1. Introduction

This study incorporates soil heterogeneity into geotechnical site response analysis to model wave scattering and the spatial variability of earthquake ground motion. Conventional 1D site response analysis neglects soil heterogeneities that scatter seismic waves and influence the amplification of earthquake ground motion. Figure 1 illustrates many of the features of the site response model, and an example of a 2D velocity profile with anisotropic, spatially correlated shear \( V_p \) perturbations.

2. Methodology

A parametric analysis was performed to assess the influence of the spatially correlated random field input parameters on site response. Table 1 defines each input parameter and provides the values used in this study. For statistically significant results, 30 realisations of each parameter permutation were analysed and results were extracted from 10 nodes along the ground surface within the Subdomain of Interest (Figures 1 and 2).

1D randomised (1D\textsubscript{mean}) \( V_p \) profiles were also extracted at the location of each recorder node in the 2D model and analysed in a 1D framework to distinguish between the effects of 1D vertical heterogeneities and averaging across many nodes and realisations, from the effects of wave scattering and 2D ground motion phenomena. Results are also compared to, and normalised by, those from a traditional deterministic (1D\textsubscript{det}) analysis with homogenous layers. An example of this workflow is shown in Figure 2 which plots, for 1 realisation, the 2D \( V_p \) model and extracted 1D\textsubscript{mean} \( V_p \) profiles, and acceleration time histories and surface-to-bedrock outcrop transfer function for 1D\textsubscript{mean} 1D\textsubscript{rand} and 2D analyses.

Table 1: Random field parameters used in the sensitivity analysis

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Symbol</th>
<th>Values Used in Sensitivity Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Shear Wave Velocity</td>
<td>( V_{50} )</td>
<td>150, 250, 400 m/s</td>
</tr>
<tr>
<td>Standard Deviation of ln(( V_p ))</td>
<td>( \sigma_{lnVs} )</td>
<td>0.1, 0.175, 0.25, 0.325</td>
</tr>
<tr>
<td>Horizontal Correlation Length</td>
<td>( l_{h} )</td>
<td>5, 25, 50, 75, 100 m</td>
</tr>
<tr>
<td>Anisotropy Factor</td>
<td>( \beta_{lnVs} )</td>
<td>1, 5, 10, 20</td>
</tr>
</tbody>
</table>

3. Acceleration Transfer Functions

Figure 3 plots all nodal and realisation mean transfer functions, with standard deviations, for two parameter permutations with \( \sigma_{lnVs} \) increasing from 0.175 (left) to 0.325 (right). The following observations can be made:

- As \( \sigma_{lnVs} \) increases, so does the spatial variability in ground motion and therefore the standard deviation in transfer functions.
- 1D\textsubscript{rand} results can replicate mean transfer function up to about 10 Hz. At higher frequencies, 2D phenomena have a greater influence on amplification functions.
- The heterogeneities cause amplification to be distributed over wider frequency bands compared to narrowband amplification peaks from 1D\textsubscript{mean} analysis.

4. Evaluation of Ground Motion Intensity Measures

To better quantify the influence of soil heterogeneity on site response and directly compare results from 1D\textsubscript{mean} 1D\textsubscript{rand} and 2D analyses, many ground motion intensity measures are analysed for all parameter permutations. These include medians of fundamental frequency \( f_0 \), the amplification at \( f_0 \), spectral acceleration at 1/3\textsuperscript{rd} [SA(T\textsubscript{0})], PGA, and Arias intensity \( (I_{\text{Arias}}) \).

- With increasing \( \sigma_{lnVs} \) there is a significant decrease in SA(T\textsubscript{0}), PGA and \( I_{\text{Arias}} \).
- SA(T\textsubscript{0}) plots on the 1:1 line, however, for PGA and \( I_{\text{Arias}} \) the 1D\textsubscript{rand} analysis is consistently higher which is likely due to these IMs being influenced by high frequencies that are affected by wave scattering in the 2D model.
- \( f_0 \), \( f_0 \), and \( \text{AF}(f_0) \) are comparable between 2D and 1D\textsubscript{rand} analyses and plot near the 1:1 line, although, on average, \( \text{AF}(f_0) \) is approximately 5% higher for 1D\textsubscript{rand} analyses.

Figure 4: Comparison of nodal acceleration time series and transfer functions between 2D and 1D\textsubscript{rand} models for Realisation 1 of permutation with \( V_{50} = 150 \), \( \sigma_{lnVs} = 0.175 \), \( l_{h} = 50 \text{m} \), and \( \beta_{lnVs} = 10 \). 1D\textsubscript{rand} \( V_p \) profiles extracted from 2D model included for reference.