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Design and development of a finite element analysis based model for impact analysis of blasts incorporating material properties

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Abstract. Herein, we present the design and development of a 'Finite Element Analysis (FEA)' based model incorporating temperature dependent material properties for impact analysis of blasts on underwater vehicles. Our primary idea is the incorporation of temperature dependent material properties in explosion studies for the design and development of new age shield engineering designs, especially focused towards the applications relevant to the underwater vehicles (e.g. autonomous underwater vehicles, submarines, submersibles, and torpedoes, etc.). We present extensive results that are key towards bench marking. Furthermore, we show and analyse the effect of explosion on square plates of different materials and distribution of stresses, strains and displacements after explosion/impact, etc., are examined in-detail. Our proposed FEA based model is governed by the basic numerical analysis, finite element analysis and thermal/material science. We implement our model in ABAQUS*TM and Matlab**TM software solution systems and develop subroutines to ensure seamless integration. In our model the focus is on large deformation finite element analysis, and we use the Jones-Wilkins-Lee (JWL) equation of state, Johnson Cook parameters, along with temperature dependent material properties. Presented results examine the role of explosion at various heights in the z axis direction on plates of different materials and the '2, 4, 6-Tri Nitro Toluene (TNT)' is used as a representative explosive material. Finally, based upon the results and their analyses suitable design guidelines related to material selection and applications are derived.

Keywords: explosion; finite element analysis; impact analysis; large deformation analysis; material properties; temperature dependent material properties

1. Introduction

A blast load is the force exerted on a structure or object by a blast wave, and it is characterized by an overpressure and impulse or duration. In cases of uncontrolled explosions, such as 'Improvised Explosive Devices (IEDs), the load is determined by the explosive's type and payload weight. When high explosives detonate Fordham (2013), a blast wave is generated, impacting the structure with incident overpressure (P_{so}), Beshara (1994).

This wave is then reflected back as reflected excess pressure (PCa), Remennikov (2003),

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n = Strain hardening coefficiant
C = Strain rate hardening,
m_t = Thermal softening constant,
D_1 D_2 D_3 D_4 and D_5 = Different fracture strain constants,
D = Damage variable,
Δ_ε = Equivalent plastic strain,
ε^f = Equivalent strain required to fracture,
σ_m = Average normal stresses,
$\bar{\sigma}_v$ = Von-Mises equivalent stress,
P_a = Applied air pressure,
V_0 = Initial relative volume,
V = Relative volume,
E_o = Initial internal energy density,
C_0–C_6 = Coefficients of the polynomial equation,
A_j, B_j, R_1, R_2, and ω = Material constants in JWL state equation as defined in Eq. (15),
P_d = Detonation pressure,
E_m = Internal energy per unit mass,
ρ_o = Density of the unreacted explosive material, and
ρ_d = Density of the reacted detonation products.