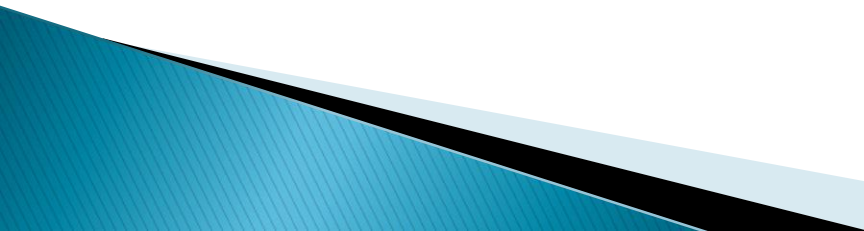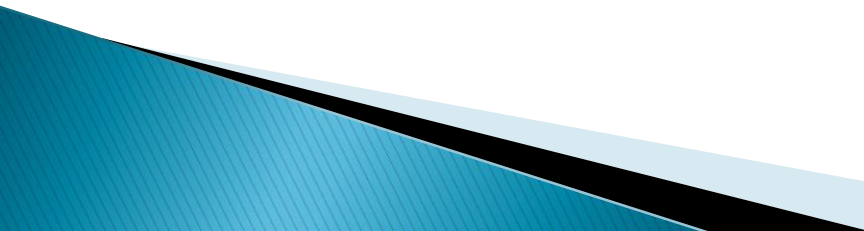# Calculation of Blast Loads

for Application to Structural Components

By
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Introduction

- The use of explosives by terrorist groups around the world that target civilian buildings and other structures is becoming a growing problem in modern societies.

- The problem of structural resistance under explosive loads has been under investigation for many years and has been well advanced in the military community. This is also the reason that the majority of these findings are not accessible to the public and are only restricted to military use.

- The Eurocode EN 1991-1-7 makes reference to the case of accidental loads and explosions, but it is mainly focused on impact actions, such as collisions from trucks, trains, ships, helicopters or any other vehicle in general.

- However, no guidelines are provided in EN 1991-1-7 for the calculation of external blast induced loads.

- Army Technical Manual 5-1300 [8]. This latter provides detailed information and procedures for the design of structures to resist the effects of explosions

- The development of a procedure that will give practical design solutions is essential for the design of new or the retrofitting of existing structures so as to be able to withstand the effects of explosive loads.

- The engineer needs to calculate the acting forces according to a certain blast scenario, which includes the type and weight of the used explosive, the distance from the structure and the geometry of the surrounding area and the structure itself.

- These forces should then be applied on the structural system at hand in order to design structural members, sections and connections that will ensure sufficient robustness of the building to survive the effects of the computed actions.

Ideal blast wave characteristics

❖ Explosion
- o Very fast chemical reaction (involving solid, dust, gas) during which a rapid release of hot gases and energy takes place
- o last for milliseconds
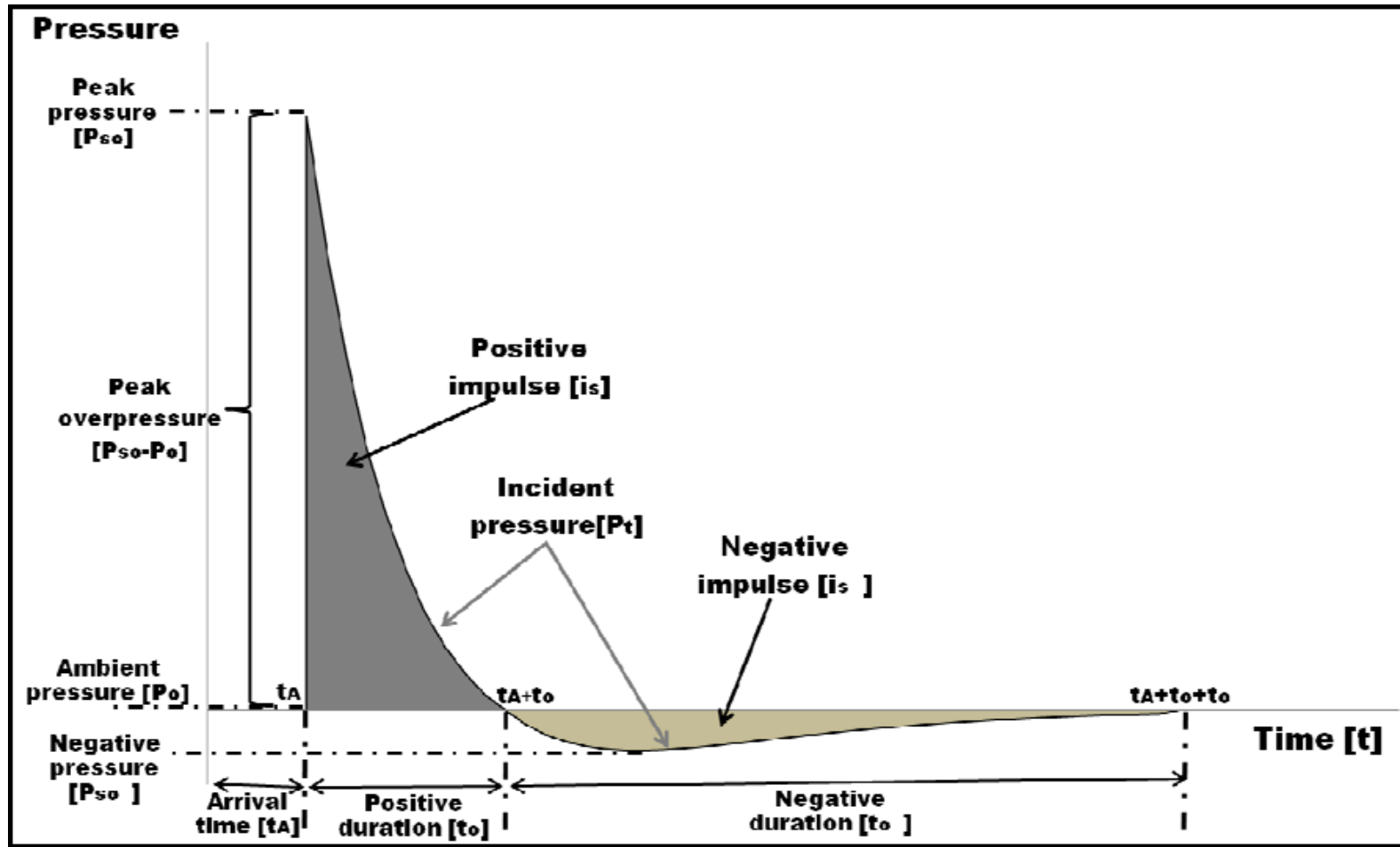- o Results in the production of high temperature and pressures

❖ Detonation process
- o Hot gases expands in order to occupy the available spaces
- o Leads to wave type propagation which is known as blast wave

❖ Blast waves
- o Contains large part of energy released during detonation and moves faster than speed

Ideal blast wave pressure – Time history

Design consideration

❖Negative phase of explosive wave not considered for design purpose

❖Because main structural damage is connected with positive phase

❖Since pressure produced in negative phase is smaller than the pressure produced in positive phase

❖Positive incident pressure is calculated from Friedlander's equation

❖For design purpose another important parameter of the blast wave is its impulse – Total force appiled on the structure

Scaling laws

❖Critical parameters for blast loading computations is the distance of the detonation point from the structure of interest

❖The peak pressure value and velocity of the blast wave decrease rapidly by increasing the distance between the blast source and the target surface

Influence of distance on the blast positive pressure phase
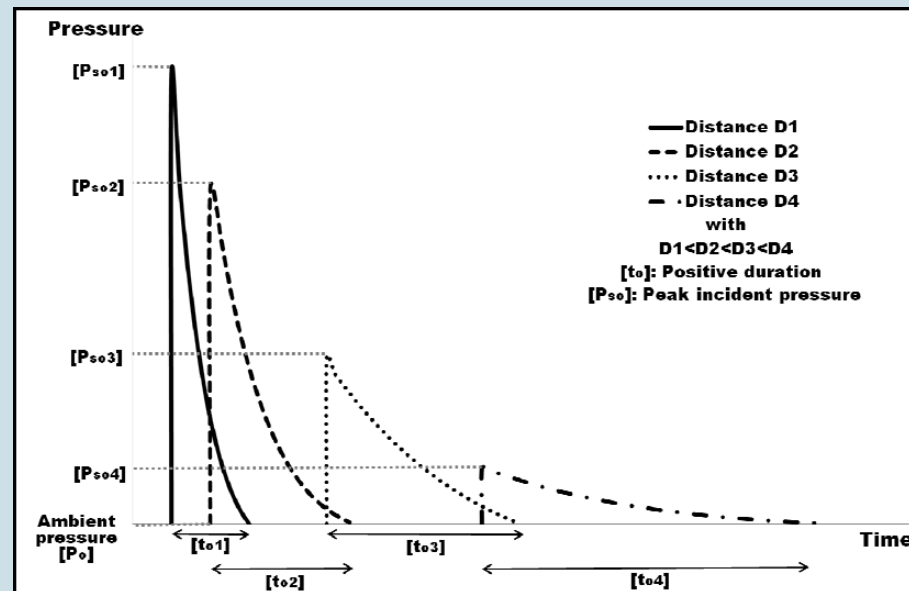
Scaling laws

❖The effect of distance on the blast characteristics can be taken into account by the introduction of scaling laws.

❖These laws have the ability to scale parameters, which were defined through experiments

❖The most common blast scaling laws are the ones introduced by Hopkinson-Cranz , $Z= R/\sqrt[3]{W}$

It states that

-During the detonation of two charges of the same explosive that have similar geometry but different weight and are situated at the same scaled distance from a target surface

-Similar blast waves are produced at the point of interest as long as they are under the same atmospheric conditions.

Explosive type and weight

First step in designing a building to sustain blast loading

➢Definition of the type and weight of the explosive for which the design will be performed.

➢In the majority of the cases solid explosives will be used in improvised explosive devices (IED)
  o Easy to transport,
  o Easy manufacturing
  o Possibility of placement in vehicles

Explosive type and weight

❖ The wide variety of explosives has led to the adoption of a universal quantity, which is used for all necessary computations of blast parameters.

❖ TNT (Trinitrotoluene) was chosen as its blast characteristics resemble those of most solid type explosives.

❖ An equivalent TNT weight is computed according to Equation
   $W_e = W_{exp} \; H_{exp} / H_e$ (MJ/kg)

❖ $1/3^{rd}$ of total chemical energy of the explosive is released by detonation Rest is released at a slower rate as heat of combustion through burning of the explosive products mix with the surrounding air

Explosion and blasting load type

Non-contact, unconfined explosions, external to a structure are considered in this report
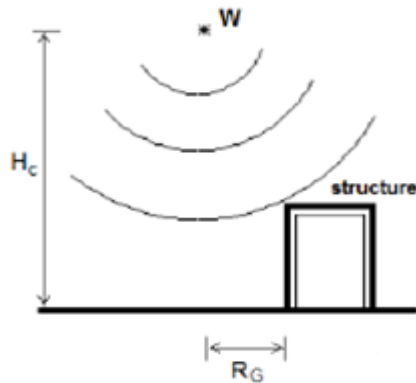
It is distinguished into three basic types,

❖Free-air bursts
❖Air bursts
❖Surface bursts

That depends on the,
  o Relative position of the explosive source and the structure to be protected Height H* above ground where the detonation of a charge W occurs
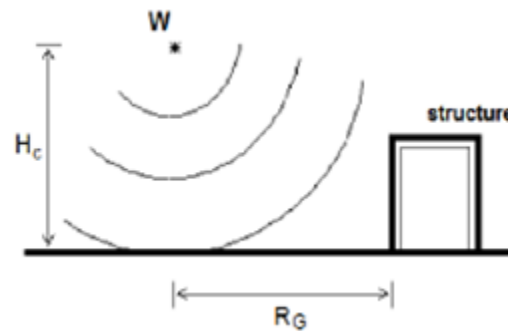 o Horizontal distance RG between the projection of the explosive to the ground and the structure.

| Free-air bursts	Air bursts	Surface bursts
❖Explosive charge is detonated in the air ❖Blast waves propagate spherically outwards ❖Impinge directly onto the structure without interacting with other obstacles or the ground.	❖Explosive charge is detonated in the air ❖Blast waves propagate spherically outwards ❖Impinge first with the Ground , Mach wave front is created.	❖Explosive charge is detonated almost at ground surface ❖propagate hemisphericaly Outwards ❖Interact with ground locally, impinge onto the structure.
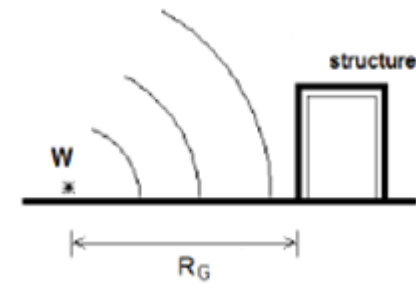
Blast wave reflection

❖The interaction between an object and a blast wave generates a pressure pattern

❖The load that has to be withstood by a structure depends on various parameters such as,
  o Type and weight of the explosive charge
  o Distance of the detonation point
  o Structure's geometry and type
  o Interaction of the wave with the environment and the ground

❖When the blast wave comes to contact with a rigid surface the pressure that is reflected is larger than the incident peak pressure P_{so}

**Three types of reflection can take place ,
depending on the angle of the reflecting surface with the propagation
direction of the blast wave.**

| ❖ 1st case Normal reflection	❖Severe case in terms of loading values ❖when a surface is perpendicular to the direction of the wave, during which normal reflection occurs
❖ 2nd case Oblique reflection	❖When the propagation direction of the wave intersects at a small oblique angle with the surface it causes the creation of an oblique reflection
❖ 3rd case Mach stem creation	❖Whereas the third case is linked to a phenomenon known as Mach stem creation ❖It occurs whenever the wave impinges on a surface at a specific angle

❖In all cases the reflected pressure is always greater than the incident pressure.
❖reflected pressure can be several times higher than 8 times the incident pressure
❖Reflected pressure's value decreases as the angle of incidence α increases

Mach stem creation over a horizontal (ground) surface and loading of a vertical surface
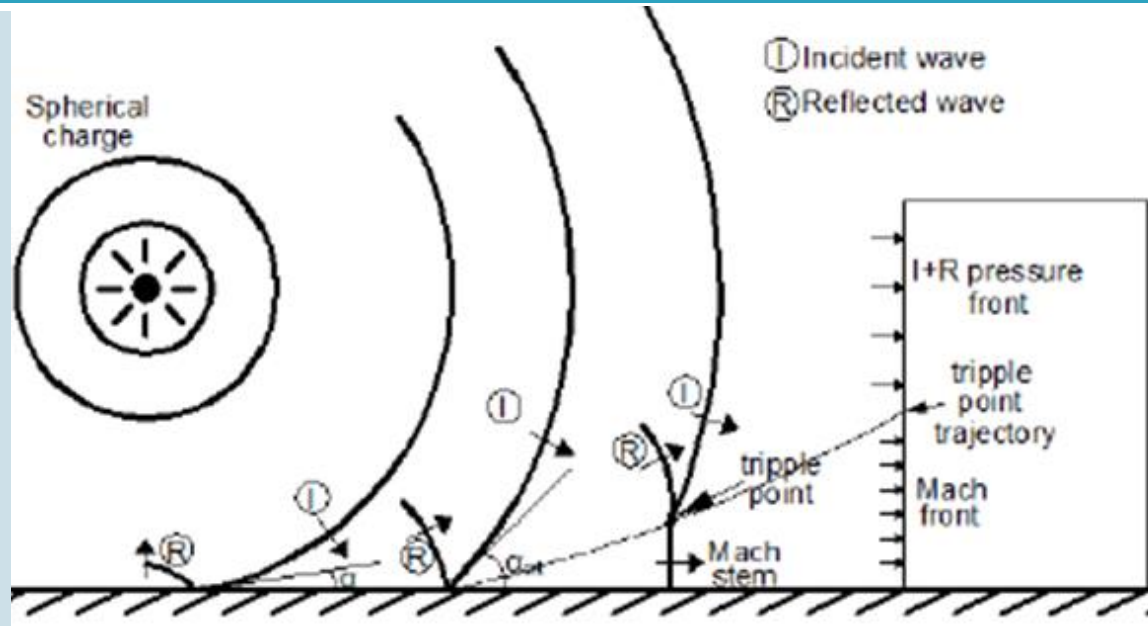
❖For shallow incident angle 40'
❖Incident wave is ahead of reflected wave
❖Typical reflection occurs

❖For larger angles 40'-55'
❖Coalescence between reflected and incident wave takes place creating mach front
❖The point of intersection of the incident, reflected and Mach waves is known as the triple point

❖The distance of the detonation point from the ground is lesser than distance from the structure
❖Mach stem is created

❑ Calculation of structural blast loads

Blast pressure determination is based on computation of,
❖Scaled distance
❖Explosive mass
❖Actual distance from the center of spherical explosion

❑ Calculation of pressure loads on building surface

Blast wave and structural interaction: A structure subjected to an external explosion will eventually be engulfed by the blast wave and normal forces will be applied to its exposed surfaces.	Response of a structure under explosion loading depends on ➢shape of the structure ➢Relative location of the blast from structure ➢Geometry of the area between the structure and the detonation point ➢natural period of the structure
Structural response is calculated without considering the interaction between the blast pressure loading and the deforming structure.	➢Pressure on the front wall ➢Pressure on the roof and the side walls ➢Pressure on the rear wall

❑ Combination rules

The load combinations that have to be applied for a building designed for an accidental action, such as blast loading, are included in Eurocode EN-1990 [14].

Pressure on the front wall

▸ First surface that will be loaded from the blast wave is the building's front façade

▸ In TM5-1300 a procedure is proposed for the calculation of the load that has to be sustained by the front face, but an assumption is made that the loaded face is within the region of the Mach stem

Definition of the total impulse applied to the front face of the building , Calculation of Pr at time tA
The pressure at the front face starts decreasing as the wave moves past the surface surrounding the rest of the structure within the clearing time tC

❖ At time tA+tC the pressure at the front surface will be substantially dropped (but still remaining higher than the initial ambient pressure)	❖ After time tA+tC the pressure is the result of the combined effect of the incident and the dynamic pressure and is provided by Equation

❖Pressure ,P = Ps + CD q
where, Ps is the incident pressure, CD is the drag coefficient,
taken equal to CD =1 for the front wall, and q is the dynamic pressure.

❖Clearing time
Tc = 4S / (1+R)Cr
S is the smallest of the surface's height H or half width W/2
Cr is the sound velocity in the reflected medium,
R is the ratio of S/G, where G is the largest of the surface's height H

Pressure on the roof and the side walls

- The front face of a structure is loaded first as a consequence of a direct blast wave that impinges on it

- As the wave propagates it surrounds the structure causing pressure rises at the roof, the side faces and the back surface

- If the side walls and the roof of the structure are parallel to the direction of the blast wave, they experience peak side-on overpressures that are equal to the incident pressure

> ❖ **Usually these details are neglected in the design and a uniform, time-varying equivalent pressure is applied, whose peak value *PR is given by,***

> ❖ Pr = CE + Psof + CD qsof

where,
- o Psof is the incident pressure at point f of the front edge of the roof,
- o CE is the equivalent load factor,
- o CD is the drag coefficient and
- o qof is the dynamic pressure corresponding to Psof.

Pressure on the rear wall

- The rear wall of the structure is the last surface that is loaded
- Loading condition is same as previous condition

❑ Combination rules

❖ The load combinations that have to be applied for a building designed for an accidental action, such as blast loading, are included in Eurocode EN-1990
- Self-weight of the structure should be included
- Live and the snow load, if applicable
- The wind and seismic loads may be neglected
- Internal explosions that could be produced from a gas leakage are considered as a
- random effect in time.

❖ On the other hand, a terrorist attack is not strictly random, since it is not based on climate or random conditions, but could be the outcome of human planning.

❖ For this reason the designer should consider the probability of having to increase the safety factors proposed by the Eurocode

❖ Consider individual requirements such as,
- expected occupancy at the time of the attack
- Type and use of the building etc.

❖ The general formula for the accidental combination

$$E_d = G + A_d + Q_{k1} + Q_{ki}$$

where,
G is the self-weight of the structure,
A_d is the design value of the accidental action (in this case the blast load),
$Q_{k,1}$ is the characteristic value of the leading variable action and
$Q_{k,i}$ are the characteristic value of the accompanying variable actions

Summary of the blast loads calculation

An explosion scenario is agreed based on

- Definition of charge weight and detonation distance
- Parameters are considered for each loaded section
- Construction of idealized triangular pressure diagram for front , side , rear wall and roof
- Load combination