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Project Title

Seamless Comparative Modeling of Natural Hazards Using the Material Point Method

University

Colorado State University

Principal Investigators

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Research Needs

At present, there are a wide variety of modeling approaches used to simulate and represent the threats of natural hazards on transportation infrastructure. One disadvantage of this approach is that direct comparisons between both methods and disparate threats lack consistency and continuity. Hence practitioners hoping to determine levels of threat and system response must use a specific method depending on the system and the type of hazard. Clearly, input parameters for varying threats are part of the inherent nature of the hazard. But the modeling approach should be consistent.

In this work, a seamless modeling approach will be used to develop what amounts to a single modeling tool that can represent soils, fluids, solids, and their combination including concepts, for example, as fluid-structure interaction. The Material Point Method (MPM) has seen limited but successful development in modeling these types of systems but in this work the natural threat rubric will be incorporated under a single modeling domain. This will allow for consistency threat assessment, the development of a single computational tool, and the ability to effectively rank the seriousness and potential damage caused using a single platform.

Research Objectives

The objectives of this work are:

1. Develop a Material Point Method tool for two-dimensional models of natural hazards effects on transportation structures (for example, retaining walls and bridges).
2. Directly simulate several hazardous events to predict load capacity and potential damage zones for differing types of hazard.

3. Focus predictive modeling efforts on hazards that are historically difficult to model and that overlap other studies by MPC researchers, including mud debris flow and rockfall events.
4. Develop a framework for comparative modeling of various hazards depending on geographical location and season to begin to quantify the types and level of threat of various natural hazards.

These objectives are predicated on the idea that a variety of methods have been used to address different loading events on transportation infrastructure from natural hazards. Hence it is difficult to generate a comprehensive means of mediating or predicting the likelihood of structural damage or failure compared to other threats. This study is meant to be a first step in developing a uniform means of evaluating these hazards so that limited resources can be allocated appropriately to prevent or reduce the likelihood of damage.

Research Methods

The Material Point Method (MPM) is a fairly recently developed particle-in-cell method of solving the equations of motion for systems under dynamic loading. It differs from the far more widely known methods of finite elements and discrete elements in that the entire domain is fixed with a geometric grid that may or may not contain discretized mass points of the modeled system. The equations of momentum are solved using a time stepping approach that allows for different particles of different materials. In this case, an example would be the forces generated by mud flow on a concrete wall.

This study will focus on numerical modeling efforts, with limited experimental and analytical work. Since the end goal of this effort is a direct comparison of varying types of loadings generated by natural hazards, the bulk of the effort will be made in developing the computational platform to complete these predictions. The author has developed preliminary models for the purposes of this proposal for the dynamic movement of an axially loaded bar, with excellent results being obtained.

Expected Outcomes

The expected outcomes of this work will include advances in modeling methods for the systems typical associated with transportation infrastructure such as concrete retaining walls and steel bridges that are loaded either by other solid particles (rockfall), Newtonian fluids (floods), and non-Newtonian fluids (mudflow). These outcomes include comparative levels of damage and failure for these different hazards that will all be computed using the same approach. The primary tangible product of this work with be prototype software that could potentially be used for research purposes by practicing engineers.

Future research studies will be impacted by this work because it is frequently unknown what levels of natural hazard loadings on structures cause failure, since most such assessments are made after the fact when direct observation is impossible.

Relevance to Strategic Goals

This study addresses the State of Good Repair USDOT strategic goal. For a variety of factors, the threat of natural hazards has been on the increase in various levels of the country. In part, this is because transportation infrastructure follows housing and business developments, and many of these have been located in areas that have much higher rates of severe weather, runoff, slope instability, or rockfall. This project, and its anticipated outcomes, reflects this new state of affairs and recognizes that what may have constituted natural hazard threats in one region of the country are far different, and more temporal, than those threats 20 years in the past.

Educational Benefits

The proposed study contains two educational elements. First, a graduate student will perform much of the work, particularly any analysis portion of the research. Second, the Honors section of the undergraduate class CIVE 360 (Mechanics of Solids) will be devoted towards assisting the visualization of results. These students usually work unfunded as part of their academic requirement for honors credits. The classes of Spring 2021and Spring 2022 will both participate.

Technology Transfer

The proposed technology will be transferred to the applied and research communities primarily through journal and conference papers in structures and/or transportation related journals and professional meetings.

Work Plan

The major tasks associated with this research are as follows:

1. Complete two-dimensional MPM model and implement both fluid and solid constitutive laws. Expected duration: 9 months.
2. Train graduate and undergraduate students in image creation and manipulation. Expected duration: 2 months.
3. Identify representative studies involving natural hazards that include experimental or direct observational data. Expected duration: 2 months.
4. Complete prototypical simulations of natural hazard effects on identical structures to form direct means of comparison. Expected duration: 4 months
5. Develop methods for quantifying level of expected damage, degradation, or threat increase. Expected duration: 7 months.

Project Cost

Total Project Costs:	$102,500
MPC Funds Requested:	$ 50,000
Matching Funds:	$ 52,500
Source of Matching Funds:	Colorado State University