FUNCTIONALIZING GRANULAR MATERIALS AT THE PARTICLE AND PARTICLE ASSEMBLY SCALE FOR VIBRATION CONTROL.

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Abstract

This thesis presents the results of an investigation which explored means to functionalize granular materials for vibration control through design at both the particle and particle assembly scale.

The first part of the work focuses on development of a novel ***highly dissipative granular material*** - termed ***"Engineered Particles"*** - formed by a rigid core encapsulated in a soft shell. This particle-scale design explores the idea that mediation of particle contacts by a soft lossy phase can enhance dissipation under dynamic excitation. This hypothesis is validated through an extensive experimental program on engineered particles manufactured using monodisperse glass spheres (D= 3.6 mm) and a silicone elastomer, targeting three different thicknesses of the silicone shell (20 to 200 mm). Morphology and density of the grains are characterized with gravimetric measurements and X-ray tomography, and particle interactions are examined using a rheometer equipped with a novel custom-designed accessory. Finally, resonant column tests are used to measure the small strain bulk dynamic properties (initial damping ratio (D_0), and shear modulus (G_{max})) of the engineered particles over a range of confining stresses (30-300 kPa). These measurements leverage advances in resonant column testing introduced in this work, that enable the analysis of off-resonance data and allow control of the vibrations applied to the specimen.

Values of D_0 of the engineered particles exceed those typical of granular materials by as much as an order of magnitude. Also associated with the introduction of the shell is a decrease of G_{max} by one to two orders of magnitude, and a significant increase in its pressure level sensitivity. The impact of the elastomer shell is controlled by its thickness, which in this work could be carefully controlled, with greater deviation from the behavior of the unmodified glass cores seen with increasing shell thickness. This suggests that control of this parameter may serve to tailor the bulk dynamic response of the engineered particles. Interparticle normal compression tests demonstrate that the contact mechanics behavior of the multi-phase engineered particles cannot be described by conventional theoretical frameworks, and indicate that, unlike what is observed in most other granular materials, the marked pressure level dependency of G_{max} is primarily driven by stiffening of the contacts.

The second part of the work explores the design of ***tunable granular metamaterials***. Experiments performed using a custom apparatus demonstrate that randomly packed granular materials with contrasting properties (modulus and density) organized in a periodic layer structure with length scale greater (>~6X) than that of the particles themselves attenuate vibrations within a specific frequency range, termed a bandgap. While the value of using discrete ordered granular elements for filtering vibrations has been previously demonstrated by other researchers, this work provides the first experimental evidence of the potential for using bulk granular materials. Tests performed on specimens manufactured with different periodic structures using the same base materials – glass beads and the engineered particles developed as part of this research - reveal the sensitivity of the bandgap characteristics (starting frequency and width) to specimen architecture, and show that as few as four repetitions of the periodic structure are required to produce a bandgap. The ability to further tune its position through control of the effective confining pressure is demonstrated. Due to the significant pressure level dependence of the modulus of the engineered particles that arises from the unique grain scale design, relatively small (~ 30 kPa) increases in confinement are found to shift the starting frequency and increase the width of the bandgap by several hundred Hz. Theoretical predictions and simulations based on the assumption of viscoelasticity support the experimental results, and provide the means to predict bandgaps for conditions beyond those explored in this work.

While demonstrated for a limited set of materials, both components of the work have broader applicability, and the large diversity in the characteristics of available natural and synthetic particulate elements opens the door to a full new class of materials.

The research also produced advancements in methods for testing granular materials. In particular, a new approach for resonant column testing was developed that allows control of the vibrations applied to the specimen and that, by enabling the analysis of off-resonance data, provides the means to rapidly derive shear modulus and damping as a semi-continuous function of shear strain.