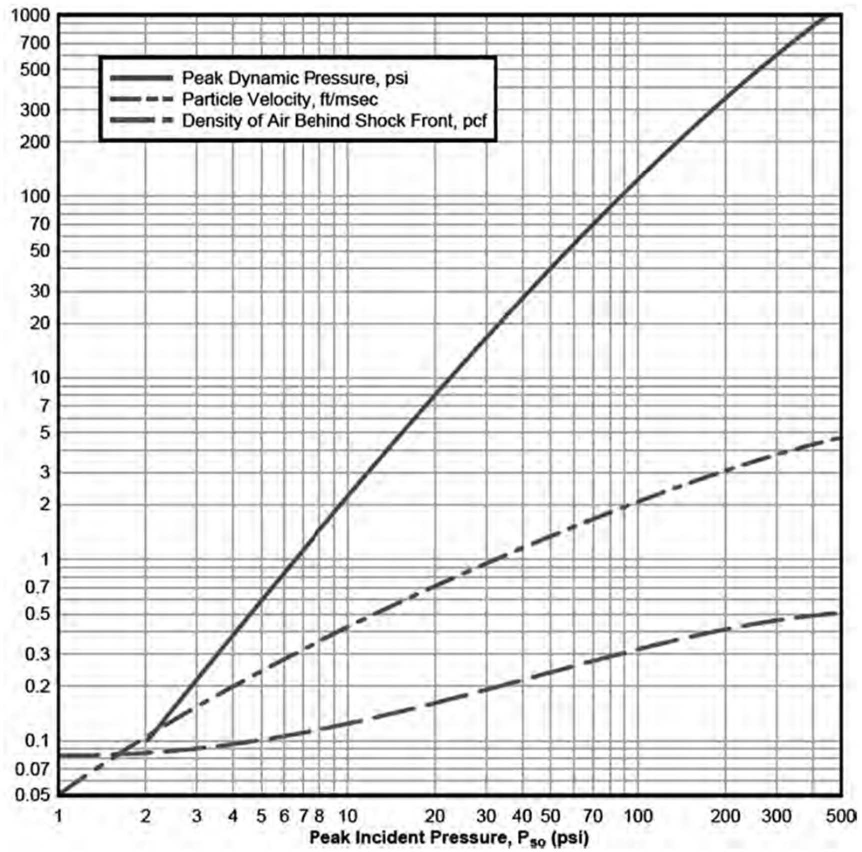
Determination of building loads

- Key input parameters for the determination of building loads are:
  - the peak side-on overpressure, P_{so}
  - the positive phase duration, t_o
  - the shock front velocity, U_s
- One other parameter necessary for the determination of building blast loads is the dynamic wind pressure, q_o (see figure)

Alternatively $q_o = 0.022\,(P_{so})^2$

- The pressure exerted on a structural element is the dynamic wind pressure, q_0, multiplied by a drag coefficient, C_d
- C_d is 2 for structural shapes, 1.25 for box shapes, and 0.8 for cylinders

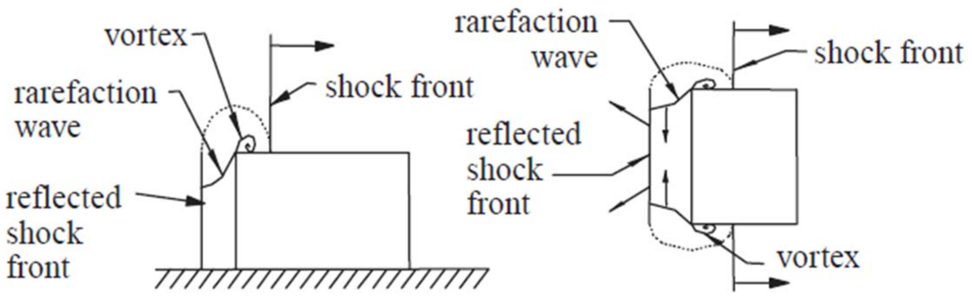
1Psi = 6.89 kN/m^2



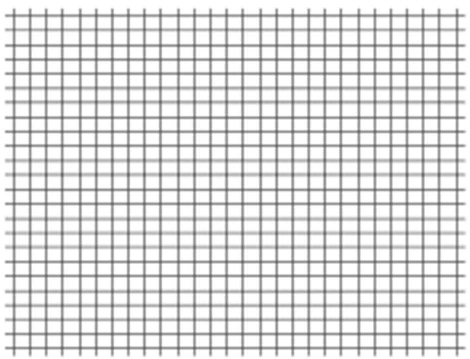
Peak Incident Pressure versus Peak Dynamic Pressure, Density of Air Behind the Shock Front, and Particle Velocity (UFC 3-340-02)

Front wall loads

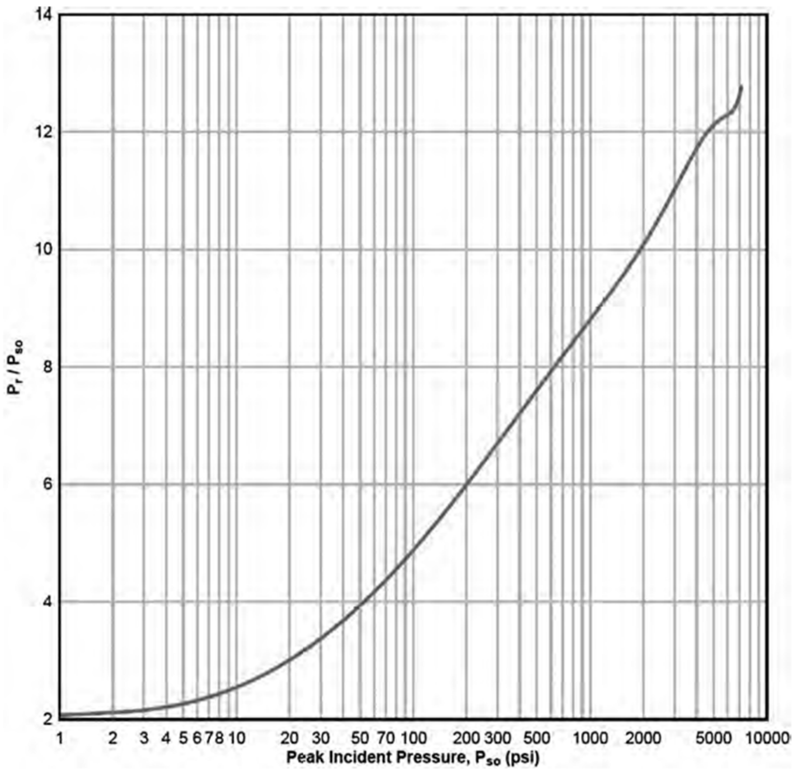
- The wall facing the explosion source is subjected to a reflection effect
- The reflection effect amplifies the blast pressure on the front or facing side of the building



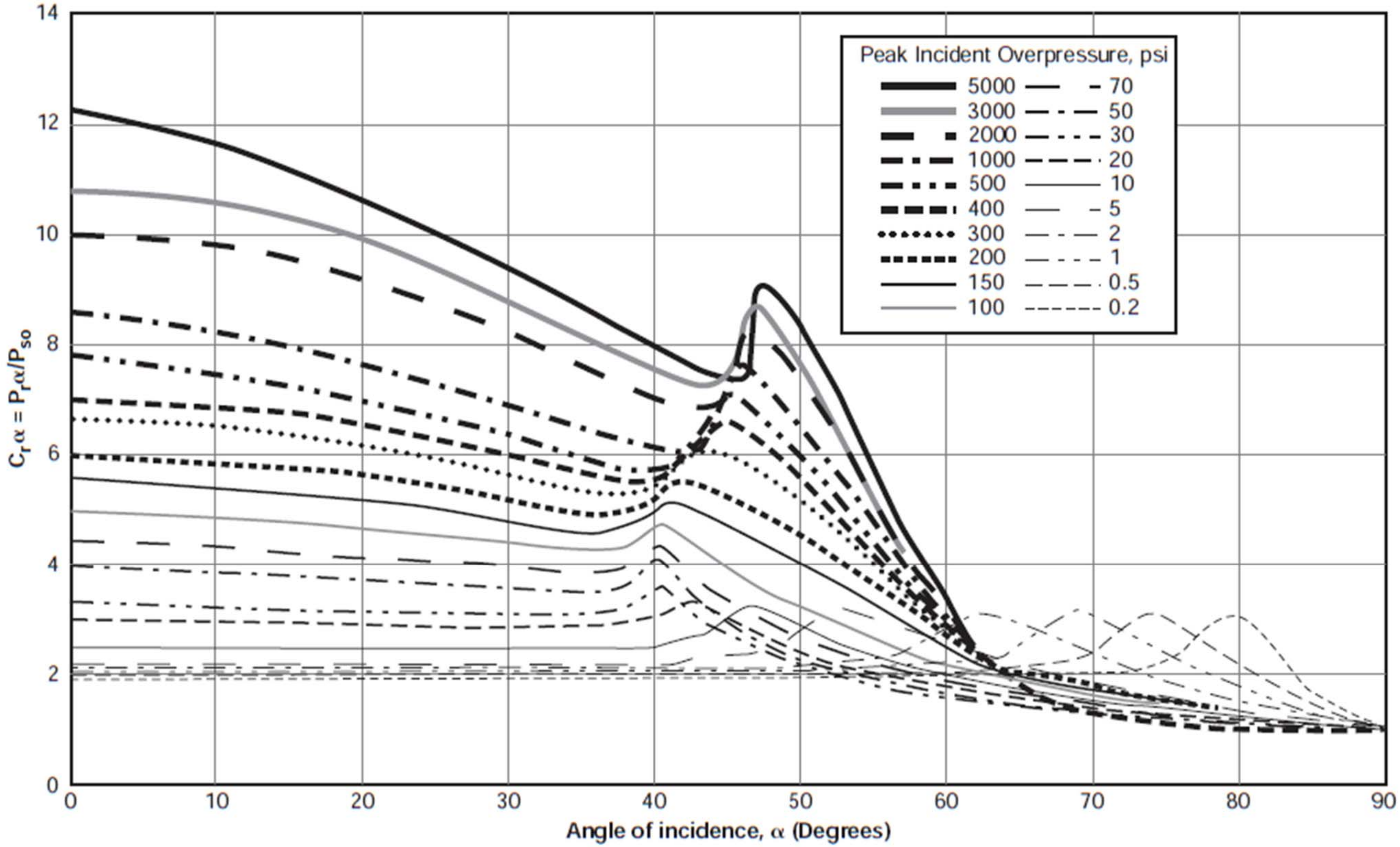
Blast Wave at Front Wall (TNO Green Book)



Example of rarefaction - a phase in a sound wave



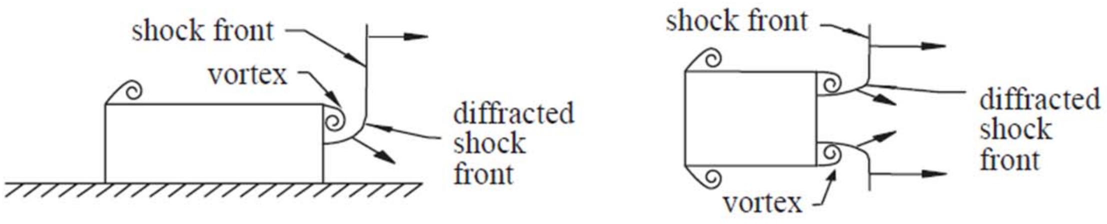
Peak Incident Pressure versus the Ratio of Normal Reflecte Pressure/ Incident Pressure for a Free-Air Burst (UFC 3-340-02)



Reflected pressure coefficient versus Angle of Incidence (UFC 3-340-02)

Side wall and roof loads

- Roofs and side walls represent surfaces that are parallel to the path of the advancing blast wave
- There is no reflection effect for this situation; however, the average pressure applicable to a specific area, for example a structural element depends on the length of the blast wave and the length of the structural element
- For the calculation of roof and side wall dynamic wind pressure, a drag coefficient C_d, determined from the table is used with the q_o value



Rear Wall (TNO Green Book)

Roof, Side Wall, and Rear Wall Drag Coefficient

Peak dynamic pressure	Drag coefficien
0–25 psi	–0.40
25–50 psi	–0.30
50–130 psi	–0.20

Rear wall

- The rear wall is the wall facing directly away from the blast source, as illustrated in figure below
- The calculation of rear wall blast loads is similar to that for the side walls or roof.
- For the calculation of rear wall dynamic wind pressure, a drag coefficient Cd is used with the q_o value

Roof, Side Wall, and Rear Wall Drag Coefficient

Peak dynamic pressure	Drag coefficien
0–25 psi	−0.40
25–50 psi	−0.30
50–130 psi	−0.20

This lecture was prepared for the 1st Edition of SUSCOS (2012/14) by Kang-Hai TAN, Nanyang Technological University, Singapore and ULg

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