Modeling of 1D wave propagation in nonlinear soils using the elasto-plastic Iwan model by four numerical schemes

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1. Context and objectives

The international project PRENOLIN is focused on verification and validation of numerical codes for ground motion simulations including nonlinear soil rheologies. In this particular study, we present implementations of the elasto-plastic Iwan model (Iwan, 1967) into numerical schemes based on finite-difference, finite element, spectral element and discontinuous Galerkin methods, and results based on test numerical simulations.

We study the amplification of ground motion in a soft layer with nonlinear behavior overlying a half-space with linear behavior. We assume a vertically incident plane SH wave with source-time function given by a Gabor wavelet. We include different amplitude levels and frequency ranges. Special attention is given to the hysteresis loops and the reversal points in the stress-strain plane, and their effects on the computed seismograms and corresponding transfer functions.

We compare key aspects of the individual numerical schemes and methods, and their advantages and disadvantages.

2. Numerical test: 1D soil column

Three levels of input motion: PGA 0.01 g, 0.1 g and 1 g

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Peak Ground Acceleration. Left: example of a linear elastic simulation (rigid base), Center: non-linear simulation (rigid base), and Right: stress-strain curves at different depths (Z=1 m to Z = 19 m).

5. Conclusions

Satisfactory fit between different numerical methods modeling non-linear wave propagation with Iwan elasto-plastic model

Key parameter: number of Iwan elements to interpolate the shear modulus decay

Next step: implementation of damping control (i.e., no Masing rules for hysteresis loops)

Equation of motion

\[ \rho \frac{\partial v}{\partial t} = \frac{\partial}{\partial x} \left( G \frac{\partial v}{\partial x} \right) \]

where \( v \) is velocity, \( G \) is shear modulus, \( x \) is the depth, and \( \rho \) is the soil density.

<table>
<thead>
<tr>
<th>H (m)</th>
<th>Vs (m/s)</th>
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<tbody>
<tr>
<td>20</td>
<td>300</td>
</tr>
<tr>
<td>∞</td>
<td>1000</td>
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50 Iwan elements                          200 Iwan elements

PGA 0.01 g

PGA 0.1 g

PGA 1 g

Summary table with the five different codes participating in the comparison.

If you are interested in validation of these codes with real data (KikNet sites) please attend the presentation 15-526 on Thursday, 3:45 pm, Ballroom G: PRENOLIN project: a benchmark on numerical simulation of 1D nonlinear site effect: Validation on real sites, by Bard P-Y et al.