Verification Assessment and Site Effects for a 2-D FEM Analysis

Addressed problem
Moderate seismic motions (Mw=4.8-5.1; PGA=0.17 m/s2) were recorded at the base and slopes crests of a valley, in order to verify two-dimensional (2D) plane strain numerical models with FEM, in time and frequency domains. The site effects by geology and topography were analysed, in order to determine which governs the local ground responses.

The location corresponds with a dam site in a steep valley. The dam is under construction as part of the Pirís hydroelectric power project in Costa Rica, designed to generate 128 MW. The site is located 70 km south of San José city, towards the central-Pacific region (Figure 1). This site lies in a highly seismic region in Costa Rica, within the Meso-American subduction trench (inter-plate) along the Pacific, as well as local faulting (intra-plate). The fore-arc has a transitional deformation according with calculated local faulting mechanisms (Phascho et al., 2006).

The numerical models were analysed with a linear elastic model due to the small strains to which the site was subjected. The site effects by topography and geological conditions were properly accounted with this model. The horizontal component of the seismic events, were loaded along the base of the models, in the longitudinal direction of the dam. The responses were quantified along the surface, with points including the accelerographs locations in order to properly compare the field measurements with the model responses.

To evaluate the site effect by geology, three scenarios were used: (1) the real case with the three units, (2) one setting was the upper unit was substituted by the intermediate, and (3) the site section with only the bedrock (Table 2).

Field measurements & 2D FEM models
One accelerograph at the valley base on rock (reference site), together with two accelerographs at each margin crest on soil (Figure 2), registered several seismic motions between September 2005 and September 2007. The events which were stronger and nearer to the site were chosen for this analysis (Table 1). The site consists of a discontinuous rock mass of turbidites (interbedded sandstones and shales). Geotechnically, the site has three units (Figure 3): (a) upper: completely weathered, transitional to soil (saprolite), (b) intermediate: moderately weathered and decompressed rock and (c) lower: slightly-weathered rock.

For more information:

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Figure 4. PGA along the surface behind the crests of (a) and (b): left and right abutments respectively, numerical (lines) and recorded values (points), (c) and (d): left and right abutment correspondingly, under the motion of 28.12.2005. 31: three layers model, 2L: two layers model, 1L: one layer model.

Table III. Measured (i) and numerical (ii) main frequencies from the Fourier spectra and fundamental frequencies (ii-fo) from the transfer functions

<table>
<thead>
<tr>
<th>Event</th>
<th>I - Measured (Hz)</th>
<th>II - Numerical models (Hz)</th>
<th>II -</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.12.2005</td>
<td>3.08</td>
<td>3.09</td>
<td>3.09</td>
<td>3.08</td>
<td></td>
</tr>
<tr>
<td>18.11.2006</td>
<td>2.5-10.5</td>
<td>4-5</td>
<td>n.m.*</td>
<td>2.5-10.5</td>
<td></td>
</tr>
<tr>
<td>30.11.2006</td>
<td>1-10</td>
<td>4-7</td>
<td>n.m.*</td>
<td>1-10.5</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions
The numerical ground responses provided a good approximation of the measured peak horizontal accelerations, for the three recorded motions in time domain (Figure 4a, b; Table 1 and Table 2). The overlap of the signals differed in a considerable extent (Figure 5), but their overall envelopes were comparable in all cases. The fit of the responses is good for this array of moderate-magnitude events within the elastic range of deformation due to the small range of strains. In the frequency domain, the numerical results differed from the records, giving two peaks at the right slope and a higher one at the left, but their amplitudes were similar. The reference site (base of the valley) showed an excellent match (Figure 6). The natural frequencies of the sites below both slopes crests coincided with the main frequencies from the Fourier spectra (Table 3). Resonance develops in the upper layer leading to local high amplifications of the ground response (Table 2). This is enlarged by the high impedance contrast within the upper unit with the rest of the rock mass.

The high amplifications registered were found to be governed by the site geology (impedance contrast), rather than the steep topography, according to the results from the different geological scenarios and 1D evaluations form the event of December 28, 2005 (Table 2, Figure 4c, d). The differences found among the numerical models and the field registers in the frequency domain, might be the result of being one-directional motions in plane strain numerical models, besides the assumptions taken for simplicity, that lead to differences in the resonant frequencies of the model in relation to the real site.

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