TNT-Blast-Equivalence for Bursting of Pressurized-Gas Conventional Vessels

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Abstract

A simple procedure is given for roughly simulating the positive phase of a blast wave arising from the sudden rupture of a conventional pressurized-gas vessel. The procedure differs somewhat from the usual TNT-energy-equivalence method. It is based on equating a bursting-gas-vessel blast to that of a high explosive charge of energy higher than the stored gas energy, and detonating farther away than the vessel considered. In conjunction with blast damage curves or formulas known from military technology, the present method can be used in roughly and quickly assessing the damage hazards that are due to a hypothetical vessel burst, or in designing protective structures. It can also be used in performing model-scale tests on structures that are potentially subject to blast loads.

1. Introduction

It has been demonstrated elsewhere [1, 2] that a bursting pressurized-gas vessel with stored pressure energy

$$E_B = \frac{p_1 V_1}{\gamma_1 - 1} \cdot \left[1 - (p_1/p_o)^{(1-\gamma_1)/\gamma_1} \right] \tag{1}$$

produces at some distance R the same pressure impulse $J = \int_0^{t^*} p.dt$ as that of an explosive charge of equivalent energy

$$E_x = e_x . G = E_B \tag{2}$$

detonating at the same distance R (e_x is the explosive's heat of explosion per unit mass, G is its mass). This has been known as TNT-equivalence and should, more precisely, be termed "TNT-energy-equivalence".

In many instances, however, it is desirable to simulate a blast wave that has not only the same impulse but also the same peak pressure as a certain bursting-pressure-vessel blast wave: such an equivalence might be termed a "TNT-blast-equivalence".

2. Peak Blast Pressure From a Bursting Gas Vessel

Knowing the volume V_1, pressure p_1, sound velocity a_1, and adiabatic exponent γ_1 of a gas contained in a vessel, the initial shock pressure p_{so} arising when the vessel bursts in an ambient atmosphere (with p_o, a_o, and γ_o) can be calculated from the so-called shock-tube equation:

$$p_{so} = p_1 \cdot \left[1 - \frac{(\gamma_1 - 1)(a_o/a_1)(p_{so}/p_o - 1)}{\sqrt{2\gamma_o} \cdot \sqrt{2\gamma_o + (\gamma_o + 1)(p_{so}/p_o - 1)}} \right]^{2\gamma_1/(\gamma_1 - 1)} \tag{3}$$

For what follows we assume that the vessel burst is an instantaneous vanishing of the vessel wall, so that the gas can expand immediately and spherically to all directions. By means of a computer program, Baker et al. [2] have calculated a set of curves for the variation of the incident shock overpressure p_B^* with distance R in the expansion of spherical gas volumes. We have reduced these curves to an approximate formula:

$$p_B^* = A . exp\left[-(4 + 0.01.A) . \sqrt{\bar{R}} \right] + 0.1 \tag{4}$$

for $A \leq 350$ bar and $\bar{R} \leq 2$, where

$$A = 8 p_{so}^* (p_o/p_1)^{(\gamma_1 - 1)/2\gamma_1} \tag{5}$$

(with $p_{so}^* = p_{so} - p_o$), and $\bar{R}$ is the scaled distance:

$$\bar{R} = R \cdot (p_o/E_B)^{1/3} . \tag{6}$$

According to [2], blast pressure p_B^* for $\bar{R} > 2$ approaches that of an energy-equivalent TNT detonation (cf. eq.(7)).

3. Peak Blast Pressure and Duration From TNT Detonation

Numerous test data have been evaluated elsewhere to generate scaled curves for the blast parameters of TNT surface detonations as a function of distance R from the detonation source [3]. We have put the peak incident blast overpressure p* and the duration t* of the positive blast phase into the form of approximate formulas:

$$\begin{aligned} p^*_{TNT} &= 1.7\cdot 10^4 \cdot exp(-7.14\cdot x^{0.28}) + 0.156 \quad \text{for } 0.1 \le x \le 8 \\ p^*_{TNT} &= 8\cdot 10^4 \cdot exp(-10.46\cdot x^{0.1}) \quad \text{for } x > 8 \end{aligned} \tag{7}$$

and

$$\begin{aligned} t^*_{TNT} &= G^{1/3}\cdot 0.06\cdot exp(1.4\cdot x^{1.4}) \quad \text{for } 0.1 \le x \le 1.3 \\ t^*_{TNT} &= G^{1/3}\cdot (13.8 - 14\cdot x^{-0.18}) \quad \text{for } x > 1.3 \end{aligned} \tag{8}$$

(pressures in bar, times in milliseconds), where $x = R/G^{1/3}$ is the scaled distance from the explosive charge of mass G (G in kg, R in meters).

4. TNT-Blast-Equivalence

Approximating the positive phase blast impulse J by $J = \frac{p^*\cdot t^*}{2}$, we can write the energy-equivalence between a gas vessel burst and a TNT detonation as

$$p^*_B \cdot t^*_B = p^*_{TNT} \cdot t^*_{TNT} \tag{9}$$

where t^*_B is the duration of the positive phase of the vessel burst blast wave.

Given a pressure vessel for which we can find p^*_B from eq. (4), we can now calculate the positive phase duration t^*_B of the vessel burst at distance R by using eq. (9). Conversely, knowing p^*_B and t^*_B, we can now find the mass G_{eq} and distance R_{eq} of an explosive charge that is blast-equivalent to the vessel burst, by simultaneously solving eqs. (7) and (8) for $G=G_{eq}$ and $R=R_{eq}$ with $t^*_{TNT} = t^*_B$ and $p^*_{TNT} = p^*_B$.

Example: A vessel containing 20 m³ helium of 200 bar pressure at ambient temperature is energy-equivalent to about 110 kg of TNT. The blast wave at R = 10 m from the bursting vessel has p^*_B = 2 bar and (through TNT-energy-equivalence) t^*_B = 10 msec. By the above procedure it is found, that the same blast wave (at least its positive phase) will occur at a distance of R_{eq}=13 m from a detonating TNT charge of mass G_{eq}=159 kg.

The same vessel at same temperature and pressure, filled with air, would be energy-equivalent to 154 kg of TNT. Its positive blast at 10 m, however, would be equivalent to 597 kg of TNT detonating at R_{eq}=24 m.

5. Conclusion

The above simple procedure to simulate the positive phase of a vessel-burst blast by an explosive-detonation blast can be used in roughly estimating damage hazards, since there exist curves and formulas for what damage will be done to concrete or brick structures when an explosive charge of given mass detonates a given distance away. TNT-blast-equivalence will most

likely give a better estimate than ordinary TNT-energy equivalence [4].

References

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[3] BAKER, W.E., et al., "Workbook for Estimating Effects of Accidental Explosions in Propellant Ground Handling and Transport Systems", NASA Contractor Report 3023 (1978).

[4] HELD, M., and STÖLZL, D., "Die TNT-Sicherheitskennlinien-Methode zur Beurteilung von Druckwellenauswirkungen versagender Behälter", Deutsche Reaktortagung, Hannover 4-7 April, 1978, Paper no. 253.

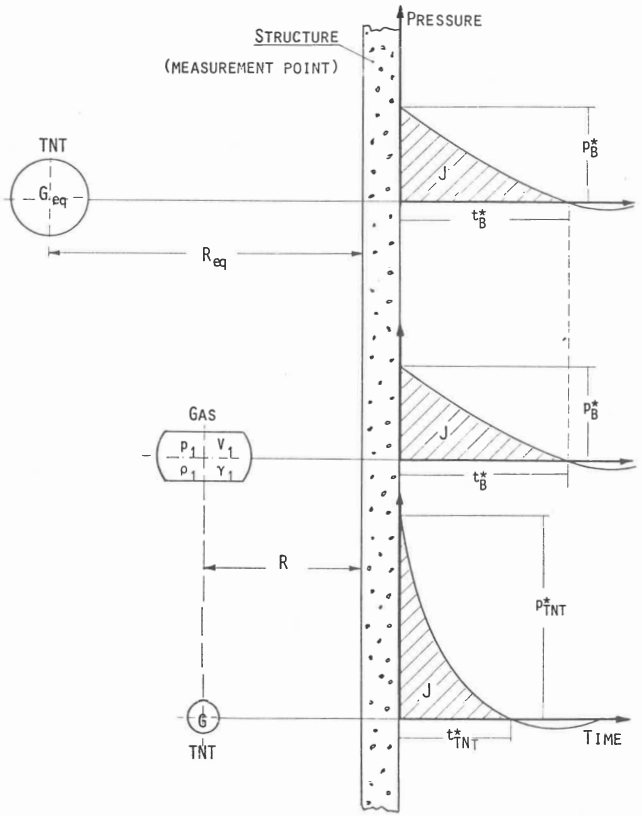

Fig. 1: Shock waves having identical positive phase impulse J.