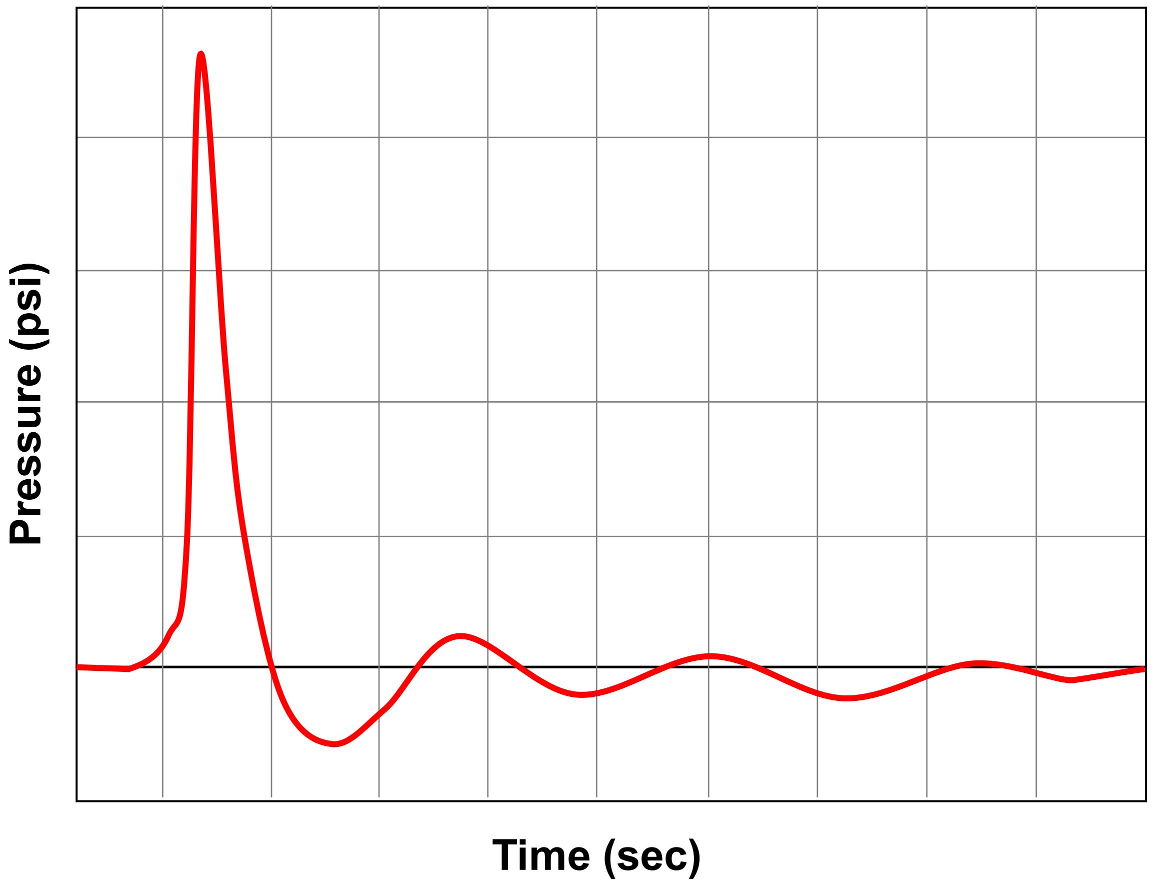
Effect of Explosion Pressure Time Waveforms on Built-in-place Refuge Alternative Stopping/Door Response



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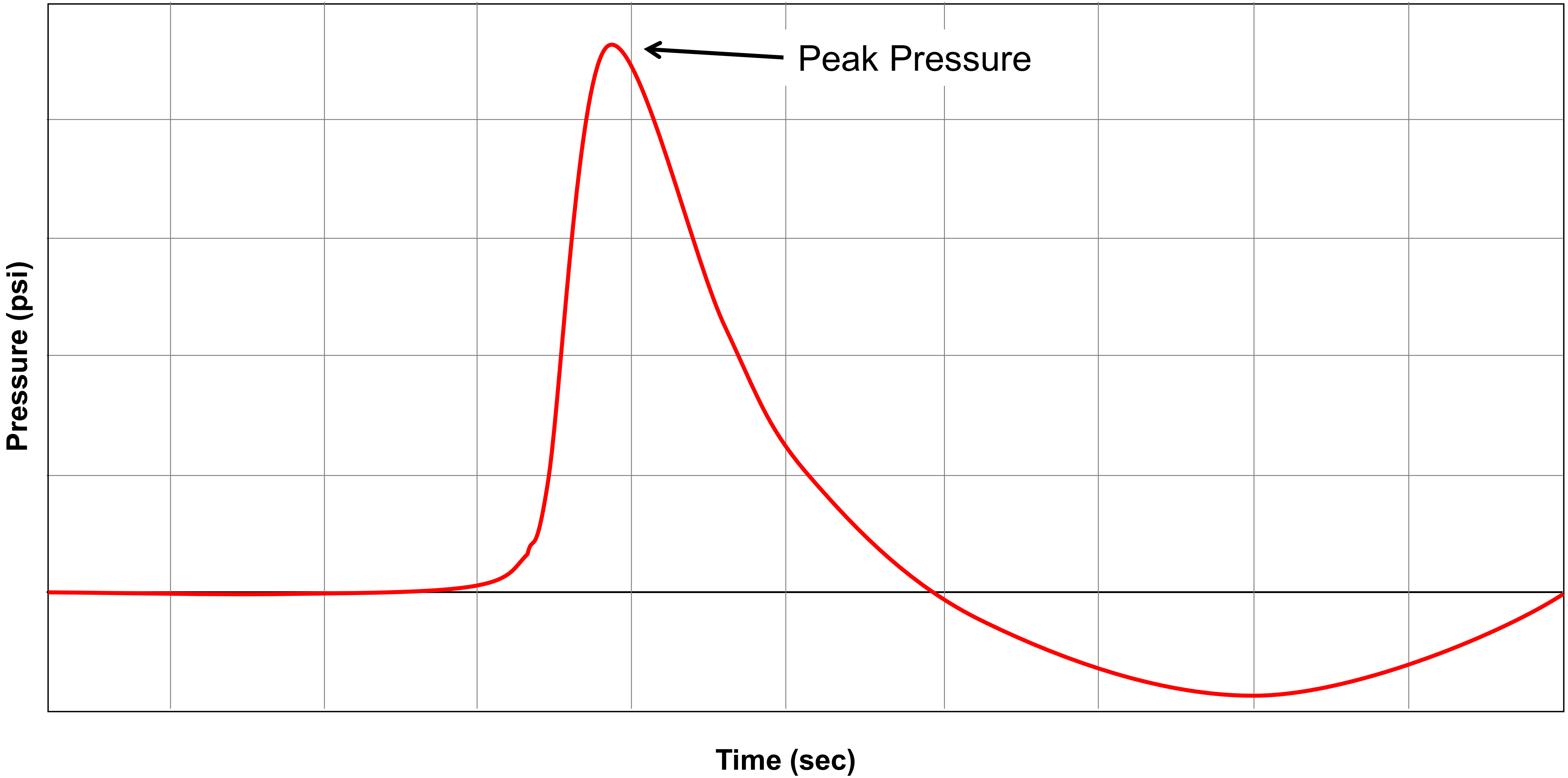
A blast pressure time history can be characterized by its *peak pressure*, rise time, and duration.



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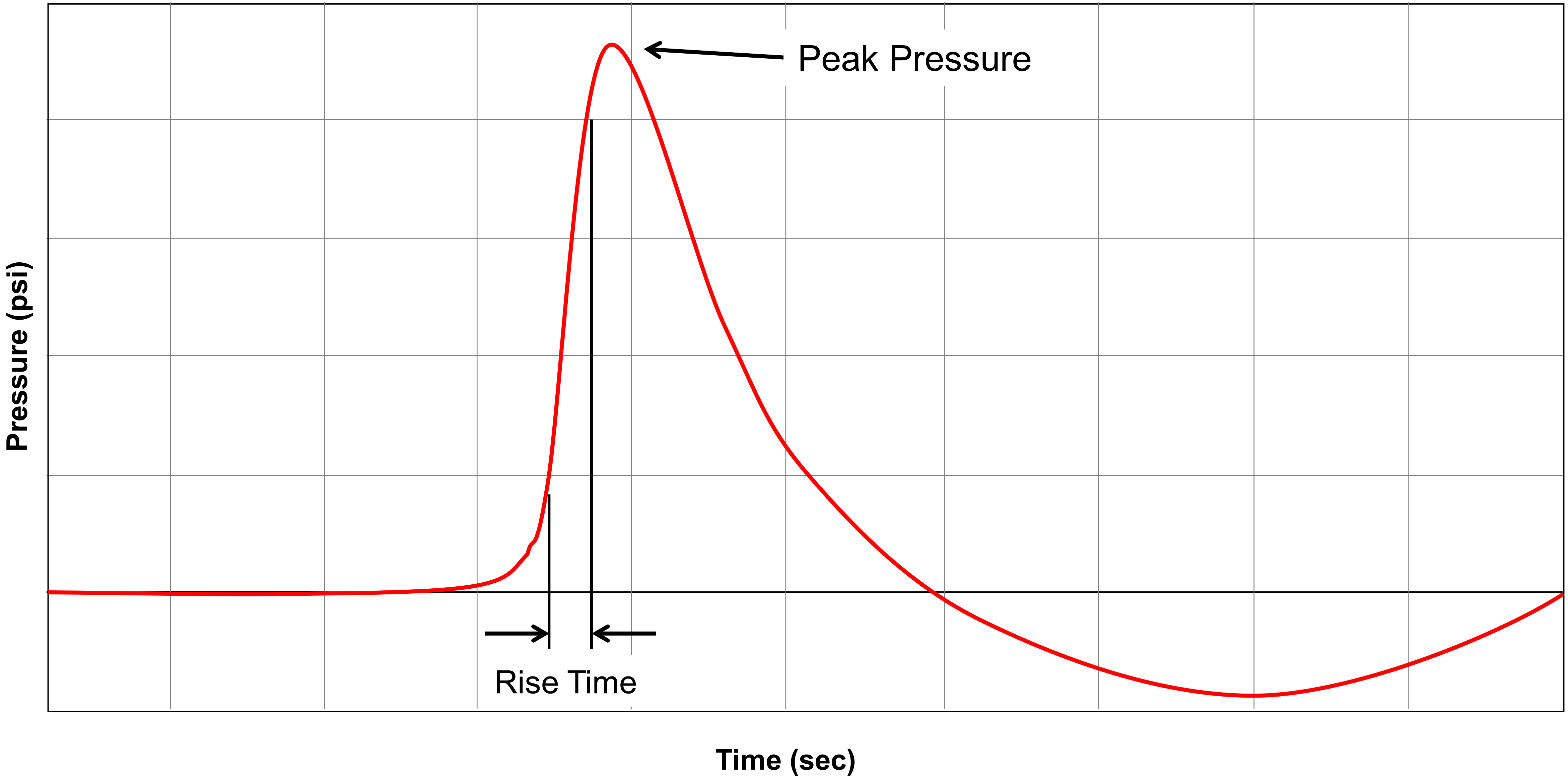

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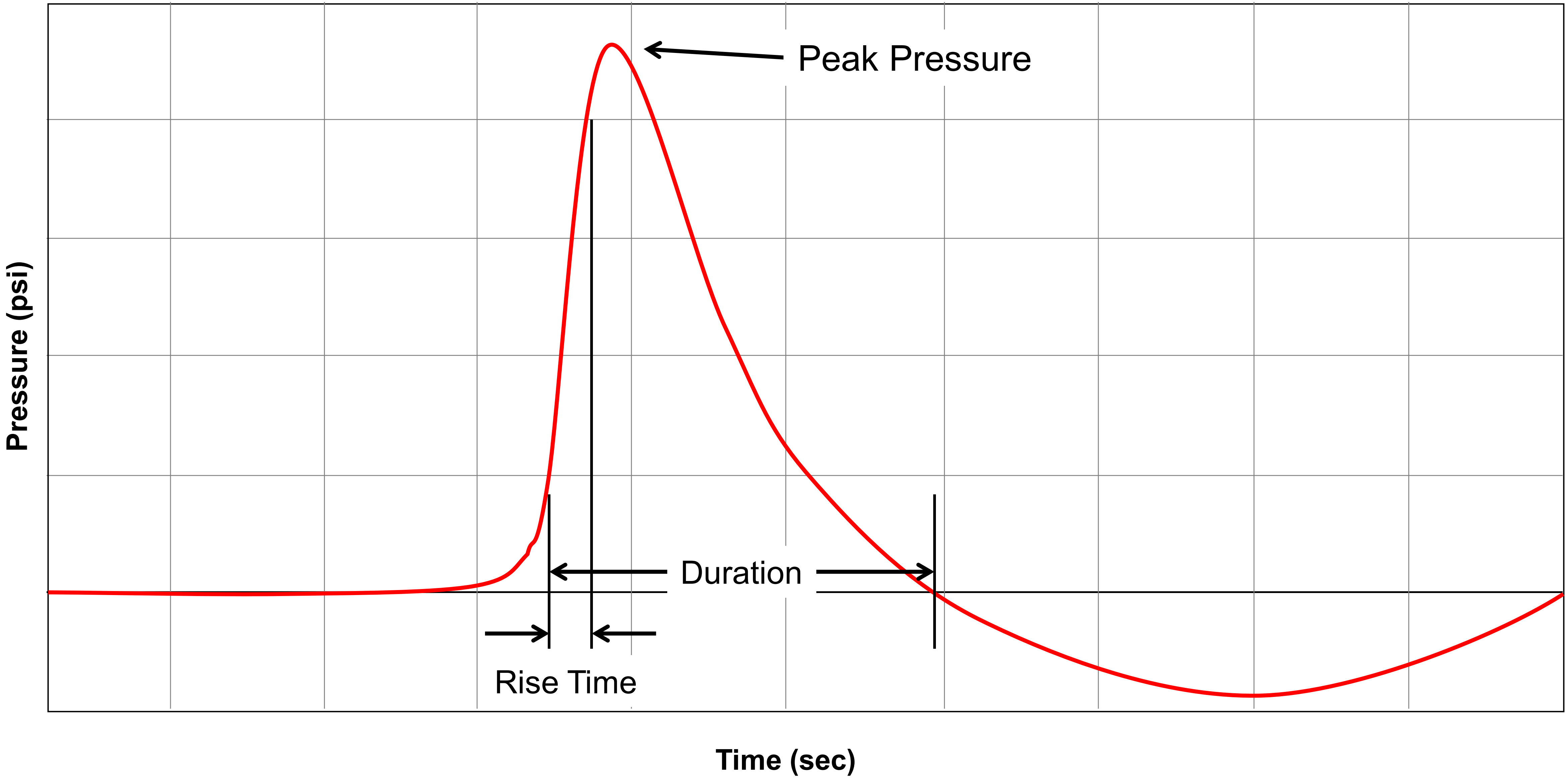
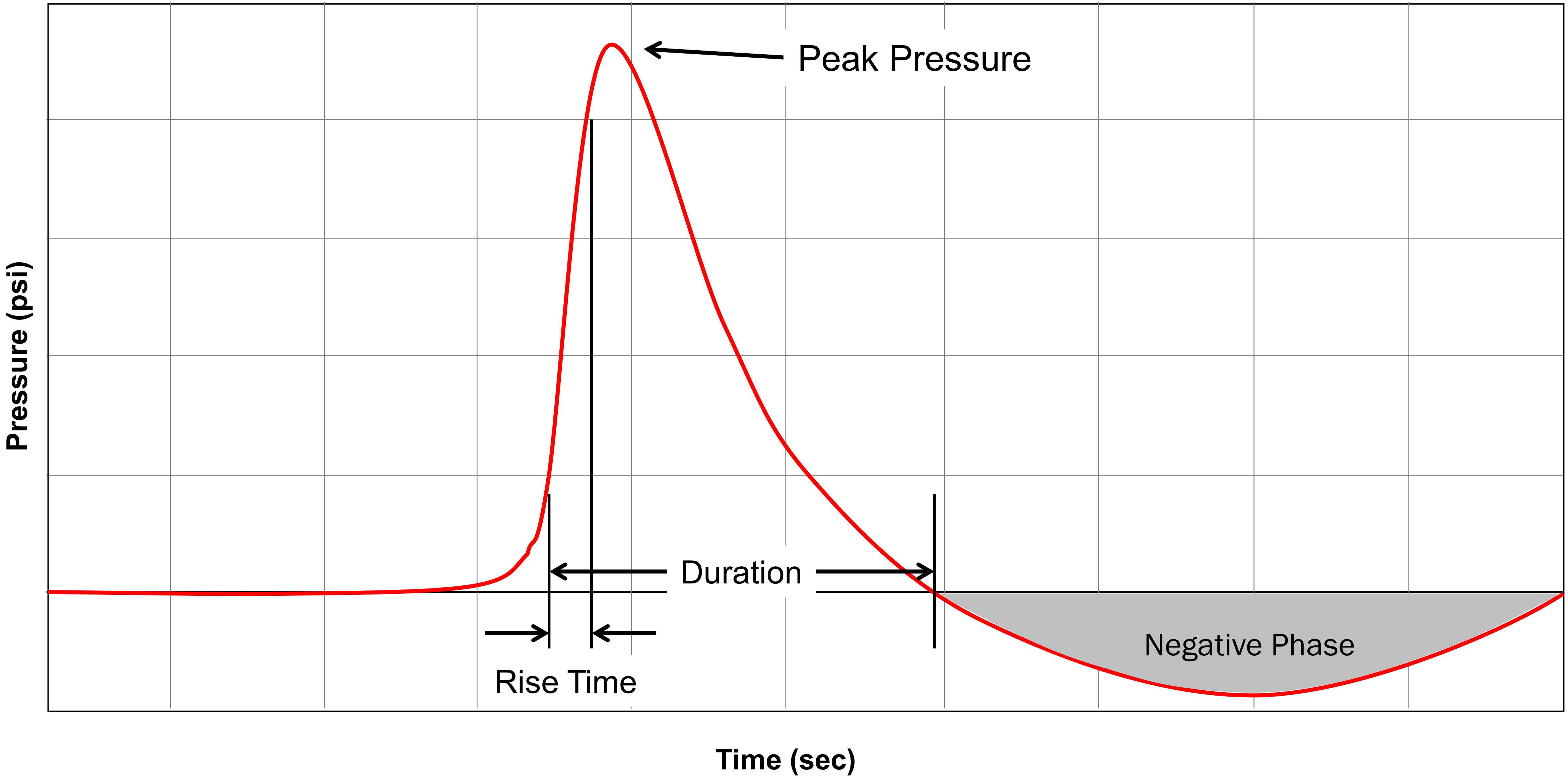
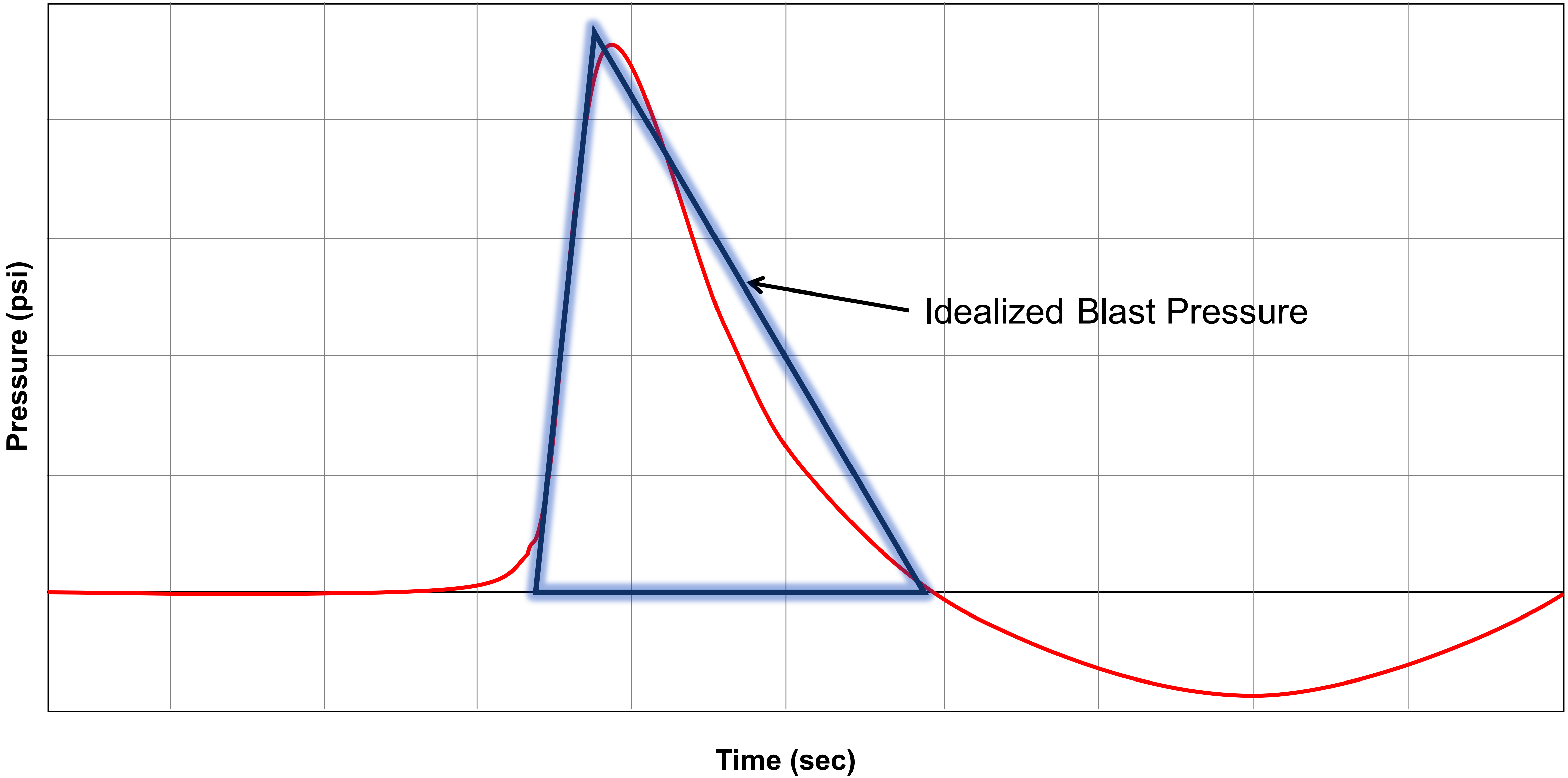


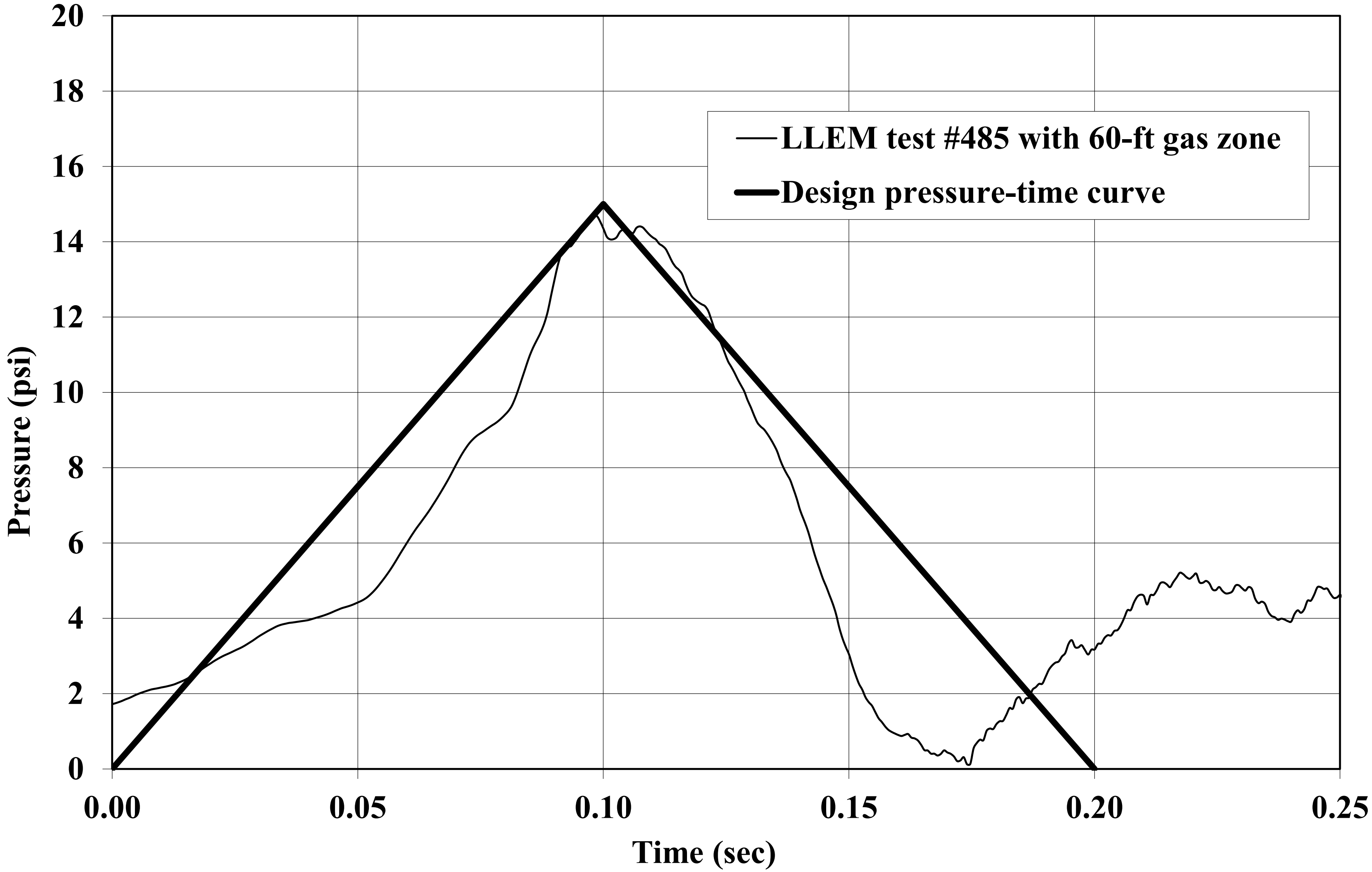
A blast pressure wave may exhibit a *negative phase* that can be important with respect to damage caused by a blast.



A blast pressure time history can be idealized to simplify analysis.



Regulations require RAs to survive an idealized isosceles-triangle-shaped blast pressure with a 15-psi peak pressure and a 0.2-sec duration.

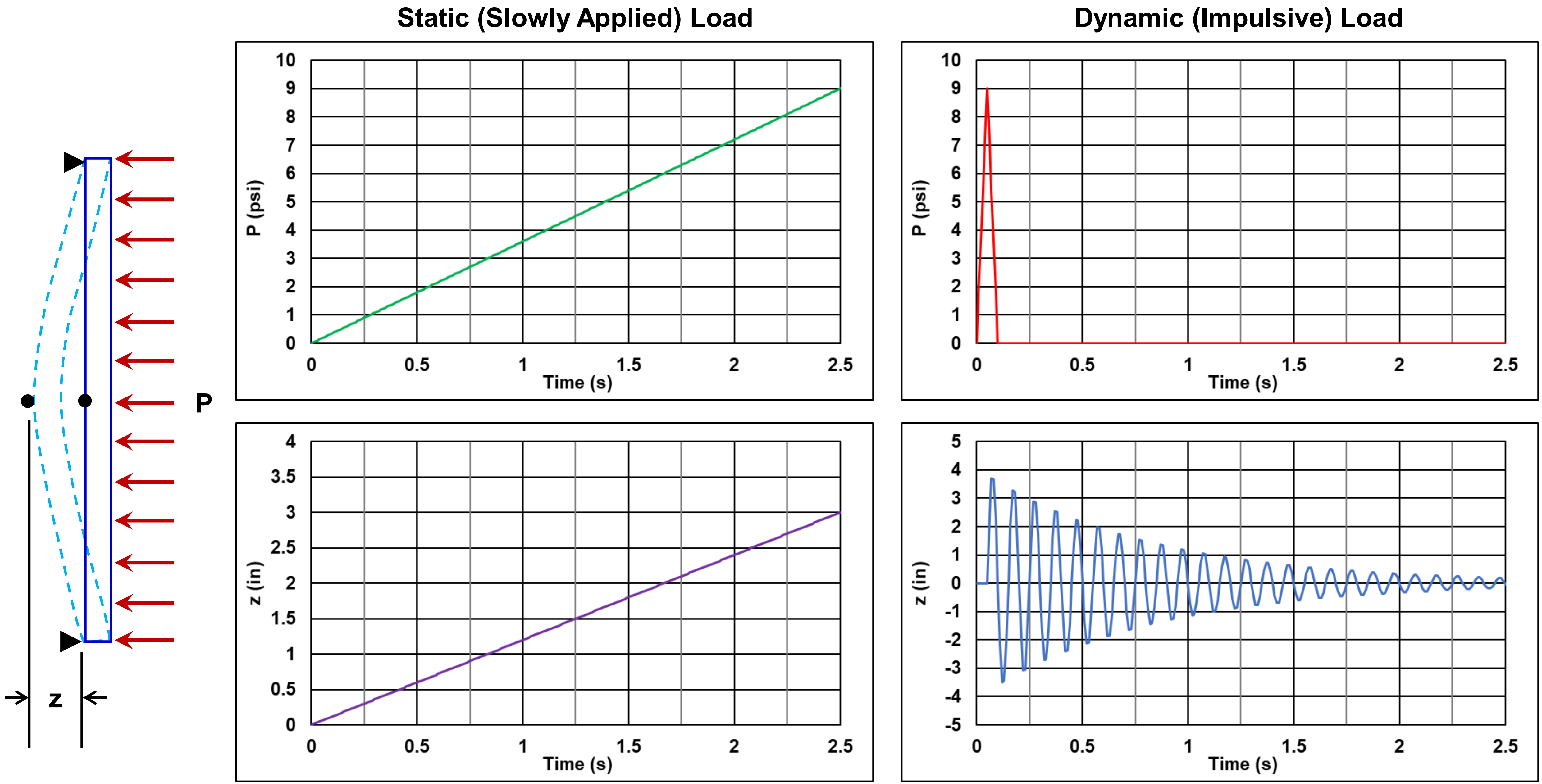


The 15-psi peak pressure is based on blast survivability information from military sources.

Peak Overpressure	Maximum Wind Speed	Effect on Structures	Effect on the Human Body
6.9 kPa (1 psi)	61 kph (38 mph)	Window glass shatters.	Light injuries from fragments occur.
13.8 kPa (2 psi)	113 kph (70 mph)	Moderate damage to houses occurs (windows & doors blown out, severe roof damage).	People are injured by flying glass and debris.
20.7 kPa (3 psi)	164 kph (102 mph)	Residential structures collapse.	Serious injuries are common, fatalities may occur.
34.5 kPa (5 psi)	262 kph (163 mph)	Most bldgs collapse.	Injuries are universal, fatalities are widespread.
68.9 kPa (10 psi)	473 kph (294 mph)	Reinforced concrete bldgs are severely damaged or demolished.	Most people are killed.
137.9 kPa (20 psi)	807 kph (502 mph)	Heavily built concrete bldgs are severely damaged or demolished.	Fatalities approach 100%.

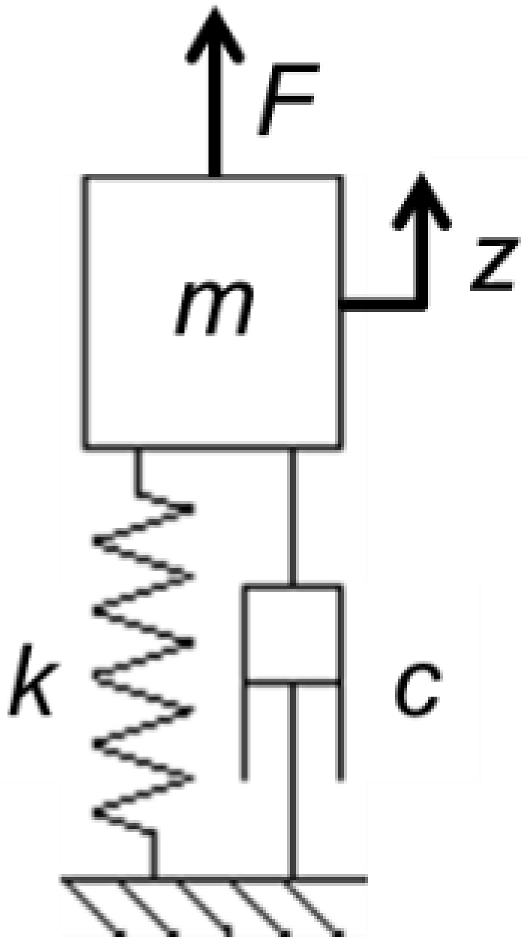
Zipf, R.K., Cashdollar, K.L., “Effects of blast pressure on structures and the human body”, NIOSH accessed 9/14/2018.
https://www.cdc.gov/niosh/docket/archive/pdfs/NIOSH-125/125-ExplosionsandRefugeChambers.pdf

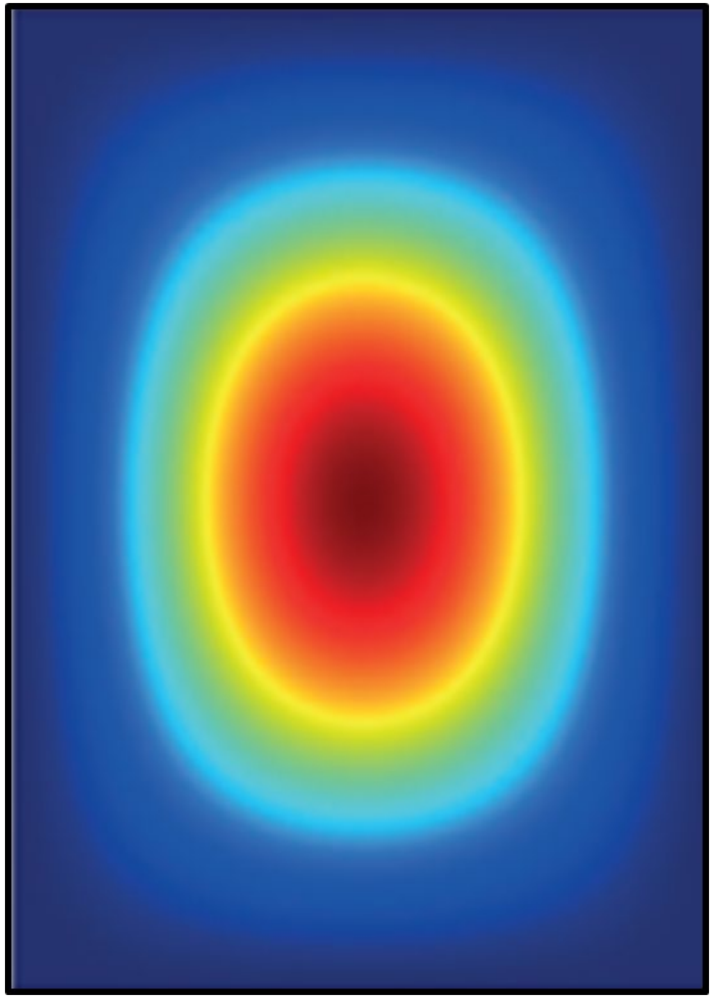
Structural response to a dynamic load, such as a blast, is oscillatory.



To simplify blast response analysis, a single-degree-of-freedom (SDOF) analysis is sometimes used.

- The structure's fundamental vibration mode is used to determine an equivalent mass and stiffness
- An *equivalent mass* is defined based on the "dynamic mass" of the structure's fundamental mode
- An *equivalent stiffness* is defined based on the "dynamic stiffness" of the structure's fundamental mode
- The response of the equivalent SDOF system can be calculated to determine the response



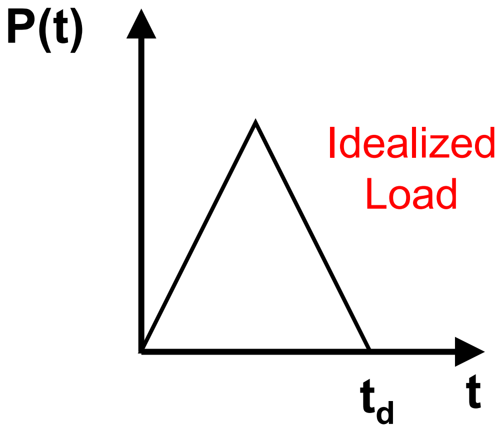


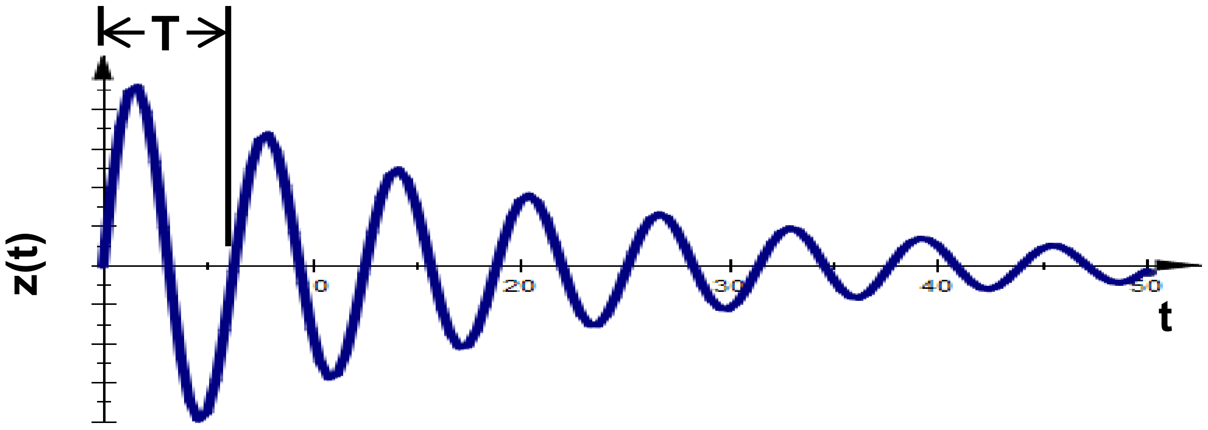
To further simplify the blast response analysis, the concept of dynamic load factor (DLF) can be used.

- The *DLF* is defined as the ratio of the dynamic response to a dynamic load divided by the static response to a static load of the same magnitude

$$DLF = \frac{z_{dynamic}}{z_{static}}$$

- The *DLF* can be used to scale the load applied in a static test or analysis to determine the equivalent maximum dynamic response to a dynamic load of the same magnitude
- The *DLF* depends on the ratio of the blast duration *(t_d)* to the natural period of the structure *(T)*

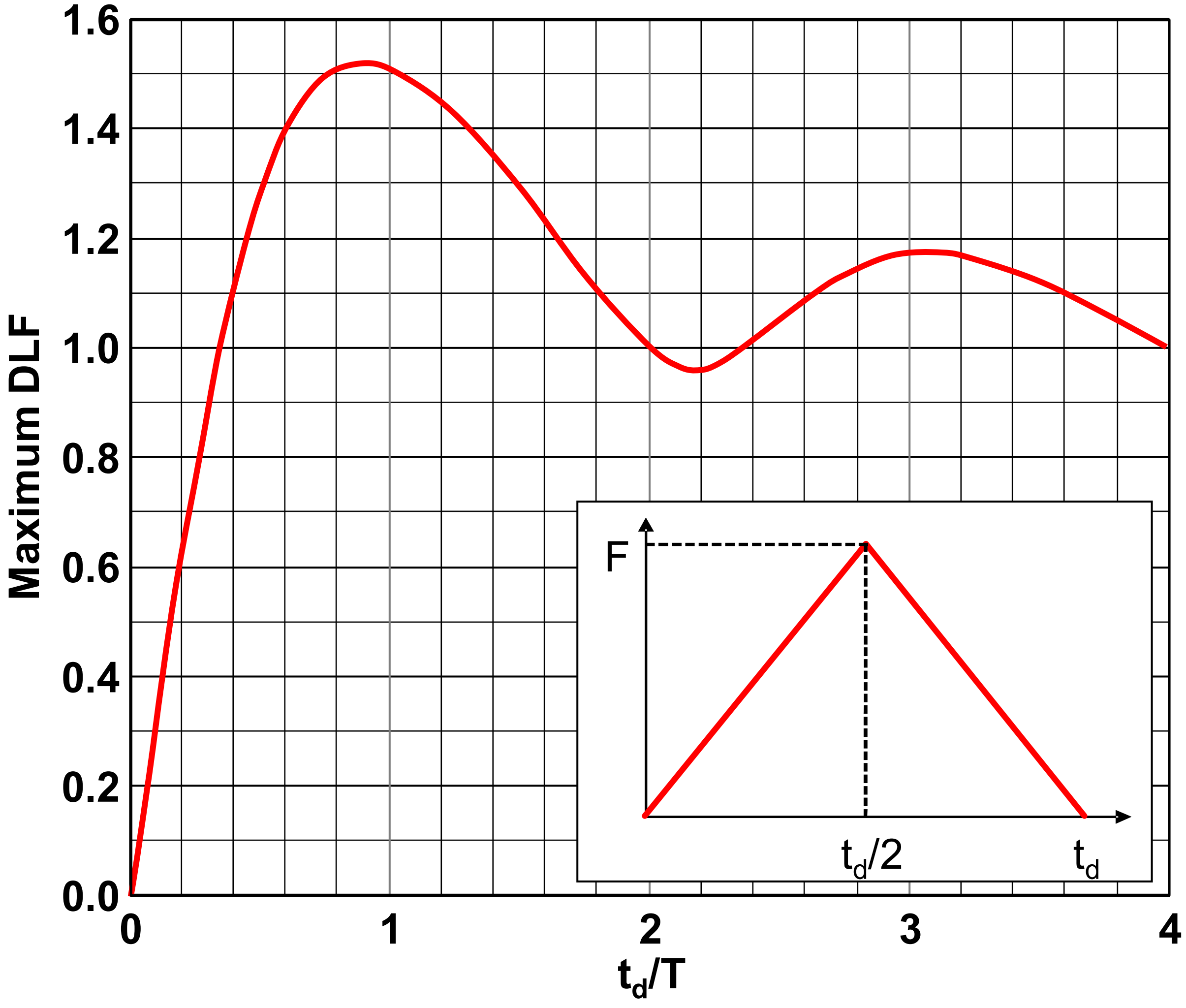




Biggs, J.M. (1964). *Introduction to Structural Dynamics.* New York, NY: McGraw-Hill Book Company.

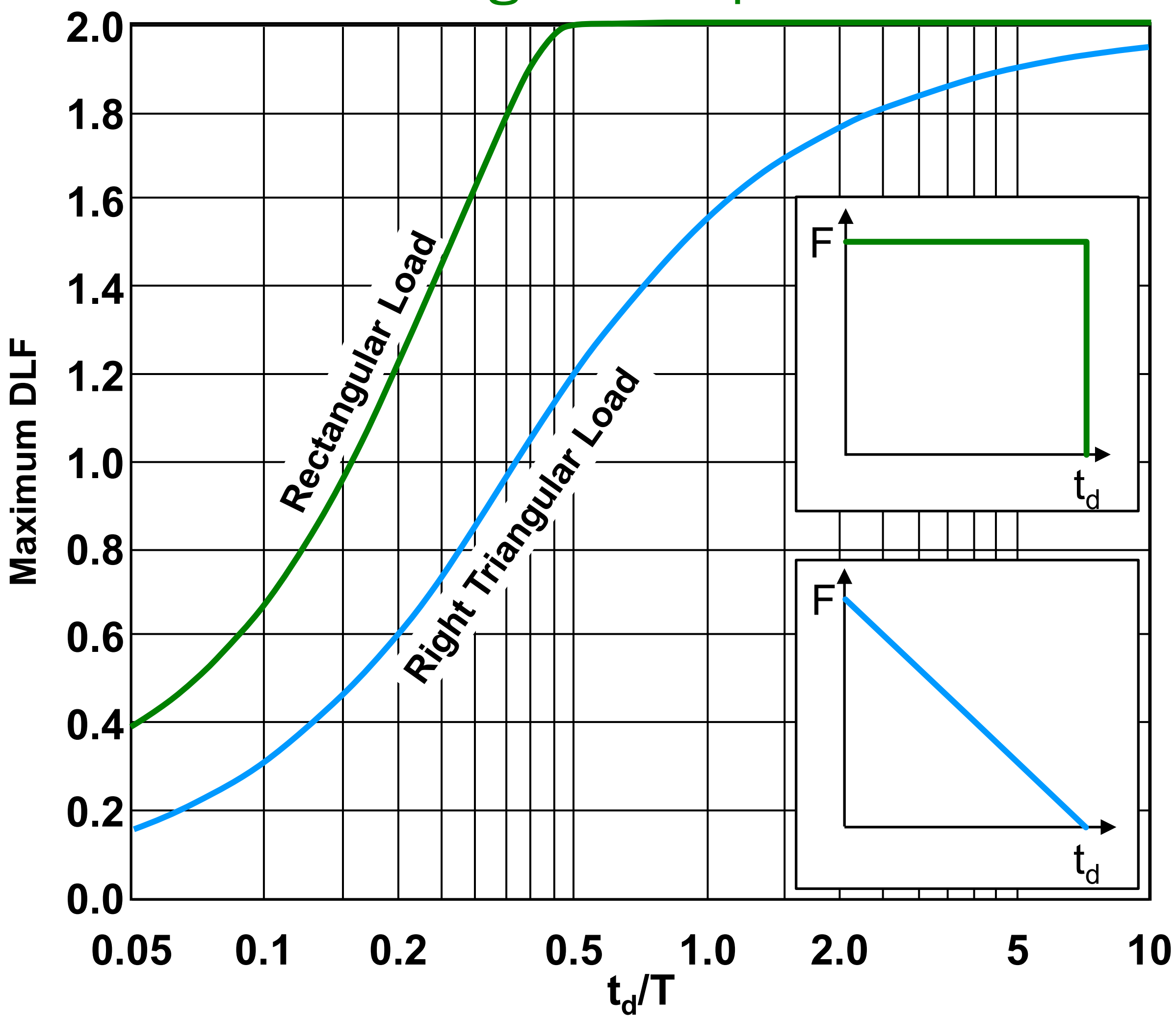
The DLF depends on the shape of the idealized blast pressure time history.

Isosceles-triangle-shaped Blast



Right-triangle-shaped Blast

Rectangular-shaped Blast



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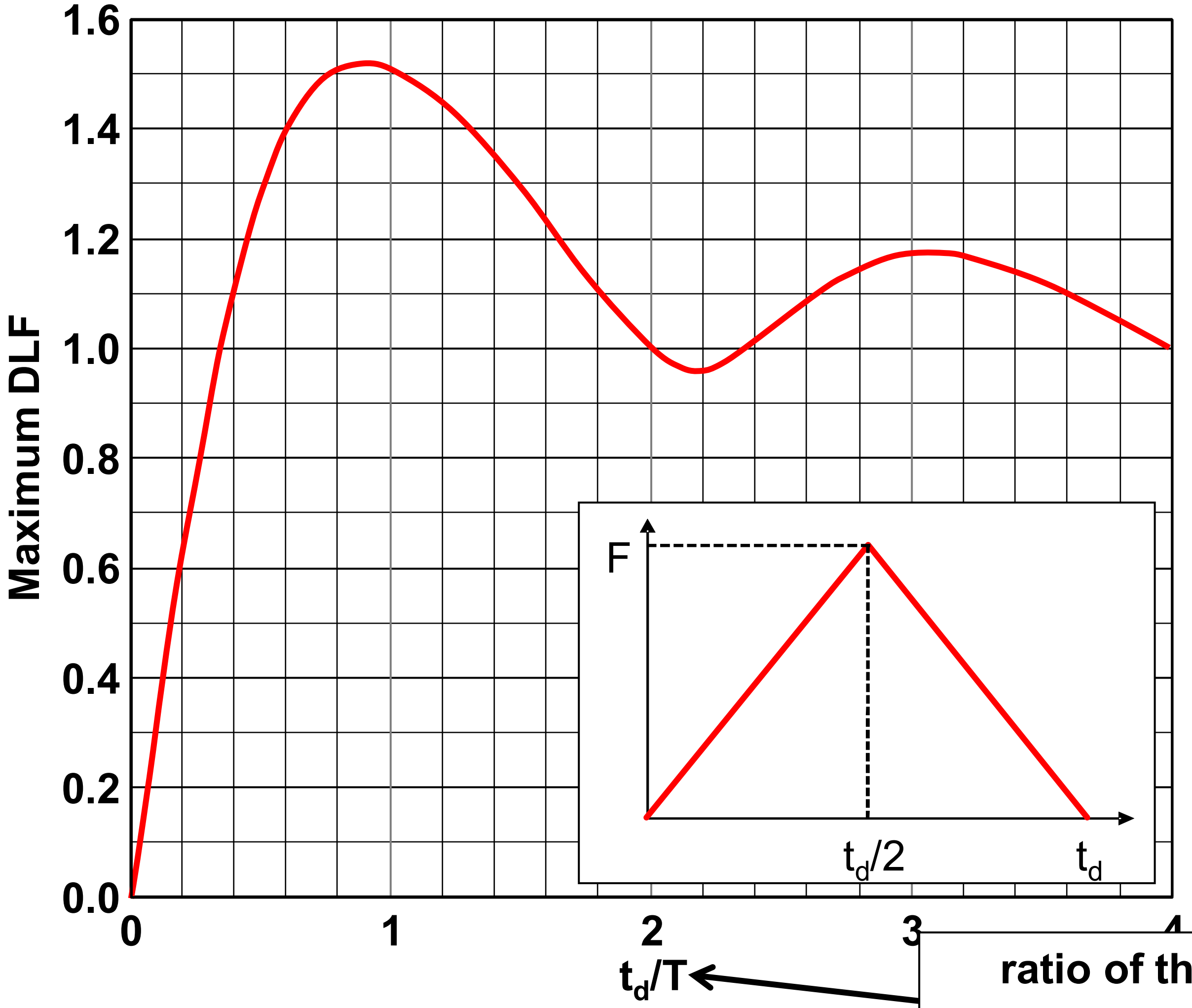

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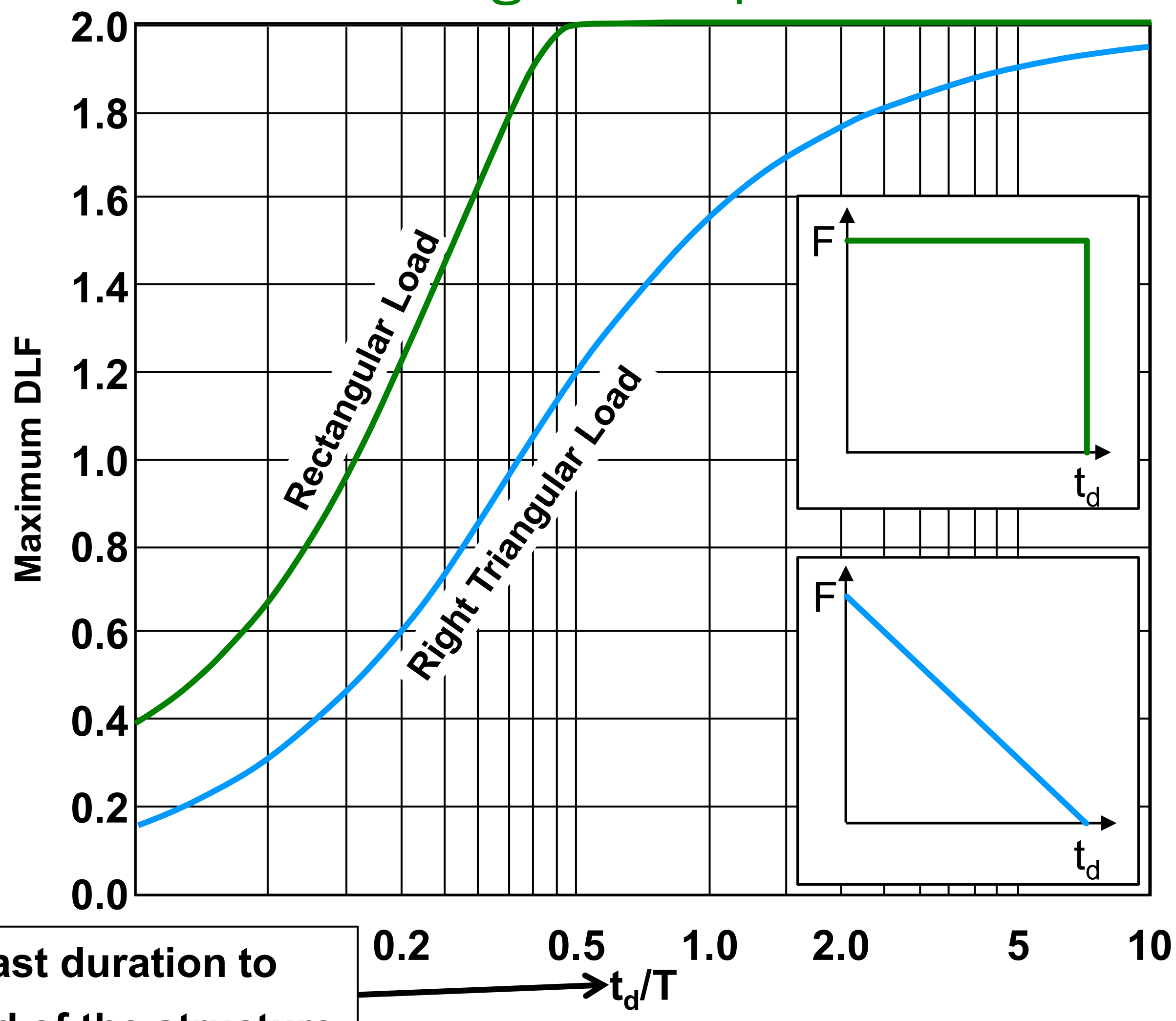
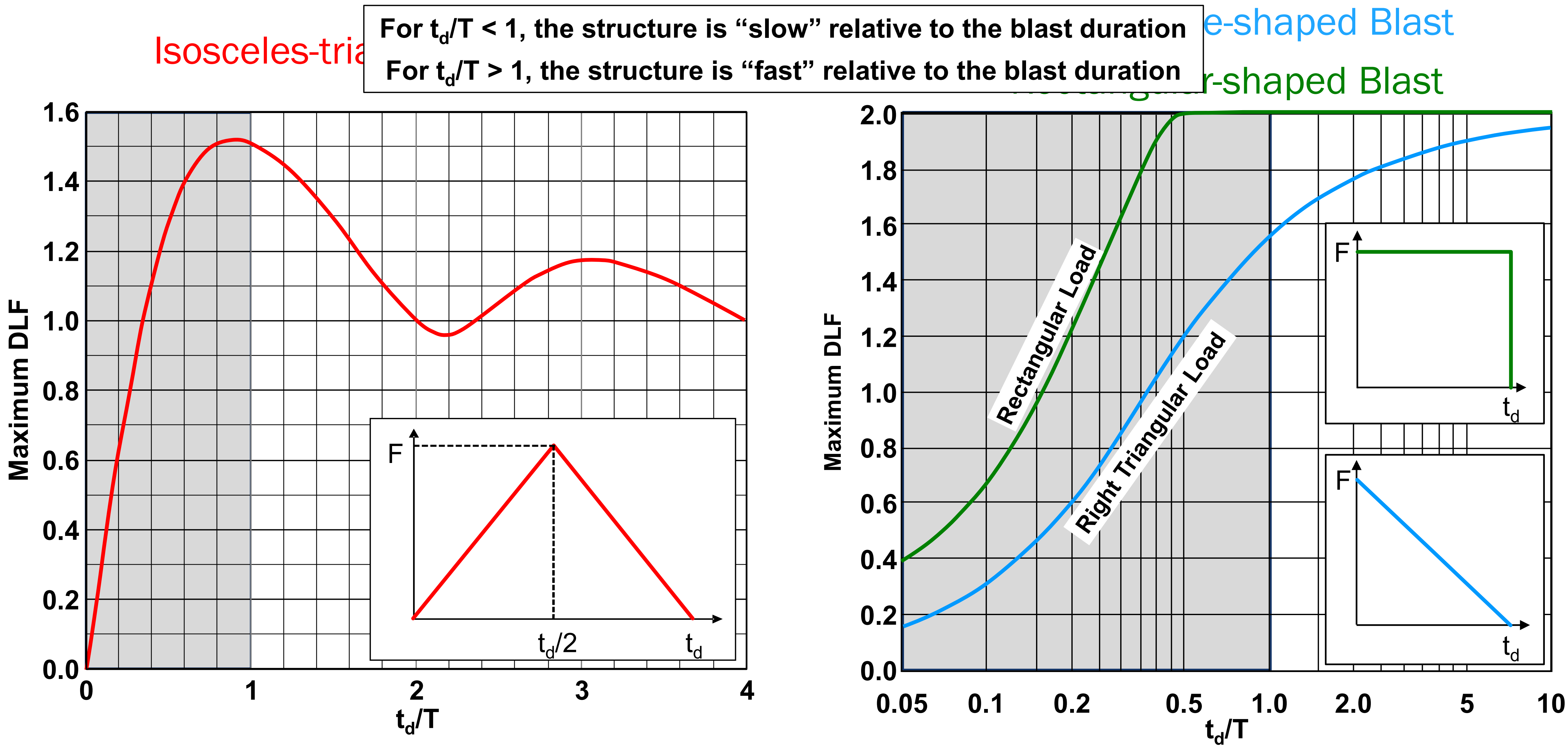


ratio of the blast duration to the natural period of the structure

Biggs, J.M. (1964). *Introducti* … aw-Hill Book Company.

The DLF depends on the shape of the idealized blast pressure time history.

For $t_d/T < 1$, the structure is "slow" relative to the blast duration
For $t_d/T > 1$, the structure is "fast" relative to the blast duration



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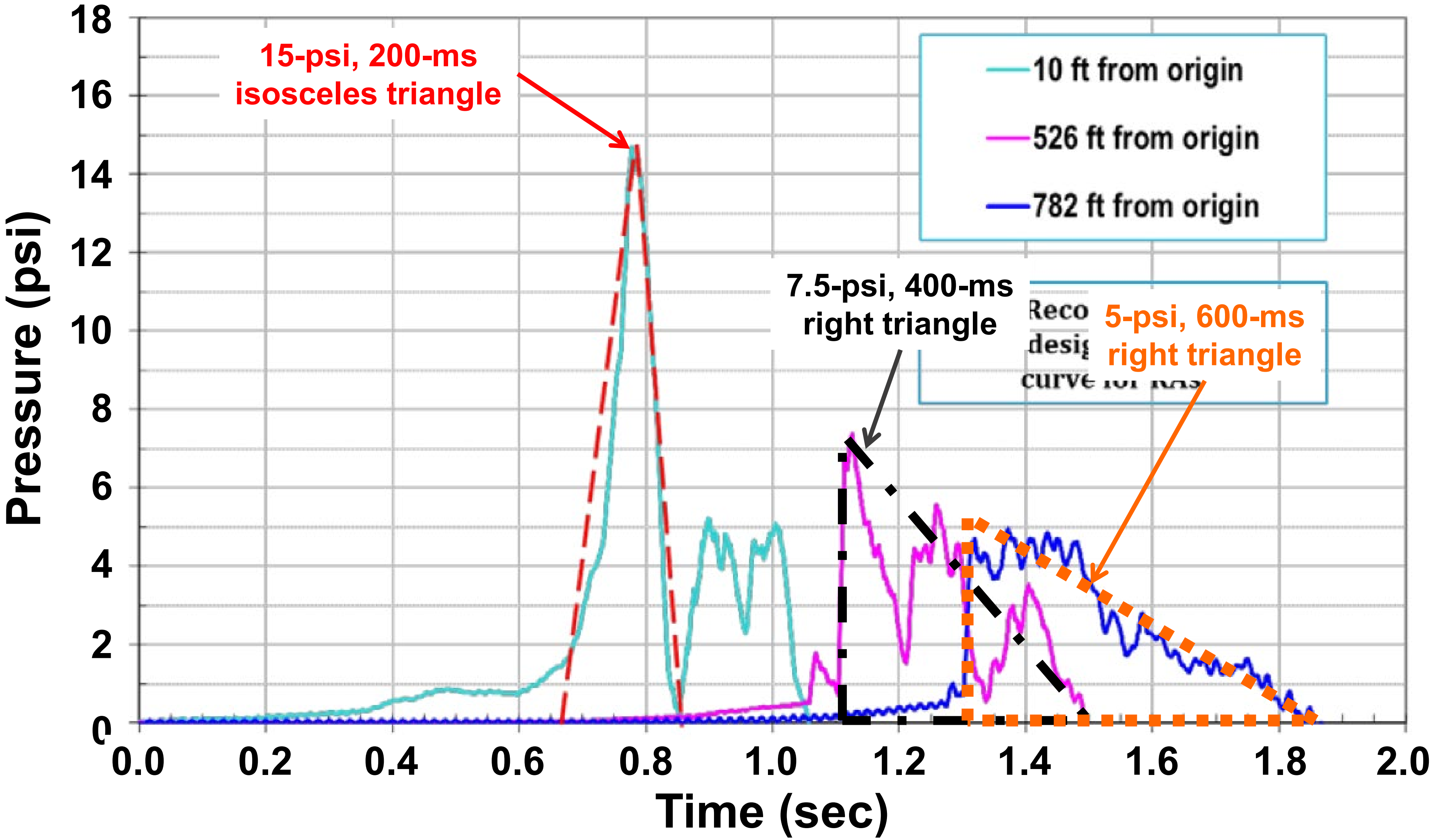
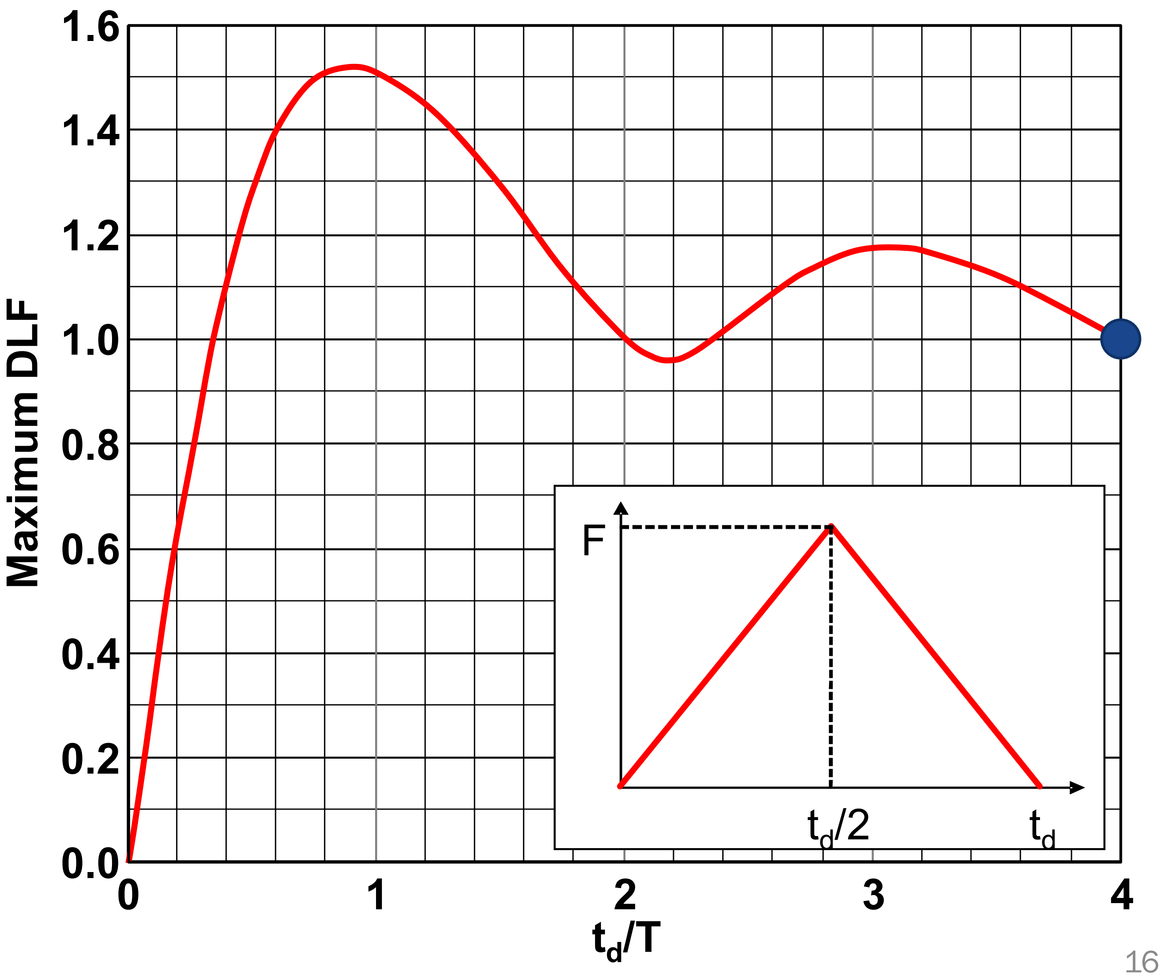
The blast pressure near an RA may have a different peak pressure, rise time, duration, and shape than the isosceles-triangle-shaped design pressure.



From RI 9698: Facilitating the Use of Built-in-place Refuge Alternatives in Mines

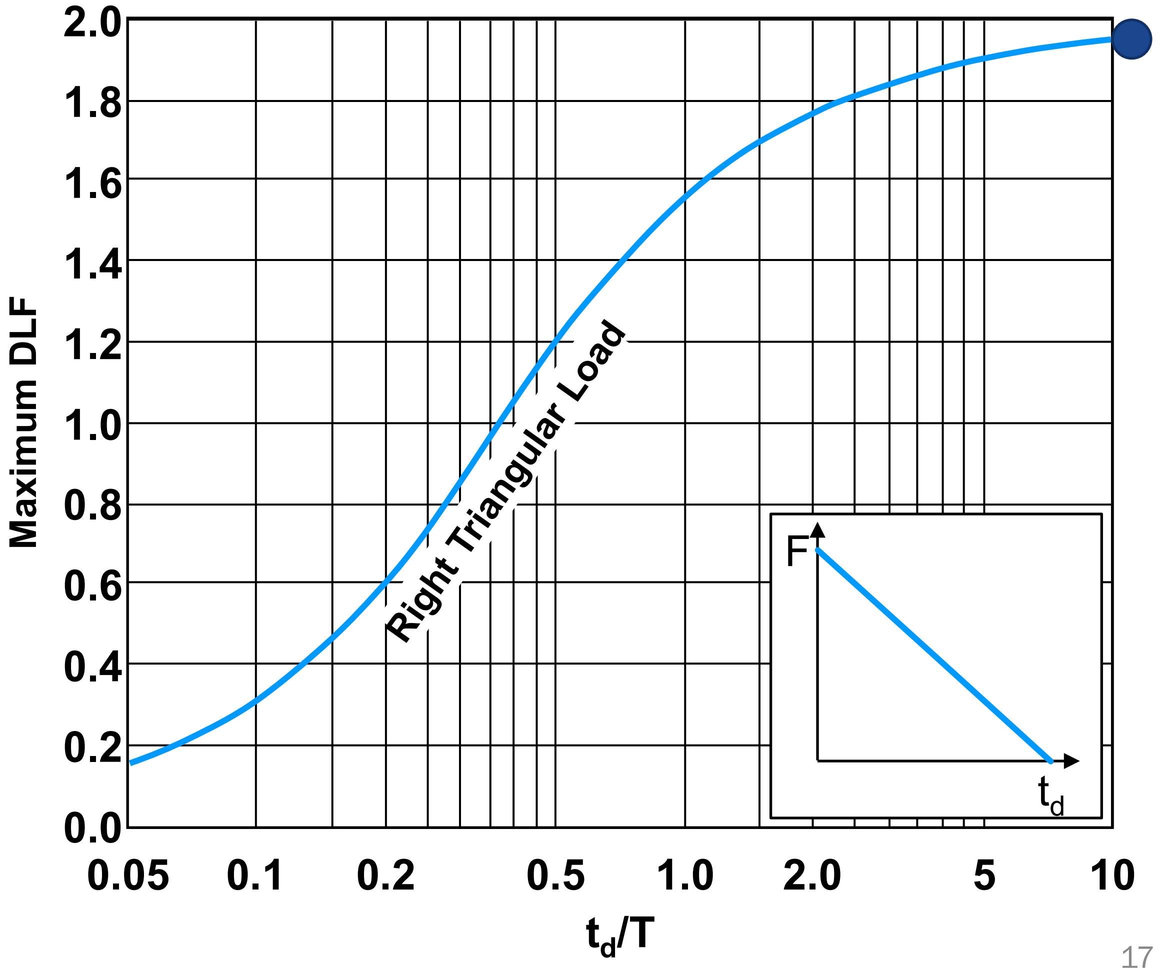
The DLF and scaled static load for the *isosceles-triangle-shaped blast load*, and the two right-triangle-shaped blast loads will be different.

- Assume a structure with a natural frequency of 20 Hz (T = 1/20 = 0.05 sec)
- Case 1: Isosceles triangle (design P) w/ 15-psi peak & 0.2-sec duration
  - $t_d/T = 0.2/0.05 = 4$
  - Max DLF = 1
  - Scaled static load = 1 x 15 psi = 15 psi



The DLF and scaled static load for the isosceles-triangle-shaped blast load, and the two *right-triangle-shaped blast loads* will be different.

- Assume a structure with a natural frequency of 20 Hz (T of 0.05 sec)
- Case 2: Right triangle w/ 15-psi peak & 0.6-sec duration
  - $t_d/T = 0.6/0.05 = 12$
  - Max DLF = 2
  - Scaled static load = 2 x 15 psi = 30 psi



Summary

- The blast pressure applied to an RA may exhibit different characteristics than the idealized 15-psi peak pressure, 200 ms isosceles-triangle-shaped pressure from the RA regulations
- The negative phase of a blast wave should be considered in structural design
- The concept of dynamic load factor (DLF) can be used to scale the blast pressure to enable the use of static analyses or test methods
- The DLF should be determined based on the idealized blast wave shape and duration, and the natural period of the structure

Questions?

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