NATURE-INSPIRED SOLUTIONS FOR ENHANCED IMPACT RESISTANCE OF STRUCTURES

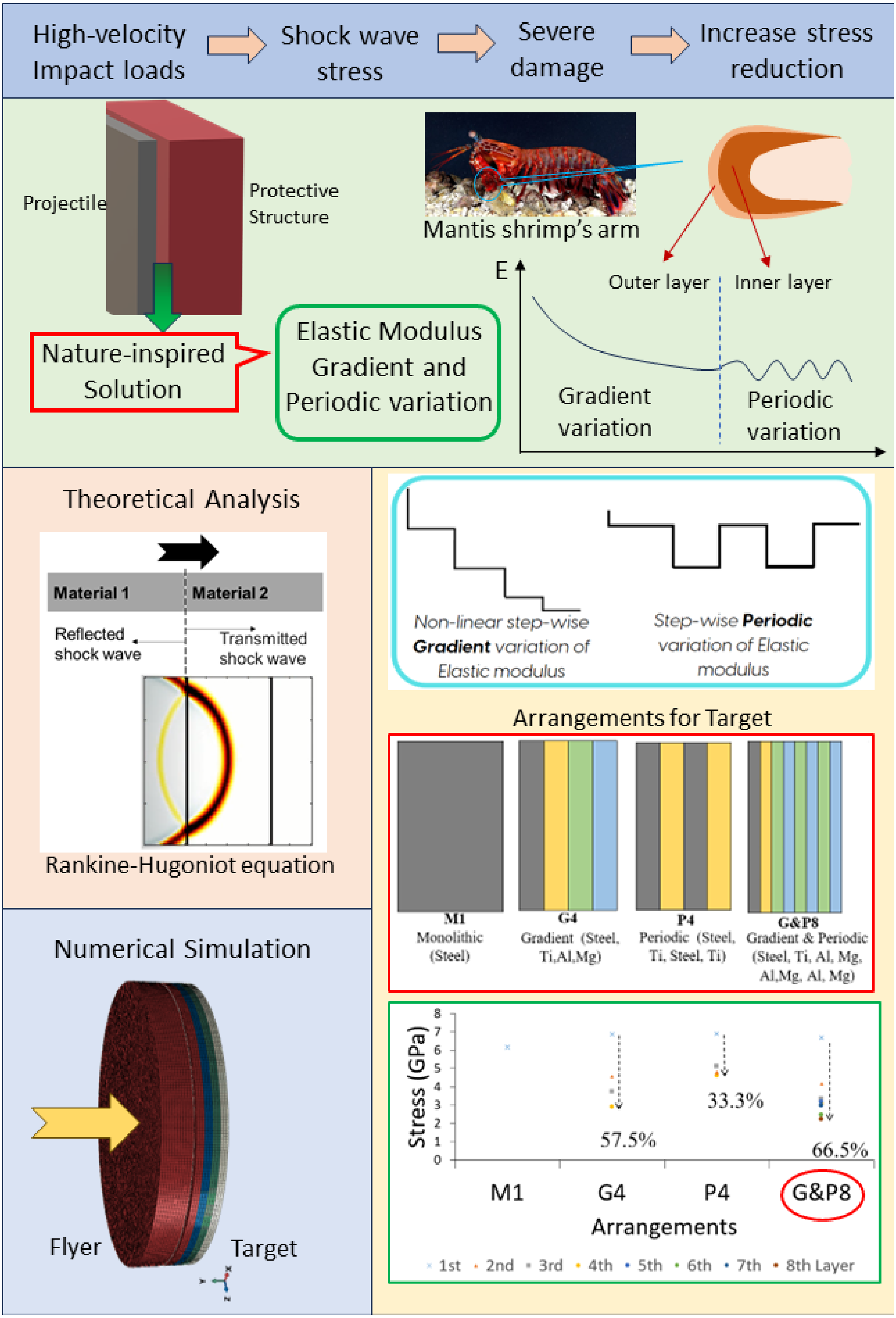
H.M.T. Sajana [1], P.L.N. Fernando [1, *]

[1] Department of Civil Engineering, University of Moratuwa, Moratuwa

High-velocity impact loads pose significant challenges due to their potential to generate dynamic responses in structures, which can cause severe damage. Structural engineers face an evolving challenge in designing structures that can effectively resist impact and blast loads. Active and passive mitigation systems are two different categories of mitigation systems. Active mitigation systems are based on detection and reaction systems, while passive mitigation systems use energy absorption and wave propagation characteristics to mitigate the effects of high-velocity impacts and shockwaves. This study investigates nature-inspired solutions to minimise damages from high-velocity impact loads on structures. By analysing the basic elements of several existing biological systems and their contribution towards the structural integrity of these systems, key potential characteristics that can be translated into impact-resisting structures have been identified. The primary focus centres on the mantis shrimp arm, drawing insights from its remarkable mechanical properties and translating them into structural engineering applications. In the present study, a solution that is inspired by the mantis shrimp arm has been developed as such, a multilayered structure was designed using metallic materials that use the mantis shrimp arm's concept of elastic modulus gradient variation. The study pursues three objectives: to identify the mechanisms employed by biological systems for impact resistance, to investigate effective and efficient systems considering the impact resistance using theoretical analysis and numerical simulations, and to propose feasible combinations of the system to resist impact loads for enhanced impact load mitigation. Based on a theoretical analysis involving shock wave propagation, this system demonstrated the potential to reduce the magnitude of the stress waves during an impact-loading event. Further numerical analysis of this system was carried out using the nonlinear finite element software ABAQUS, where the impact of a metallic flyer at a known velocity on a target of the multilayered structure was simulated. The magnitude of the incident stress wave of the final material in the target was obtained to evaluate the performance of this system. The results demonstrated that the proposed multilayered system has the potential to reduce the magnitude of the incident stress waves in the system when compared to the monolithic system with no variation of the elastic modulus. The arrangement of gradient variation of elastic modulus results in a pressure reduction of approximately 66% and 58% in theoretical and numerical analyses, 41% and 33% in stepwise periodic variation, and 80% and 67% in combined gradient and periodic variations. The study reveals that incorporating materials with gradient variations in elastic modulus in the layered structure can effectively reduce pressure waves than the monolithic structure. The combined arrangement of gradient and periodic structures can potentially improve mitigation performance. The findings suggest further research on microstructural aspects, comparison with different biological systems, experimental studies, and deeper design and optimisation of combined arrangements. These findings contribute to developing innovative engineering solutions and paving the way for structures that can withstand high-velocity impact loads effectively.

Keywords: Elastic modulus gradient; Impact resistance; Nature-inspired; Multilayered structure; Stress waves.

[*] Correspondence: lakshithaf@uom.lk


High-velocity Impact loads
Shock wave stress
Severe damage
Increase stress reduction
Projectile
Protective Structure
Mantis shrimp's arm
Outer layer
Inner layer
E
Nature-inspired Solution
Elastic Modulus Gradient and Periodic variation
Gradient variation
Periodic variation
Theoretical Analysis
Material 1
Material 2
Reflected shock wave
Transmitted shock wave
Rankine-Hugoniot equation
Non-linear step-wise Gradient variation of Elastic modulus
Step-wise Periodic variation of Elastic modulus
Arrangements for Target
M1 Monolithic (Steel)
G4 Gradient (Steel, Ti,Al,Mg)
P4 Periodic (Steel, Ti, Steel, Ti)
G&P8 Gradient & Periodic (Steel, Ti, Al, Mg, Al,Mg, Al, Mg)
Numerical Simulation
Flyer
Target
Stress (GPa)
57.5%
33.3%
66.5%
M1
G4
P4
G&P8
Arrangements
1st 2nd 3rd 4th 5th 6th 7th 8th Layer