



MICROZONING STUDIES IN THE MAULE REGION, CHILE

M. Araneda*, J. Monge**, M.S. Avendaño*

*Depto. Geofísica, Universidad de Chile, Casilla 2777, Stgo. Chile

**Depto. Ing. Civil, Universidad de Chile

Abstract

The region of Maule, which is located between parallels 34°40'S and 36°15'S with an area of 30302 Km², lies within a seismic gap. This study covers the nine main cities and towns which include about 50% of the population and dwellings of the region.

The purpose of this study is to carry out an evaluation of soil for foundation. A high percentage of houses and public buildings, within this region are made of adobe. This is why it is necessary to evaluate the risk and the quality of the soil for future expansion of the cities and towns of the region.

Microzoning results, mainly evaluate by microseismic refraction experiments, which yield values for longitudinal and transverse wave, geology information and underwater level.

The results shown on isovelocity curves of the second layer and isopach line of the first layer of the cities of Curicó, Molina, Talca, San Javier, Linares, Parral, Cauquenes, Constitución and San Clemente, which show a good correlation with the former given parameter.

The cities which are located on the Central Valley show mean velocity of $V_p=1200-1800$ m/s and $V_s=530-910$ m/s with a depth of 2.5-3.5 m which correspond to gravel deposit of the Central Valley. The velocity of the city of San Clemente $V_p=940$ m/s, $V_s=395$ m/s correspond to power fine clays. Talca is composed by gravel and volcanic ash and the correspondent transition zone, shows $V_p=1700$ m/s, $V_s=850$ m/s y $V_p=790-1600$ m/s, $V_s=305$ m/s respectively. The transition zone is not well defined to the geophysical information. By the way the volcanic ash zone shows a great dispersion of values of velocity and thickness of the correspondent layer. Constitución, the last city shows a great dispersion of values of V_p and V_s and of the thickness of the correspondent layers.

Generally the Region of Maule show very good soil for foundation, considering the second determined strata. In this way the first strata must be taken away. The thickness of this strata varies from 1.5 to 3.5 m.

Introduction

Many methods have been used to microzonic areas of interest: Akamatsu et al (1995) made a microzonation

earthquake Algermissen *et al.*, 1976, is making probabilistic studies to estimate the maximum acceleration. In the case of strong ground motion records as they represent the real target events are the most reliable (e.g. Tuleker and King, 1984; Lermo *et al.*, 1988). In addition examples can be given using nuclear explosion (Rogers *et al.*, 1984) quarry blast, vibration (Atakan 1991) and signal such a tremors from commuter trains (Nakamura 1989).

In general all the methods give a partial knowledge of the seismic zonation or microzonation as in Chile, where cities like Valdivia, Concepción, Talcahuano, Santiago, Taltal, Tocopilla, Coquimbo, La Serena, Viña del Mar, San Antonio, Valparaíso and Arica have been mainly led to the buildings damage according to the MSK intensity scale, geological information and other particular studies.

Geological Setting

The areas comprised in this study are constituted by the Central Valley and the Coast Range. The first is constituted by Quaternary sediments. These sediments are mainly present in the Central Valley and in the adjoining valley. The Central Valley is a morpho-tectonic unity characterized by strong deposits of sediments. These deposits have few to high consolidation and are principally composed by laharcic deposit and Alluvial sediments of pleistocene and recent age.

The second formation is constituted by mountain chains which border up the east zone of the Central Valley and are composed by volcanic-continental formation of the Central Range stratified and folded of the Tertiary to Pleistocene age. These rocks are run through by intrusive rock borders, that constitute dikes, mantle lodes and volcanic necks.

Analisis of the results

Seismic experiments were distributed among the most important cities and some village of the Maule Region in an attempts to make the samples as representative as possible Table I summarizes the collected data and figures 3 to 11 show the cities with the distribution of the seismic experiments, the isovelocity curves of the 2nd layer and isopach line of the 1st layer.

TABLA I

| | 1st Layer | | | 2nd Layer | | | 3rd Layer | | | Intensity | | Level underground water |
|--------------|-------------------------|-------------------------|---------------|-------------------------|-------------------------|---------------|-------------------------|-------------------------|---------------|-------------|----------|-------------------------------|
| | V _D [m/s] | V _S [m/s] | Thick. [m] | V _D [m/s] | V _S [m/s] | Thick. [m] | V _D [m/s] | V _S [m/s] | Thick. [m] | R-RF Bob | M-M K | |
| San Clemente | | | | | | | | | | | | |
| Profile 1 | 925 | 394 | >13 | 950 | 400 | >11 | | | | X | VIII-IX | >10 m |
| 2 | 780 | 370 | 4-5 | 930 | 395 | >13 | | | | X | VIII-IX | >10 m |
| 3 | 740 | 260 | >2.0 | | | | | | | X | VIII-IX | >10 m |
| Constitución | | | | | | | | | | | | |
| Profile 1 | 615 | 227 | 4.0 | 1150 | 510 | 7.0 | 2103 | 1040 | >12 | X | VIII | >2 m |
| 2 | 450 | 170 | 3.0 | 760 | 312 | 6.0 | 1850 | 840 | >18 | X | VIII | >2 m |
| 3 | 588 | 206 | 3.5 | 1140 | 520 | 3.0 | 1550 | | >17 | X | VIII | >2 m |
| 4 | 440 | 150 | 4.5 | 1390 | 630 | 9 | | | | X | VIII | >2 m |
| 5 | 750 | 265 | 1.0 | 1200 | 572 | >15 | | | | X | VIII | >2 m |
| 6 | 250-400 | 115 | 1.5 | 1190 | 570 | 5.0 | 1700 | 850 | >15 | X | VIII | >2 m |
| 7 | 700 | 255 | 2.0 | 1324 | 575 | >12 | | | | X | VIII | >2 m |
| 8 | 600 | 205 | 2.5 | 1135 | 520 | 4.0 | 1600 | | >15 | X | VIII | >2 m |
| Molina | | | | | | | | | | | | |
| Profile 1 | 500 | 160 | 0.5 | 2130 | 1065 | >13 | | | | VIII-IX | VIII | >4 m |
| 2 | 1200 | 390 | 3.0 | 2310 | 1175 | >12 | | | | VIII-IX | VIII | >4 m |
| 3 | 1600 | 530 | 3.0 | 2500 | 1260 | >13 | | | | VIII-IX | VIII | >4 m |
| 4 | 1200 | 535 | 3.0 | 2120 | 1060 | >14 | | | | VIII-IX | VIII | >4 m |
| 5 | 1100 | 440 | 3.0 | 2200 | 1170 | >13 | | | | VIII-IX | VIII | >4 m |
| Líneres | | | | | | | | | | | | |
| Profile 1 | 700 | 255 | 2.0 | 1250 | 550 | 5.0 | 1870 | 915 | >12.0 | VIII-IX | VIII | 8 - 15m |
| 2 | 500-780 | 240 | 3.0 | 1900 | 965 | >14.0 | | | | VIII-IX | VIII | 8 - 15m |
| 3 | 830 | 330 | 2.5 | 1800 | 890 | >12.0 | | | | VIII-IX | VIII | 8 - 15m |
| 4 | 500-1000-345 | 2.0-5.0 | | 1815 | 910 | >12.0 | | | | VIII-IX | VIII | 8 - 15m |
| 5 | 764 | 260 | 2.5 | 1600 | 755 | >12.0 | | | | VIII-IX | VIII | 8 - 15m |
| 6 | 550 | 190 | 1.5 | 2160 | 1080 | >12.0 | | | | VIII-IX | VIII | 8 - 15m |
| 7 | 430 | 150 | 0.7 | 770 | 350 | 4.0 | 2250 | 1160 | >13.0 | VIII-IX | VIII | 8 - 15m |
| 8 | 360 | 105 | 2.8 | 2140 | 1060 | >14.0 | | | | VIII-IX | VIII | 8 - 15m |

| | | | | | | | |
|---------------------|--------------|-------------|------|-------------|------|------------------|---------|
| Parral | | | | | | | |
| Profile 1 | 545 | 190 4.0 | 1700 | 800>12.0 | | VIII-IX VII-VIII | 7 - 10m |
| 2 | 445 | 148 3.5 | 1500 | 745>17.0 | | VIII-IX VII-VIII | 7 - 10m |
| 3 | 770-1040-392 | 4.5-7.1 | 1650 | 770>12.0 | | VIII-IX VII-VIII | 7 - 10m |
| 4 | 460 | 165 3.5 | 1180 | 530 5.0 | 1900 | 965>12 | 7 - 10m |
| 5 | 375 | ~ 115 1.7 | 915 | 392 2.5-7.0 | 1417 | 645>12 | 7 - 10m |
| 6 | 380 | ~ 115 2.0 | 1035 | 427 4.0-7.5 | 1660 | 770>13 | 7 - 10m |
| 7 | 710 | 225 2.5 | 1050 | 430 3.0 | 1650 | 768>12 | 7 - 10m |
| Cauquenes | | | | | | | |
| Profile 1 | 445 | 148 0.5-2.0 | 565 | 180 2.5-4.5 | 750 | 265>17 | 2 - 7m |
| 2 | 870-1200-425 | 2.5-4.0 | 1700 | 830>15 | | VIII-IX VII-VIII | 2 - 7m |
| 3 | 660 | 250 5.0 | 1725 | 850>15 | | VIII-IX VII-VIII | 2 - 7m |
| 4 | 985 | 415 4.0-7.0 | 1625 | 813>17 | | VIII-IX VII-VIII | 2 - 7m |
| 5 | 763 | 320 1.5-9.5 | 1385 | 628>18 | | VIII-IX VII-VIII | 2 - 7m |
| 6 | 630 | 215 3.0 | 2177 | 1085>12 | | VIII-IX VII-VIII | 2 - 7m |
| 7 | 910 | 392 4.0 | 1440 | 655>15.0 | | VIII-IX VII-VIII | 2 - 7m |
| Talca | | | | | | | |
| Profile 1 | 430 | 140 4.0 | 1900 | 965>11 | | X VIII-IX | >8 m |
| 2 | 690 | 250 4.5 | 2090 | 1070>10 | | X VIII-IX | >8 m |
| 3 | 740 | 300 2.5 | 1620 | 760>12 | | X VIII-IX | >6 m |
| 4 | 650 | 245 2.0 | 830 | 370 6.0 | 1660 | 775>8 | >8 m |
| 5 | 700 | 257 2.5 | 1700 | 850>12 | | X VIII-IX | >8 m |
| 6 | 1260 | 550 6.0 | 2150 | 1050>10 | | X VIII-IX | >8 m |
| 7 | 1180 | 530 5.5 | 1800 | 890>12 | | X VIII-IX | >5 m |
| 8 | 1055 | 425 2.5 | 1225 | 535>13 | | X VIII-IX | >6 m |
| 9 | 300 | 140 1.0 | 617 | 291 3.0 | 1880 | 714>12 | >6 m |
| 10 | 680 | 250 3.4 | 1680 | 780>16 | | X VIII-IX | >8 m |
| 11 | 825 | 330 5.9 | 1520 | 685>17 | | X IX | >8 m |
| 12 | 390 | 125 2.0 | 790 | 305 5 | 1825 | 895>13 | >8 m |
| 13 | 1130 | 515 4.0 | 1770 | 864>15 | | X IX | >5 m |
| San Javier | | | | | | | |
| Profile 1 | 580 | 200 5.0 | 1360 | 600 5.0 | 2345 | 1180>20 | -4.0 |
| 2 | 680 | 265 3.0 | 1780 | 870 5.0 | 2490 | 1250>18 | -4.0 |
| 3 | 440 | 160 1.0 | 1260 | 555 7.0 | 1780 | 870>15 | -4.0 |
| 4 | 660 | 260 3.0 | 1430 | 650>18 | | X VIII-IX | -4.0 |
| 5 | 360 | 105 1.0 | 1190 | 530 5-11 | 2140 | 1050>6-13 | -4.0 |
| 6 | 600 | 220 1.0 | 1060 | 430 3.0 | 2280 | 1170>17 | -4.0 |
| Curicó | | | | | | | |
| Profile 1 | 600 | 220 4.0 | 1770 | 864>12 | | VIII-IX VIII | >6 m |
| 2 | 605 | 225 4.0 | 1900 | 965>12 | | VIII-IX VIII | >6 m |
| 3 | 720 | 250 3.0 | 1720 | 800>14 | | VIII-IX VIII | >8 m |
| 4 | 800 | 360 3.5 | 1750 | 860>13 | | VIII-IX VIII | >8 m |
| 5 | 860 | 357 5.0 | 2150 | 1050>14 | | VIII-IX VIII | >8 m |
| 6 | 890 | 360 5.0 | 1800 | 890>15 | | VIII-IX VIII | >8 m |
| 7 | 550 | 190 4.0 | 2160 | 1080>16 | | VIII-IX VIII | >8 m |
| 8 | 980 | 415 3.0 | 1910 | 960>17 | | VIII-IX VIII | >8 m |
| 9 | 1030 | 425 3.5 | 2075 | 1060>16 | | VIII-IX VIII | >8 m |
| Putu | | | | | | | |
| Profile 1 | 440 | 160 4.0 | 1100 | 440 6.0 | 1643 | 765>18 | >2 m |
| Pencahue | | | | | | | |
| Profile 1 | 300 | 105 7.0 | 1400 | 645>19 | | IX-X VIII-IX | >8 m |
| Pelarco | | | | | | | |
| Profile 1 | 450 | 155 2.0 | 1070 | 435 8.0 | 2000 | 1200>15 | >4 m |
| Empedrado | | | | | | | |
| Profile 1 | 500 | 150 1.0 | 650 | 245 3.5 | 800 | 335>18 | >10 m |
| Villa Alegre | | | | | | | |
| Profile 1 | 200 | 0.5 | 330 | 2.5 | 1800 | 890>18 | >4 m |
| 2 | 414 | 4.0 | 1680 | 180 9.0 | 2770 | >14 | >4 m |
| 3 | 400 | 3.0 | 2030 | >15 | | IX-X VIII | >4 m |

Considering the parameters of the seismic zonation mentioned before and the geomorphological location two well defined zones can be distinguished, they are:

-Central Valley zone located to the east of the Coast Range where are the cities of Curicó , Molina, Talca, San Clemente, San Javier, Linares and Parral and the towns of Pelarco and Villa Alegre.

-Coast Range zone where are Constitución and Cauquenes and the towns of Putu, Pencahue and Empedrado.

The soil of the Central Valley are mainly composed by recent gravel deposition with different degrees of consolidation, that velocity vary between $V_p=1000$ m/s, $V_s=345$ m/s and $V_p=2570$ m/s, $V_s=1260$ m/s, with a vegetal and fine soil cover with thickness which vary among outcrop and 6 metres.

This zone show 3 exceptions that are San Clemente, a part of the city of Talca and Parral. San Clemente shows low velocities ($V_p=740$ m/s, $V_s=260$ m/s and $V_p=950$ m/s, $V_s=400$ m/s) in comparison to

characteristic gravel velocity. The thickness of the two strata, which seem to be of the same material, reach 13 meter depth.

According to available data (Araneda *et al.*, 1991) the materials found in San Clemente constituted regular consolidated clay given that fact there wouldn't be any concordance with the geology described by Thiele (1995).

Talca is founded over volcanic ashes and recent gravel deposition, but also exists a transition zone noticed by geology, which is not seen on the seismic waves analysis.

In the 1st layer, volcanic ashes show velocity of $V_p=390$ m/s, $V_s=125$ m/s to $V_p=825$ m/s, $V_s=330$ m/s with. Thickness of 2 to 6 meters.

The 2nd layer show velocity very similar to the gravel ones $V_p=2090$ m/s, $V_s=1070$ m/s to $V_p=1520$ m/s, $V_s=685$ m/s. By the way, the elastic behaviour of the volcanic ashes seems to be very different to the seismic answer. Astroza y Monge (1992) in order to check the values given by Medvedev, determined the average increment for the quaternary deposits comparing the isoseismals on rocks with the intensities obtained in 88 cities and villages located in the damaged area of the earthquake of Valparaíso on March 3, 1995.

| Geologic unit | Number of data | Increment of intensity intensity respect to rock |
|-------------------------|----------------|---|
| Volcanic pumicite ashes | 19 | 1.5 - 2.5 |

The transition zone which is marked by geology is not seen on the velocity analysis.

Parral also shows 2 kinds of soil: volcanic pumicite ashes with similar characteristics to the ones found in Talca and early alluvial fan deposit.

The towns of Villa Alegre and Pelarco show the same soil characteristics of the Central Valley, a thin soil cover over a strong gravel strata.

In the Coast Range zone, soils have different origins: early alluvial deposit (Cauquenes) over an irregular topography with irregular velocities and thickness likes it is shown on Table 1. The important fact with this city is that the old alluvial deposits show the same characteristic of the Central Valley, only experiments # 1 shows a big difference (1st layer $V_p=445$ m/s, $V_s=148$ m/s; 2nd layer $V_p=565$ m/s and $V_s=180$ m/s).

Sand and gravel deposits of different ages (Constitución). These sediments mainly consists on non-homogeneous sandy fluvial deposits as shown by the measured velocity and strata. The city is located on the border of the Maule river in a plain with a slight slope to the north. Generally, the velocity of the 1st layer are quite low $V_p=750$ m/s, $V_s=345$ m/s with variable thickness among 1 to 4.5 m.

The second and third layer are, in some cases, probably affected by the ground water level due to they present relative high velocities, although it is not common on sand $V_p=1135$ m/s, $V_s=520$ m/s to $V_p=2103$ m/s, $V_s=1040$ m/s.

Putu, Pencahue and Empedrado villages are composed by sand thick layer of clay and a thick layer of clay, respectively Araneda, Avendaño (1995).

Conclusion

Soil microzoning technology seems appropriate for this study, since there is a solid correlation between velocities and type of soils established through geological observation. The foundation soils found in the

Maule Region can be clasified in the following way:

| Velocity | | Geology Formation | Ground wat. lev. m | Q |
|-------------|-------------|-------------------|-----------------------|-----|
| V_p (m/s) | V_s (m/s) | | | |
| 1200-2500 | 500-1260 | gravel | > 6 | I |
| 1000-1200 | 400- 500 | gravel | > 6 | II |
| >1000 | | | | III |

Vegetal and thin soil can be considered as I very good II regular III deficient IV bad.

Although volcanic ashes have high velocities $V_p=2090$ m/s, $V_s=1070$ m/s to $V_p=1520$ m/s $V_s=685$ m/s, should be considered on type II but objectly.

Aknonledgements

The support recived in part to own research through the 1931000 Fondecyt proyect, is gratefnnly acknowledged.

REFERENCE

- Akamatsu, J., K. Nishimura, M. Komazawam (1995). Microzonation of a sedimentary region based on comparative analisys of microseismic and gravity anomaly. *Proceedings of the Fifth International Conference of Seismics Zonation, I*, 933-940.
- Algermissen, S.T. and D.M. Perkins (1976). A probabilistic estimate of maximum aceleration in rock in the contiguous united state. *U.S. Geological Survey Open-File Report*,74-416.
- Araneda, M., J. Monge and M.S. Avendaño (1991). Soil behavior analisys in anomalous intensity region after the 1985 earthquake, Chile. *Proceedings of the Fourth International Conference on Seismic Zonation, Stanford, California, II*, 443-449.
- Araneda, M.,M.S. Avendaño (1995). Map validity of isosists in the earthquake by microzoning studies, Chile. *Proceedings of the Fifth International Conference on Seismic Zonation, Nice, France, II*, 1443-1450.
- Astroza, M., J. Monge (1992). Studies of seismic micro and Mezozoning in Chile: Limitation to the use of weak types of Constitución. *Revista Geofísica, Instituto Panamericano de Geografía e Historia*, 37,15-30.
- Atakan, K. (1991). Assessment of local site effects in the Etne Region, Southwestern Norway using microtremors and vibrator signals. *Institute of Solid Earth Physics, University of Bergen, Norway. Internal Summary Report*, 5p.
- Lermo, J.F., M. Rodriguez and S.K. Singh (1988). Natural period of the sities in the valley of Mexico from microtremor measurement and strong motion data. *Earthquake Spectra*, 4-4,805-814.
- Medvedev, S.E. (1965). Engineering seismology. Jerusalem, Israel. Program for Scientific Translation.
- Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surfece. *Quarterly Report of Railway Technical Res. Inst. of Japon*, 30,Nº1,25-33.
- Rogers, A.M., R.D. Borchardt, P.A. Covington, D.M. Perkins (1984). A comparative ground rsonce study near Los Angeles using recordings of Nevadas nuclear tests and the 1971 San Fernando earthquake. *Bull. Seismol. Soc. Am.*, 74,1925-1949.
- Thiele, R. (1995). Geología del cuaternario en la región del Maule. *Proyecto Estudio del Riesgo Sísmico en la Región del Maule, Fondecyt.(unpublished)*.
- Tucker, B.E. and J.L. King (1984). Dependence of sediment-filled valley response on input amplitude and valley properties. *Bull. Seismol. Soc. Am.*,74, 153-165.

