Project 2:
Newmark-SEM

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CONTEXT

Motivation

- Spectral Element Method (SEM) is capable of modeling 3D seismic wave fields in complex topography at a scale of hundreds of kilometers, and thus capture a big picture of earthquake strikes and associated landslide hazards.

- Newmark displacement model acts on a local scale, considering key factors such as geological material strength, geometry, and degree of soil saturation. It is well noted that the characteristics of spatially distributed ground motions as well as regional site conditions significantly affect triggering of landslides.

- A coupled numerical model can find important applications where we can systematically study coseismic landside processes using a large variety of earthquake scenarios and hydrogeological conditions.

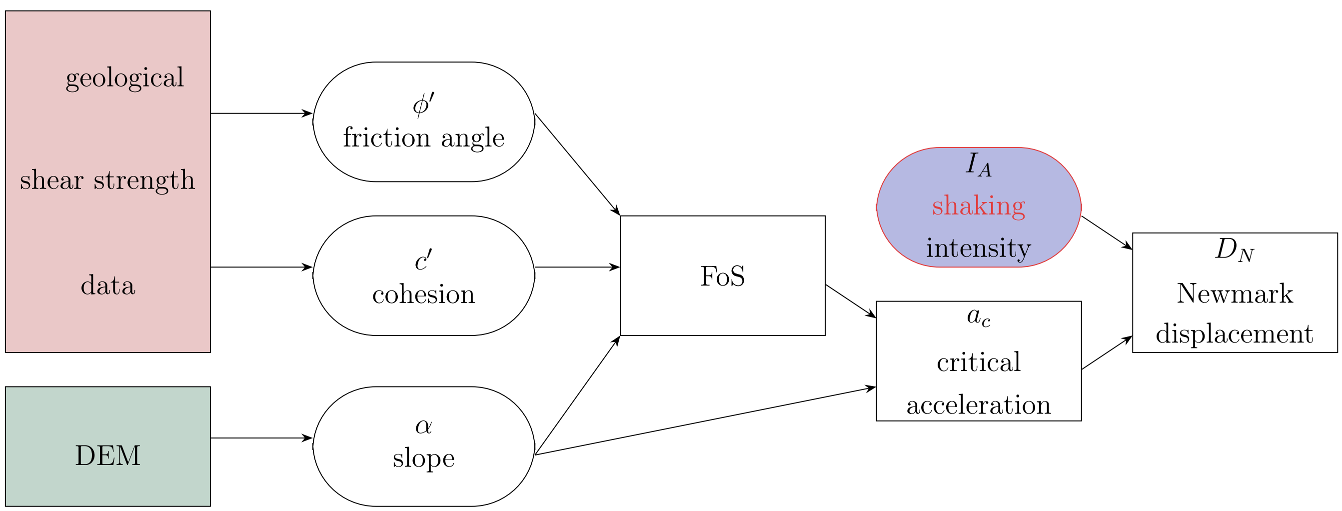
Coupled Approach

1. Present weak coupling of Newmark's formula with a SEM code, to produce Newmark displacements, and finally an LSM, in 2 cases:
   (a) a simpler 2D case,
   (b) a more complete 3D case.

2. Study strong coupling based on a PINN approach [PINN], where Newmark's formula is integrated into a machine learning model via the loss function—this is an advanced option and is also treated in the PINN-LandslideInventory project. An alternative is to "learn" the seismic wave propgagtion itself using a PINN based on the wave equation.

3. Investigate more complex physical modelling of landslides using a nonlinear, large-displacement FEM/SEM formulation.

Newmark



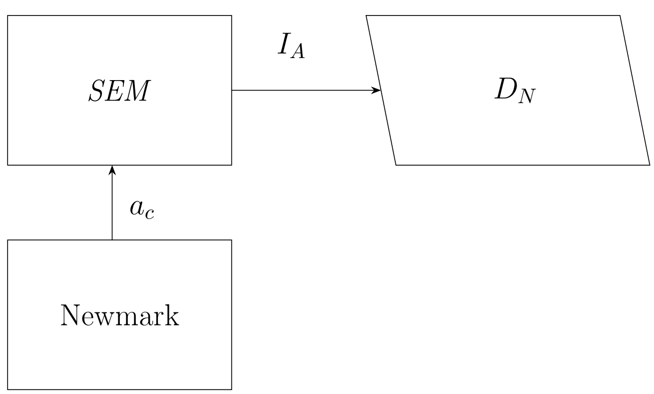
- Newmark analysis requires either,

  $\Rightarrow$ I_a to compute the Newmark displacement D_N, or
  $\Rightarrow$ PGA (peak ground acceleration) to compute the exceedance E (see the document FOS-Theory.pdf).

- The objective of this project is to use SEM (spectral element method) to provide these values.

SEM

- The spectral element method (SEM) is well-adapted to seismic wave propagation—see lecture notes.
- SPECFEM is a world-renowned code, based on SEM, for performing seismic wave propagation and generating (synthetic) seismograms.
- SPECFEM is an excellent tool for exploring scenarios, in particular extreme events. As such it can provide a basis for damage evaluation, and prevention and/or mitigation policies.
- Workflow is based on (loose) coupling:

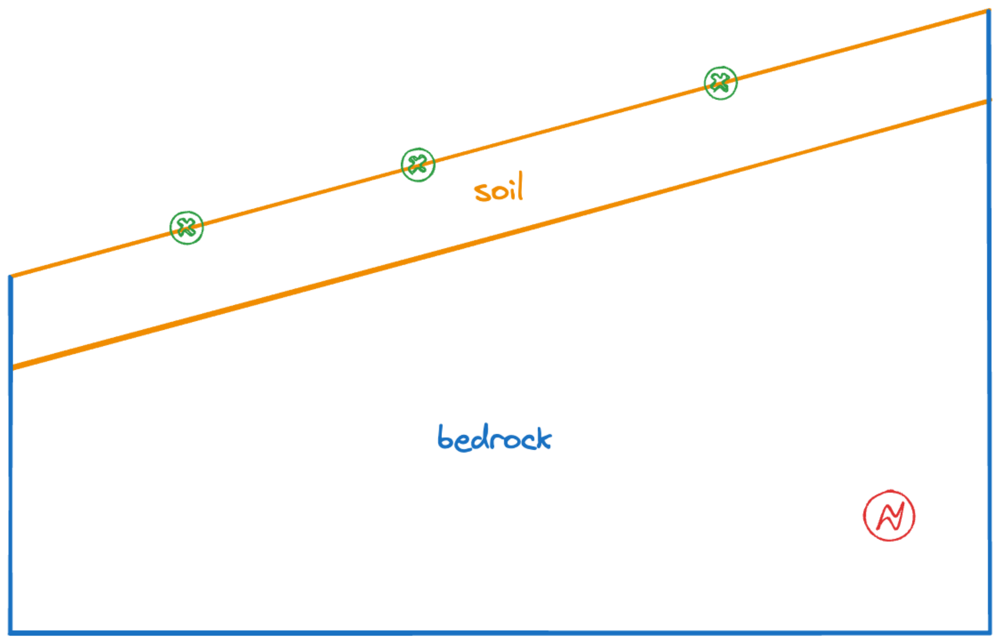


Project Steps

1. Read, understand and write a summary of the formulation, methods and findings of [SEM-N]. Take care to carefully define and explain all the relevant parameters that are used/required for the modeling. Consult the paper's references if needed, as well as my lecture notes on SEM.

2. Set up an initial, 2D test case, where we have a single-slope, two-layer model (see figure below). For this we require

   (a) representative geological parameters, (see also Section 3.2 of [SEM-N])
   (b) characterization of a typical seismic source,
   (c) ALL the parameters needed for Newmark, ALL the parameters needed for SPECFEM2D.



3. Use SPECFEM2D to generate seismograms at the chosen stations. Then code the Newmark model, perform the coupling and create a displacement map.

4. Simulate a homogeneous medium (no soil layer), where we consider both layers to be bedrock with $v_s = 100$ m/s, and compare the displacement map with the previous step. Draw detailed conclusions.

5. On the 2-layer model, perform a parametric study, by varying

   (a) the slope angle, α,

(b) the saturation level. Comment on all results.

6. We are now ready to do a full 3D analysis, repeating all the above steps. The 3D analysis requires

   (a) a topological map of an area of interest, and the generation of an adapted finite element mesh,
   (b) a geological map providing all needed data for the simulations,
   (c) seismic data, if available, otherwise we can just simulate the seismograms.

Advanced Steps

1. Is a PSHA (Probabilistic Seismic Hazard Analysis) of interest to PHIVOLCS? To discuss with them. This requires an attenuation relationship (regression) based on known, historical seismic events. If of interest, then perform such an analysis, replacing the I_A or PGA by the PSHA.

2. Evaluate a strong coupling approach, based on PINN, and compare with the model-based approach above.

3. To better calibrate both the Newmark model and the seismic wave equation, we can formulate and solve inverse problems. This is explained in detail in [DT].

References

References

[SEM-N] Huang, Duruo, Gang Wang, Chunyang Du, Feng Jin, Kewei Feng, and Zhengwei Chen. "An Integrated SEM-Newmark Model for Physics-Based Regional Coseismic Landslide Assessment." *Soil Dynamics and Earthquake Engineering* 132 (May 1, 2020): 106066. https://doi.org/10.1016/j.soildyn.2020.106066.

[PINN] Dahal, Ashok, and Luigi Lombardo. "Towards Physics-Informed Neural Networks for Landslide Prediction." *Engineering Geology* 344 (January 1, 2025): 107852. https://doi.org/10.1016/j.enggeo.2024.107852.

[DT] M. Asch. *A Toolbox for Digital Twins: from Model-Based to Data-Driven*. SIAM (2022).