2.0 ENGINEERING SEISMOLOGY AND EARTHQUAKE GROUND MOTIONS

2.1 Tectonic Setting

The information presented in this section is derived from the USGS "Earthquake Summary" web site (http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/#summary). Additional information on the geology in the region affected by the 2010 M_w=8.8 Chile earthquake is presented in Section 3 of this report.

The M_w = 8.8 Offshore Maule, Chile earthquake occurred in a subduction zone in which the Nazca plate passes eastward and downward beneath the South American plate. The rate of convergence of the two plates is 70 mm/year.

Human inhabitants of the Chilean coast report numerous major prior events in this region. One of the first recorded events was a shock near Concepción in 1562. Another earthquake in 1570 triggered a tsunami that led Spaniards to rebuild Concepción on higher ground. Earthquakes in 1730 (apparently near Valparaíso) and 1751 (Concepción) generated tsunamis that caused flooding and damage in Japan. The effects of an 1835 earthquake near Concepción were observed by Charles Darwin and Robert FitzRoy. A 1906 earthquake near Valparaíso of magnitude 8.2 generated a tsunami that produced run up heights in Hawaii as great as 3.5 m. The southern extent of that earthquake overlaps with the northern extent of the 2010 event. To the south of the 2010 earthquake zone is the source of the giant 1960 earthquake of magnitude 9.5, which was the largest 20th earthquake world-wide. Since 1960, the largest event prior to the 2010 earthquake was a magnitude 8.0 earthquake north of Valparaíso in 1985. That event generated a Pacific Ocean tsunami that reached heights of 9 m on the Chilean coast near Coquimbo and affected boats in Hawaii.

Ruegg et al. (2009) identified the Concepción–Constitución area (S35^o–S37^o) as a "mature seismic gap, since no large subduction earthquake has occurred there since 1835." They noted that the convergence of about 68 mm/year since the last large interpolate subduction earthquake of 1935 would have accumulated more than 10 m of displacement. Ruegg et al. (2009) warn, "Therefore, in a worst case scenario, the area already has a potential for an earthquake of magnitude as large as 8–8.5, should it happen in the near future." Thus, earth scientists were aware of the potential for a large earthquake in the south central Chile area.

2.2 Earthquake of February 27 2010

The mainshock occurred at 3:34 am local time on February 27, 2010. Its epicenter is located at S36.027° W72.834° (http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/neic_tfan_cmt.php). The USGS moment tensor solution indicates a seismic moment of 1.8×10^{22} N·m, moment magnitude of M_W = 8.8, and hypocentral depth of 30 km. Based on the regional tectonics, the critical nodal plane from the moment tensor solution strikes 14° west of due north and dips at 19° to the east.

Figure 2.1 shows a Google Earth image superimposed with the mainshock location and aftershock locations segregated by date (those within the first 48 hours of the event and those

occurring subsequently). Aftershocks within the first 48 hours are often assumed to result from redistribution of the stress in the mainshock rupture zone (Benioff, 1985; Kiratzi et al. 1985). Aftershock locations were obtained from the USGS server. Most of the aftershocks occur in a region approximately 530 km long (along strike) by 180 km wide. Figure 2.2 shows the aftershock distribution color-coded by depth along with a section of the aftershock pattern, which shows the dipping fault surface. The closest distance from the fault to the coastal areas of Chile was approximately 25 km.

The surface projection of a finite fault model of the mainshock is also shown in Figure 2.1. This finite fault model was generated by Gaven Hayes based on waveform inversion (image from http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/finite_fault.php). The rectangular model strikes at 17.5° west of north and dips at 18.0° to the east. The seismic moment release based upon this plane is 2.39×10^{29}+029 dyne·cm. There are two zones of high slip, with the maximum slip being approximately 14.5 m.

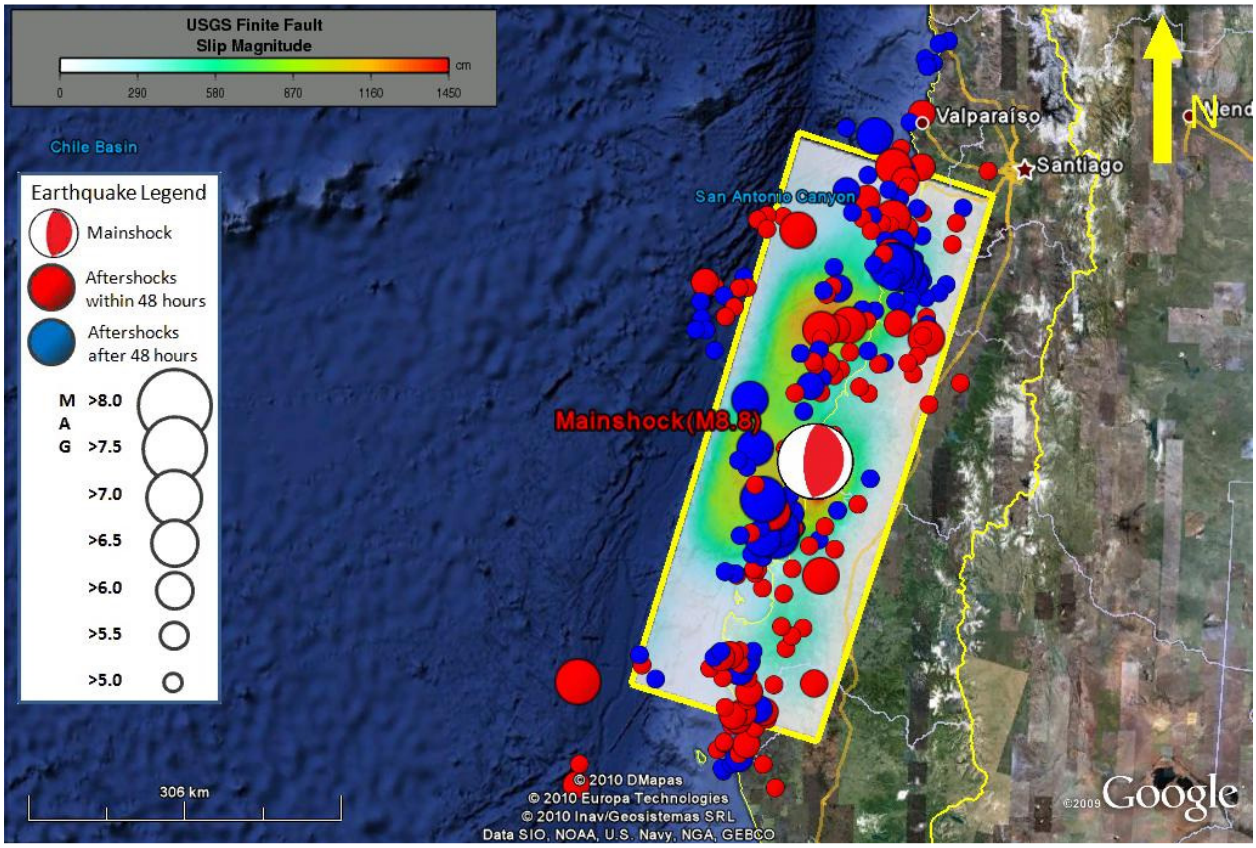

Figure 2.1. Google Earth image superimposed with aftershock distribution (locations from USGS) and fault plane solution from G. Hayes (obtained from USGS web page)

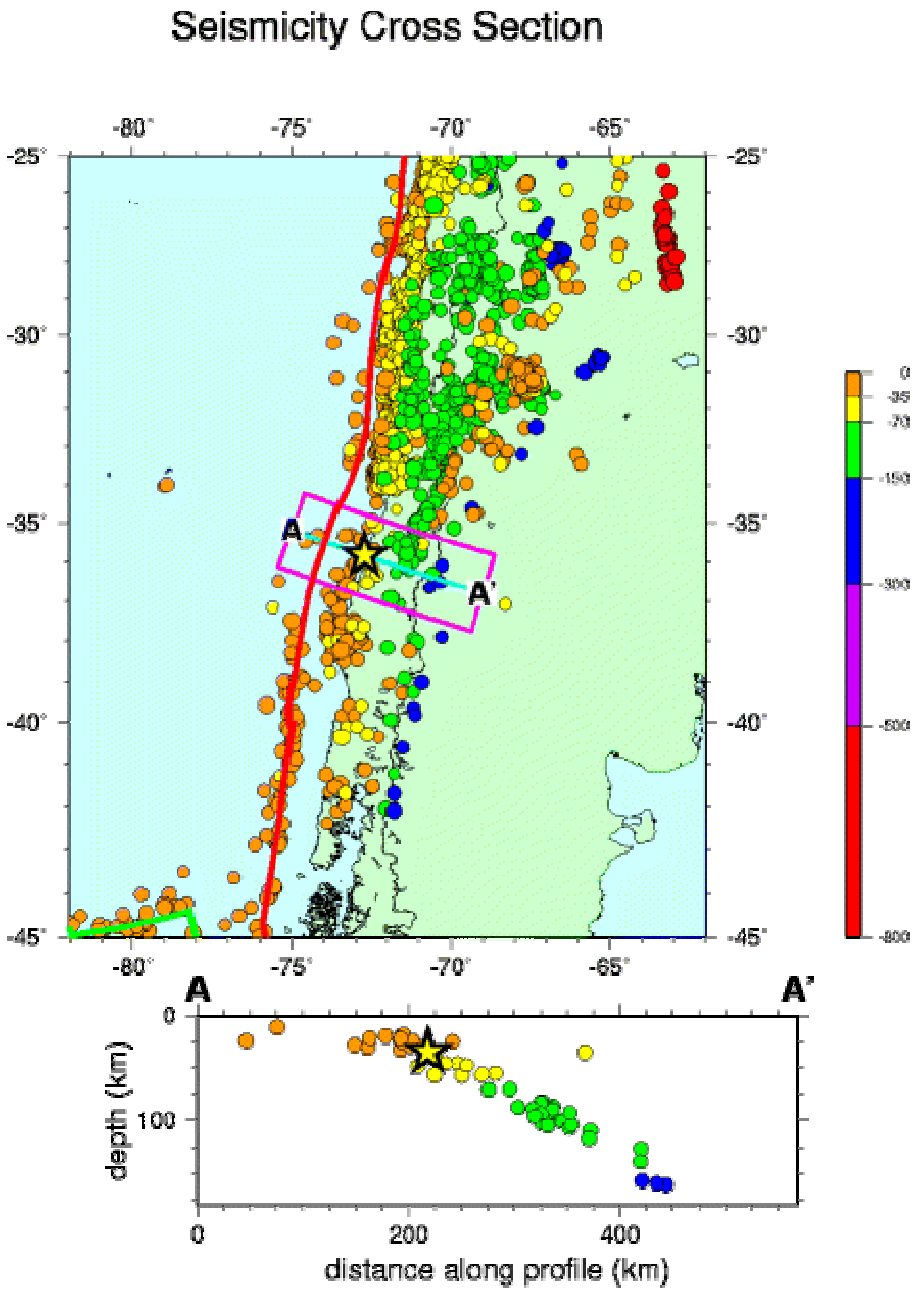

Figure 2.2. Aftershock distribution by depth. Star indicates hypocenter of mainshock. Figure from USGS web page (http://neic.usgs.gov/neis/eq_depot/2010/eq_100227_tfan/neic_tfan_c.html).

2.3 Ground Motions

Seismograph networks in the portions of Chile that experienced strong ground motion from the Offshore Maule earthquake are maintained by RENADIC (Red National de Acelerografos Departamento de Ingenieria Civil, Universidad de Chile = National Network of Seismic Monitoring Devices – Department of Civil Engineering, University of Chile), RENASIS (Red

National de Acelerografos Departamento de Sismológica, Universidad de Chile = National Network of Seismic Monitoring Devices – Seismology Department, University of Chile), and Pontificia Universidad Católica de Chile (Catholic University of Chile).

As of this writing, preliminary results from the portions of the RENADIC and RENASIS networks have been released in a series of web reports (http://www.terremotosuchile.cl/). These reports contain plots of acceleration waveforms and response spectra for selected stations. Table 2.1 lists stations that recorded the earthquake in the RENADIC and RENASIS networks based on personal communication with C. Ledezma (April 21 2010). The locations of those stations are shown in Figure 2.3. Also shown in the table are the peak horizontal acceleration (maximum of the two horizontal components) for stations described in the available web reports. Data for stations without a reported PHA or "Data Report Reference" in Table 2.1 is not available in the web reports.

With the exception of the four RENASIS stations, the data released to date does not include digital acceleration files, or response spectra. An example of the type of records that are currently available in the Boroschek et al. (2010) preliminary reports is shown in Figure 2.4.

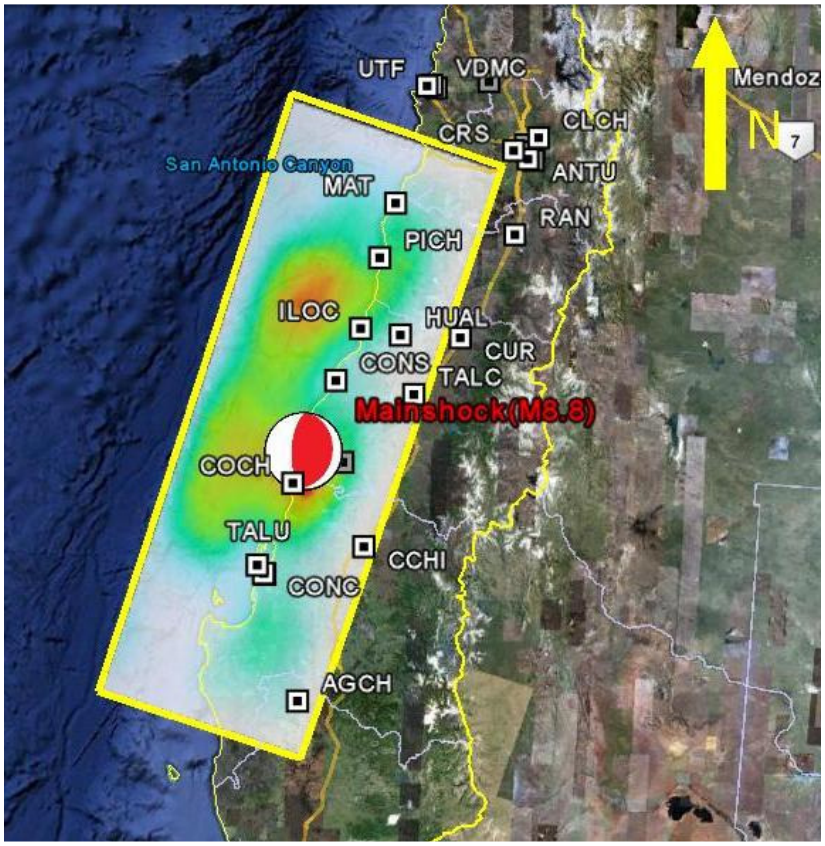

Figure 2.3. Locations of stations maintained by RENADIC and RENASIS that recorded mainshock

We understand that the Pontificia Universidad Católica array is concentrated in Concepción, which was strongly shaken by this event. There are unconfirmed reports that these stations did

not record the mainshock or its principal aftershocks due to maintenance problems. However, no official reports on station locations or data availability are available as of this writing.

Table 2.1. Information on RENADIC and RENASIS strong motion data released in plots within PDF files (as of 18 May 2010)

Station Code: Station Name	PHA (g)	Lat	Long	Source	Data Report Reference[2]
SAN: Universidad de Chile Depto Ing. Civil (Interior Edificio) Santiago	0.17	-33.4572	-70.6617	RENADIC	BEA 2010a
SANM[1]: Estación Metro Mirador Santiago	0.24	-33.5135	-70.6060	RENADIC	BEA 2010a
CRS[1]: CRS MAIPU RM	0.56	-33.5087	-70.7719	RENADIC	BEA 2010a
FSR: Hosp. Tisne RM	0.30	-33.5006	-70.5792	RENADIC	BEA2010a
RIO[1]: Hosp. Sotero de Río RM	0.27	-33.5769	-70.5811	RENADIC	BEA 2010a
CUR[1]: Hosp. Curico	0.47	-34.9808	-71.2364	RENADIC	BEA2010b
VLCH: Hosp. Valdivia	0.14	-39.8306	-73.2390	RENADIC	BEA 2010b
VDMM[1]: Vina del Mar (Marga Marga)	0.35	-33.0482	-71.5099	RENADIC	BEA 2010c
VDMC[1]: Vina del Mar (Centro)	0.33	-33.0256	-71.5508	RENADIC	BEA2010c
CCSP: Colegio San Pedro, Concepción	0.65			RENASIS	UC, 2010
CLCH: Cerro Calán, Santiago	0.23	-33.3961	-70.5369	RENASIS	UC, 2010
ANTU: Campus Antumapu, Santiago	0.27	-33.5691	-70.6335	RENASIS	UC, 2010
ROC1: Cerro El Roble	0.19	-32.9759	-71.0156	RENASIS	UC, 2010
UTF: VALPARAISO – UTFSM		-33.0346	-71.5956		
MAT[1]: MATANZAS		-33.9604	-71.8734		
RAN[1]: RANCAGUA - HOSPITAL REGIONAL		-34.1645	-70.7417		
PICH: PICHILEMU		-34.3871	-72.0136		
ILOC: ILOCA		-34.9362	-72.1811		
HUAL[1]: HUALAÑE		-34.9765	-71.8053		
CONS: CONSTITUCION		-35.3401	-72.4057		
TALC: TALCA		-35.4299	-71.6649		
CQNS[1]: CAUQUENES		-35.9628	-72.3242		
COCH: COBQUECURA		-36.1307	-72.7945		
CCHI: CHILLAN		-36.6043	-72.1042		
TALU[1]: TALCAHUANO – USGS		-36.7591	-73.1221		
CON: CONCEPCION - Colegio Inmac. Conc.		-36.8281	-73.0483		
CONC: CONCEPCION-COLEGIO Ma Inmaculada		-36.8221	-73.0599		
AGCH: ANGOL		-37.7947	-72.7081		
VLCH: VALDIVIA – HOSPITAL		-39.8306	-73.2390		

[1] Station code assigned in this report (no superscript indicates station code from Chilean source)

[2] BEA=Boroschek et al.; UC = Universidad de Chile

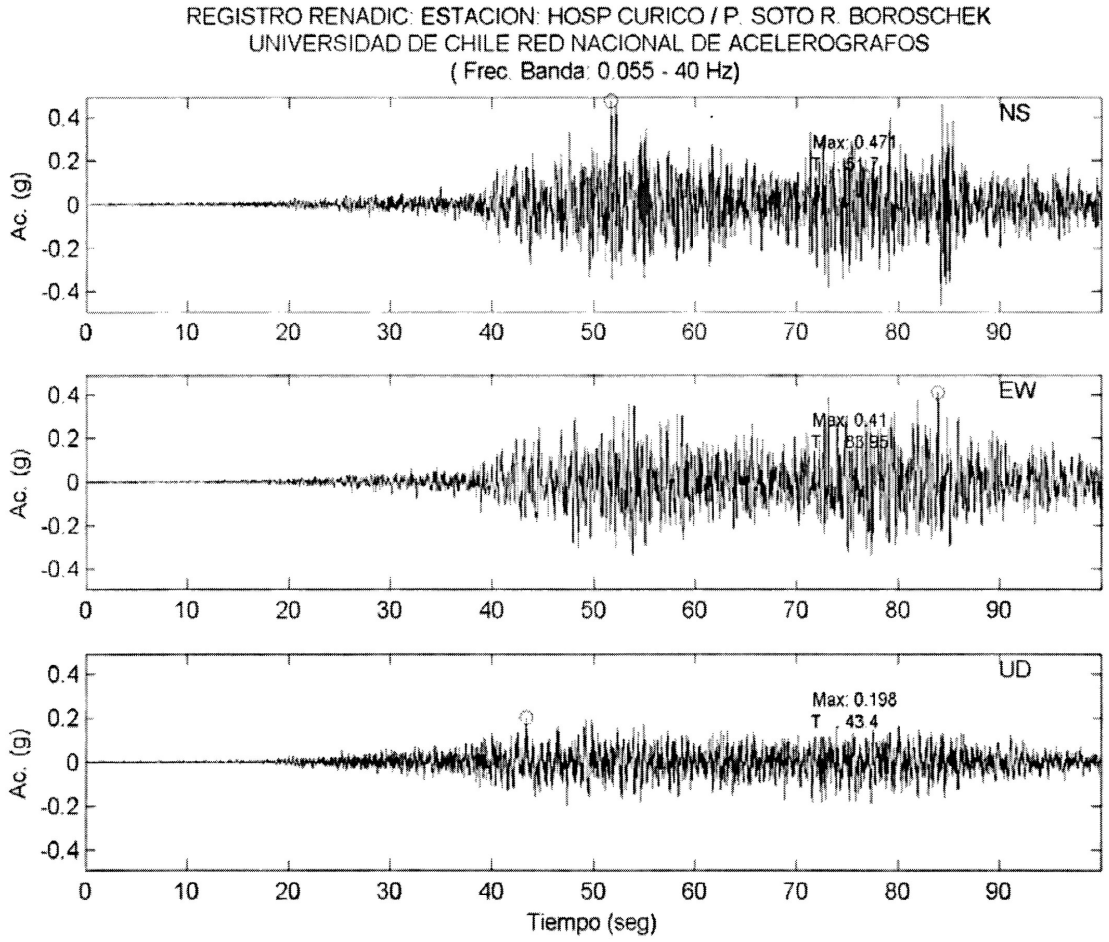

Figure 2.4. Acceleration-time series recorded at the Hospital in Curico during the 2010 Mw=8.8 Chile Earhquake

2.4 References

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