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 Pirrís 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 fore-arc region. The main seismic sources in Costa Rica are the Meso-American subduction trench (inter-plate) along the Pacific, as well as local faulting (intra-plate). The fore-arc has a transtensional deformation according with calculated local faulting mechanisms (Pacheco 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 are 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.

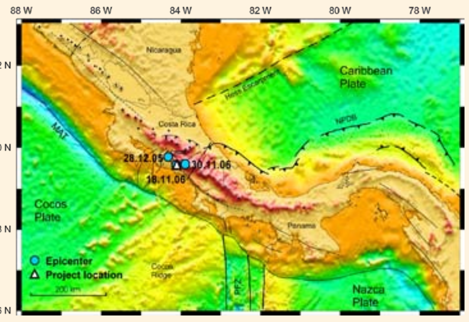

Figure 1. Geotectonic setting of Costa Rica (modified after Flueh & von Huene, 2007), and epicenters of the seismic motions used in this assessment. MAT: Meso-American Trench, PFZ: Panama Fracture Zone, NPDB: North Panama Deformed Belt.

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.

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

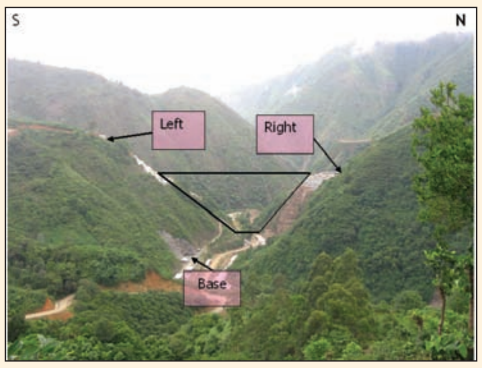

Figure 2. Dam site looking in downstream direction with sketch of dam and accelerographs placement.

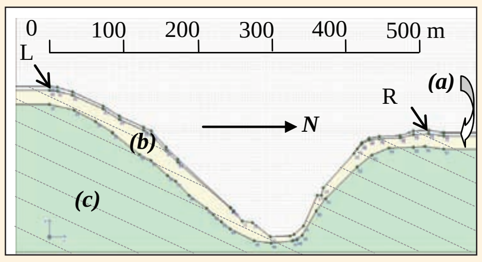

Figure 3. Measurement points that correspond with the accelerographs locations in the field, L: left, R: right. Equal horizontal and vertical scales; discontinuous lines: apparent dip of the bedding.

Table I. Registered site responses and Fourier spectra frequencies

Event / Station	Peak ground acceleration (PGA in cm/s^2)			Fourier spectra (Hz)
	NS	EW	Vertical	
28.12.2005				
Base	10.99	16.82	9.53	0.9-9
Right crest	129.26	82.91	39.25	4
Left crest	120.18	120.15	58.05	3
18.11.2006				
Base	7.26	16.02	6.42	2.5-10.5
Right crest	40.96	40.91	33.79	4-5
30.11.2006				
Base	3.94	8.80	3.66	1-10
Right crest	20.75	18.84	13.91	4-7

Table II. Numerical PGA and amplification factors at the accelerographs sites

Event	Right site		Left site	
	PGA (cm/s^2)	*A.f.**	*PGA* (cm/s^2)	*A.f.*
28.12.2005	127.6	11.6	118.8	10.8
2 units	36.9	3.4	29.1	2.6
1 unit	28.8	2.6	32.0	2.9
1D	103	9.4	68	6.2
18.11.2006	43.3	5.9	53.3	7.3
30.11.2006	25.8	6.5	28.9	7.3

**A.f.*: amplification factor

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 extend (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

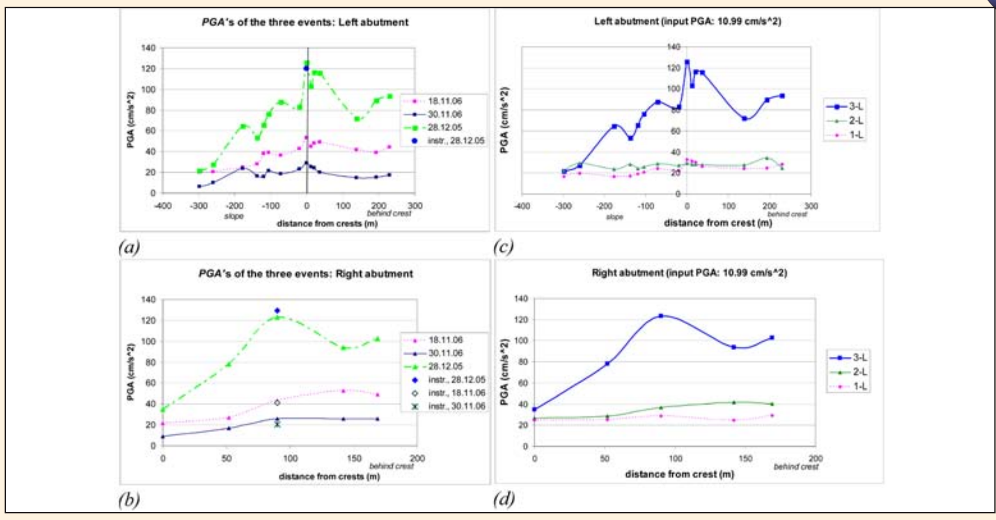

Figure 4. PGA along the surface behind the crests of (a) and (b): left and right abutments respectively, numerical (lines) and recorded values (points). (c) and (d): left and right abutment correspondingly, under the motion of 28.12.2005. 3L: three layers model, 2L: two layers model, 1L: one layer model.

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

Event	*i*- Measured (Hz)			*ii*- Numerical models (Hz)			*iii*- f_o (Hz)	
	Base	Right	Left	Base	Right	Left	Right	Left
28.12.2005	0.9-9	4	3	0.9-10.5	1.7, 4.5, 7	4-6	5-6	3.5-4.5
18.11.2006	2.5-10.5	4-5	n.m.*	2.5-10.5	1.7, 6.5	6.3		
30.11.2006	1-10	4-7	n.m.*	1-10.5	1.7, 6-7	6		

*n.m.: not measured

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.

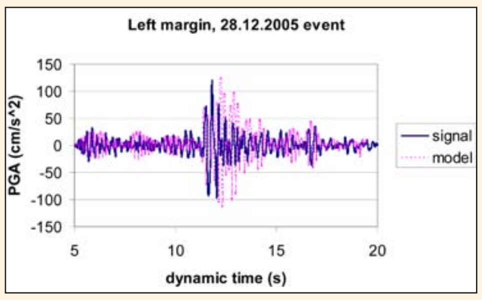

Figure 5. Registered and numerical acceleration time history at the left slope crest, for the event of December 28, 2005.

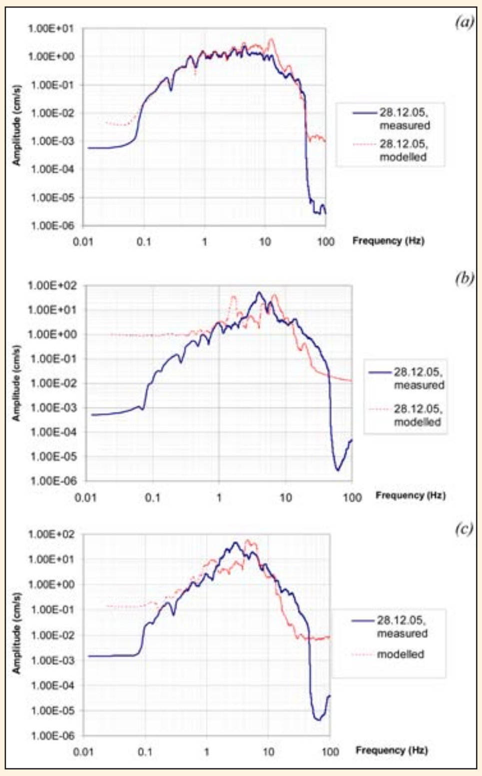

Figure 6. Registered and numerical Fourier spectra for the event of December 28, 2005 at: (a) valley base (reference rock site), (b) right slope crest, (c) left slope crest.

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