ANTOFAGASTA RADIUS PROJECT CASE STUDY

FINAL REPORT

Project for IDNDR
OCHA, United Nations

ANTOFAGASTA, SEPTEMBER 1999.

CONTENTS

Chapter 1 INTRODUCTION

1.1 General Description of the City

Antofagasta, a name in Quechua language meaning "Town of the Great Salar", is the main city and port in Great Northern Chile and the capital of the region also called Antofagasta. It is located at Bahia Morena to the south of the Mejillones peninsula, 23º38' S. and 70º25' W. The Tropic of Capricorn crosses the airport area 25 km to the north of the city.

Antofagasta has 228,408 inhabitants according projections for 1996 using the 1992 population census. Its desert coastal climate is quite stable during the year and temperature ranges from 13ºC to 24ºC. As the city is located at the coastline of the Atacama Desert, it shares its total lack of rainfall.

A Bolivian city before 1879, it occupies a terrace at the base of the bleak, arid coastal mountains named Cordillera de la Costa. Its early growth resulted from the nitrate boom that began in 1866 and from the Caracoles silver discovery of 1870, at which time the name Antofagasta became official. Thus, its origin and development have been closely related to the mining production advances in the desert and The Andes, which serve as communication path with the rest of the world. During the nitrate and silver boom, the city consolidated as a seaport for exporting minerals, importing mining equipment, machinery, food and consumer products in general for the mining population. This also implied a strong immigration of people from other parts of Chile and Europe, influencing its customs and the pre-dominant architecture of the oldest sections of the city.

The 1930 world crisis not only put a brake to the expansion process, but was also an economic disaster implying a step back for nitrate production and a huge decrease in the population. Until 1950, construction was almost non-existent and people were mainly engaged in administrative activities and shipping the copper production at the seaport from the highlands.

In the last decades, Antofagasta has faced a new prosperity cycle, which is explained mainly by the great increase in foreign investment for mining, especially copper, and the production expansion of old mines. This has caused an increase in the flowing population hired for setting up these projects and also a great expansion in highway and airway communication, telecommunication, big national shopping centers (supermarkets, drugstores, department stores, etc.), hotel industry development, and massive establishment of mining industry suppliers.

Supplying the mines and exporting copper and sulfur are still its major activities. Besides foundries and refineries, ore-concentration and sulfuric acid manufacturing facilities, there are local food and beverage processing industries. Today, Antofagasta is the shipping port for the copper mined at La Escondida and Chuquicamata, the latter being known as the world's largest open-pit mine. It has an important seaport, industries and service provision for the region. More than 20% of the country's total export is shipped from here, amounting to about US$3,600 million annually. It is also worth noting its industrial area, whose factories use modern technology related mainly to the mining and metallurgical field. In the last few years, industries have moved to the city access areas.

The city also has three regional universities with the country's highest ratio of students to its total population. These colleges are focused principally on professional and research training in technological and business areas directly concerning the dominant economic activities.

There is a regional government base in the city and as well as bases for all the nationally existing fiscal institutions. Besides, the main mineral and industrial suppliers and financial and business services have set up in the city. There is a regional Industrial Association based in the city, too.

In brief, the city started developing 130 years ago, with the object of becoming a communications bridge between mineral export activities and the world. This task is now directed to the commercial and financial fields and to mining and industrial production as well.

The following table shows that these features have become more noticeable. The regional expansion of mining production has increased three times in one decade. It shows that national increase is nine times higher than that for the corresponding increase worldwide. Evidently, there is a structural change with the logical effects on the natural environment and production relations, which show qualitative rather than quantitative changes.

	1986 (tmt)	World 1986 (%)	1996 (tmt)	World 1996 (%)	Variation 1986-1996
CODELCO Chuquicamata (state)	515.2	6.13	632.3	5.81	
Escondida Ltd. Mining Co.	0.0	0.00	841.4	7.73	
Regional Mining (except above)	57.3	0.68	313.9	2.89	
Regional total	572.5	6.82	1787.6	16.43	212.24
National total	1401.1	16.69	3115.8	28.64	122.38
World total	8393.2	100.00	10878.2	100.00	29.61

Table 1.1 Marketable Copper Production in the Antofagasta Region
(Fine copper in thousands of MT, tmt)

The importance of the table is reinforced when considering other complementary issues that give evidence of the enormous regional production growth in the last few years. The direct foreign investment from 1991 to 1996 amounted to US$ 2937 million, one of the highest in the country, with an average growth of 43.7%, which 95.5% was due to mining. As a result of the great mineral investment, the regional GGP has increased at an annual average rate of 8.2%, ranking fourth among the regions. This regional production growth has affected indirectly other activities in terms of production and employment. It is especially interesting to point out that the workforce has increased at an annual average rate of 4% between 1991 and 1996, while direct employment in mining companies has grown only 1.4%, thus decreasing unemployment average from 15% to 13%. Mining represents about 60% of the regional GGP.

This expansion has brought about a sudden increase in electrical supply investment, which doubled the generating capacity in the last decade. The current capacity of 1.4 MW will be tripled in the next three years. This has caused an important price decrease, stimulating industrial growth. Plans for seawater desalination and use for human and industrial consumption are set up by taking advantage of low energy costs.

1.2 Demographic Data

The regional population amounts to 410.724 inhabitants, corresponding to 3.1% of the national population. This determines a density of only 3.2 inhabitants/km^2, which is quite under the country's average density. 84.4% of the regional population lives in Antofagasta and Calama. City inhabitants are 228,408, of which 113,405 are men and 115,003 are women. 226,850 are urban citizen and only 1,558 are rural.

The regional urban population lives in eleven scattered small towns (the commune capital closest to the regional capital is at 64 km away and the farthest one is at 392 km) which are related to mining activity either by exploitation or furnishing of services. A meaningful portion of the urban population comes from other zones. Those who were born in the region come from families whose previous generations migrated from bordering countries, the Chilean bordering zone to the south (Small North) and from other countries, mainly Europe and Arabia. Immigration, both past and present, has been due to the appeal of mining activity, first silver, second nitrate and then copper. At present, other mining projects are opening up.

The rural population is scarce and it represents only 2.7% of the regional population, while national rural population is 16.5%. It is represented mainly by indigenous people, Kunzas or Atacameños and Aymaras, who live in towns 2000 and 3600 m.o.s.l. These are the only indigenous populations, of millenary tradition, that belong to the Andes world shared with Bolivia, Peru and the northeast of Argentina. They are mainly shepherds, though many of them have migrated towards the city and the mining centers.

The regional economy makes up 5.3% of the country's GGP, its product per capita ranking is second to the region of Magallanes and twice the national one.

For the 1985-1997 time span, the regional GGP had an accumulated growth of 96%, with an annual average rate of 5.8%. Economic activity is greatly dependent on mining and its cycles of international demand and price. The mining activity represents about 60% of the regional GGP, which makes up 32% of the country's mining GGP. Other important sectors are the manufacturing industry (6.2%), transport and communications (6.1%), construction (5.9%) and individual service (5.6).

The unemployment rate has been lower than 5% of the workforce, fluctuating between 2.3% and 5.2%. This is explained mainly by the tremendous growth of copper mining investment. This figure is quite low if compared with the national average, which was 6.7% for the same period.

For the last ten years, the workforce productivity in the region of Antofagasta had an average greater than 155% as to the national media and its growth is greater than the national one.

1.3 Special Feature of the City

Antofagasta has a unique morphology. It is 27 km long from north to south and an average width of 2 km, as shown in the map enclosed (Fig 1-1) The average cost of the consumer basic consumption is 30% higher than in the capital area of the country because its is quite far away from the basic product suppliers. This fact makes transport and communications more expensive. House and rent prices are also very high due to the lack of proper building land and its morphology. These prices are 50% higher than those in the capital area. So, there is a tendency to reduce construction quality, especially for the low-class sector. Moreover, construction regulations have not been historically strict.

The region and the city have notably expanded both urban and productively, Employment has increased and poverty has decreased steadily in the last few years. But there is still a socially marginal group formed of those people who have not improved their living conditions or working abilities and those low- and middle-class youngsters who face unemployment rates duplicating the average. All this results in 15% of the population living in poor houses located mainly in the north sector and in the hills surrounding the city. This situation also affects the middle-class population that is highly unstable because of lack of employment, which, in turn, is due to the liberalization of work and the reduction of work protection resulting from the application of the economic policies in the last two decades. This is graphically expressed by the increasing outsourcing of the tasks and processes by the big mining and business enterprises. This brings about a reduction of funds for house maintenance and quality.

Biannual	Contractors (Workers' average)	Permanent (Workers' average)	Average % (Contractors/Permanent)
1987-1988	2308	19010	12.1
1990-1991	3584	22003	16.3
1993-1994	9310	19091	48.7
1996-1997	19384	17930	108.1

Table 1.2 Mining Contractors in Antofagasta (biannual average)
Information based on SERNAGEOMIN: "Anuario de la Minería".

The oldest buildings are located downtown next to high buildings for government offices and financial institutions and the shopping center of the town. This area is close to the seaport (surrounded by the city) and is crossed by the railway built in the early days. Under these circumstances and as a result of the great mining expansion mentioned, traffic problems and air contamination have increased. An investment program has started in order to move seaport activities to Mejillones (60 km to the north) in the next 15 years. This involves re-directing the railway and urbanizing the site.

To the north and along the main axis, we find the low-class houses for poor people working in the city and non-permanent mining workers, and also the main local food and beverage industries next to the mining industry suppliers and the fuel collection tanks for the big mining centers. Due to the special geographic feature of the city, a great portion of the low-income population has built their houses at the bottom of the hills, in areas difficult to access and with low quality land. To the north, the city is connected with Mejillones and other northern seaports by a coastal highway. To the north end, there are small farms, orchards and poultry breeders. The international airport is located north outside the city. There is a railway to transport the mining production from Chuquicamata to Antofagasta. This railway also reaches Bolivia.

In the southern part of the city, there are residential areas with high buildings, universities and recreational centers (parks, coastal avenue, sport centers, etc.). Most mining workers (at Escondida, Carolina de Michilla and others) and middle- and upper middle class families live here. The high-income population lives at Jardines del Sur, located at the south end. A highway connects the city first with an industrial area at La Negra (where there are a cement industry, a smelting industry and other mining companies) and then with the road to Escondida. Also to the south of the city, we find Escondida seaport, Coloso, where a gravity duct is used for receiving the mineral.

Most food and finished products for the population come from the south of the country in trucks. The 1991 landslide and the 1995 earthquake destroyed the highway in part and caused supply problems. An earthquake could also affect the northern highway. The airport was used successfully in these cases.

Water comes from tributaries and rivers originating in the Andes through a 300-km pipeline. It is treated to eliminate excess arsenic and changed into tap water at the northeast access to the city.

Electric power is generated in thermoelectric plants at Tocopilla (at 210 km) and Mejillones (at 60 km). Both are located to the north of the region. There is an interconnected system using gas or electric power from the northwest of Argentina.

Petroleum and its by-products are collected in storage tanks within the urban area. These tanks are filled directly from ships through pipelines.

Chapter 2 DISASTERS IN ANTOFAGASTA

2.1 Historical Records

Chile has been historically affected by natural disasters and the Region of Antofagasta is not an exception. In June 1991, an alluvion killed about 100 people, others lost their houses and economic loss was great. The 1995 earthquake affected mainly the port of Antofagasta. It did not kill anyone and there was no great economic loss. But this is not the "historic" earthquake expected for the north of Chile and south of Perú.

2.2 Seismic Antecedents

There have been great earthquakes in Antofagasta. Some of them have been followed by "tsunamis", like those in 1877 and 1922. No one died and there was little facility loss. In 1929, an earthquake-like movement occurred between Pisagua and La Serena. Two people died in Antofagasta and some were seriously hurt. Old walls fell and 60 houses were almost destroyed. The Seismology Service estimated an intensity of 8º, reaching 9º in Estacion Pampa Union. In 1950, an earthquake killed 4 people and hurt dozens of others in Antofagasta. Old and poorly kept buildings fell or cracked. A "tsunami" that affected the zone between Antofagasta and Talcahuano took place on November 5th, 1952. It was due to an earthquake whose epicenter was off the Chilean coast. Some boats disappeared and several coastal sectors of Antofagasta were flooded. The water did not go down for three hours and one of the waves was 3.6 m high.

On June 30th, 1995, an earthquake of magnitude 7.3 in the Richter scale and maximum intensity of VII occurred at a depth of 36 km with the epicenter in Cerro Moreno airport. The population panicked and some buildings were damaged. The seaport was seriously affected and it has not been fully repaired so far.

In neighboring cities like Taltal, seismic activity has been recorded since 1913. On July 13th, 1936, a strong earthquake damaged 80% of the houses. Tap water tanks and pipelines collapsed and the city was deprived of water for several days. Electricity posts and telegraph wires fell. On December 28th, 1996 a strong earthquake occurred in Antofagasta and La Serena. In Taltal, it had an intensity of 8º in the international Mercalli scale. 3 people died, 6 were hurt and an unknown number of people were slightly hurt. Hundreds of families were affected, 50 houses were destroyed. Tap water service, electric power and telegraphic communications were interrupted. On June 17th, 1971, an earthquake of intensity V in the Mercalli scale and magnitude 7º caused houses to fall, there were landslides in the hills and communications were interrupted.

Earthquakes have occurred in Tocopilla since 1877 (Urrutia, R. et al. 1993). The earthquake and tidal wave were disastrous. They caused landslides in the hills, thus blocking the highways. On August 25th, 1916, an earthquake caused glasses to break and nitrate trains could not run owing to landslides. On December 20th, 1967, there was an earthquake of VIIº in the Mercalli scale. 10 people died and many were hurt. Communications were interrupted and public buildings were damaged. The government issued a decree of "catastrophe zone" for the commune.

For Mejillones, there are data for the earthquake and "tsunami" occurring on May 9th, 1877. This affected the Chilean coast up to Chiloe and also the coasts of Japan and New Zealand.

2.3 Possible Future Disasters

Among other world areas, northern Chile has been identified as one very likely to have a great earthquake. Since historic records report the last one in 1877 in Arica and there have not been any serious interplate earthquakes, (Comte, D. et al. 1994) since then, this could happen at any moment. On the other hand, as Chile is located in an active continental border where the South American plate and the ocean cortex collide, northern Chile and Antofagasta are especially vulnerable. This zone accumulates a lot of energy, which is released by seismic activity.

According to historical records, there is an earthquake every 121 years in Arica (a city located at 700 km to the north of Antofagasta and for which there is data of seismic activity for 1513-1604-1868-1877). 122 years have passed since the last one, so a big earthquake should occur in northern Chile and Peru in the near future.

2.4 Comparison with Other Disasters

The expected earthquake for Antofagasta would surpass the loss caused by the worst disaster, an alluvion, occurring on June 18th, 1991. 91 people died and 19 disappeared; 700 houses were destroyed; 198 could not be inhabited; and 4,000 houses were damaged but could be used. 921 families became homeless and there was an estimation of 20,000 people affected. The Regional Emergency Committee started working immediately. Special shelters, community kitchens and an emergency camp were set up. There was medical care in the shelters in order to control mange, lice and bronchial problems, especially in children and old people. The emergency plan involved a lot of cleaning, debris removal to find lost people, care to the people hurt, setting-up of shelters, food supply, and medical care.

Public services like tap water supply, electric power, communications systems and trash collection collapsed. The economic sector including businesses and work sources had big losses estimated in US$71,000,000.

Tap water supply and sewerage collapsed for three days. 90% of the tap water supply pipelines were working after 21 days. The city became highly polluted. 117 emergency tap water tanks were set up in different parts of the city. Water trucks were used for partial supply. Repairing the sewerage system, including collectors and outlet chambers, cost US$ 2,457,000. Repair took about 3 months.

In those places more affected, electric posts fell and 250 fifty families were deprived of electric power. The system was repaired after 8 days and costs were estimated in US$ 500,000.

The main problem was the communications network overload. The system continued working fairly well. Only one neighborhood did not communicate for several days.

The alluvion involved street cleaning and repair. 500,000 tons of mud, rock and detrital material was removed. The system began to work after 11 days. Access to the city was difficult and there was a lot of debris.

The railway to the south could not be used for 2 years. The two city accesses, north and south, were temporarily useless. The streets, especially those in the most affected sectors, were full of debris, mud and detrital material, thus blocking the traffic and making it difficult for the people to move.

Several mining enterprises stopped working for 3 days or 1 month. Small-scale mining stopped and it took it 3 months to recover its production level.

There are no other historical records of disasters in Antofagasta; however, there is geological evidence of some.

2.5 Health Area Disaster

In the health area, the worst disasters were in 1918 and 1920, coinciding with the end of I World War. At that time, the flue virus killed 36,115 people. After 1920, there were some epidemics with high death rate in Antofagasta. In 1957, 35,508 people were infected with the flu virus. There is not an exact death record, but 4,702 people died in the country. Mass vaccination programs have enabled to control the appearance of other epidemics.

Smallpox epidemics in 1902, 1903, and 1905, which originated in Bolivia, affected the Antofagasta inhabitants, killing 387 people. In 1909, 1910, and 1911, other cases appeared but their number decreased in 1924. So, it was not considered as an epidemic any more.

The bubonic pest killed 115 people in Antofagasta in 1904. A similar situation occurred in 1905, 1907, 1908, 1912, and 1913, decreasing in 1920. The last case appeared in 1930.

There are no clinical records of cholera for the last two years.

Antofagasta has faced various contamination problems, arsenic and lead being the most important in this century. The high content of arsenic in the water is due to the its origin. Water flows through rock formations with high concentrations of arsenic, killing children due to arsenic dehydration. In 1965 and 1970, two plants for removing arsenic in water and supplying the population at Calama and Antofagasta were built. Since water is scarce, several local mining industries have provided economic resources for the study of seawater desalination and use in the industrial processes, thus leaving tap water for people use.

Antofagasta inhabitants have also been affected by lead contamination. Serious health problems, especially in children and old people, have been detected in the last few years. Lead concentrate has been transported from Bolivia for 8 decades. It is collected at the Antofagasta-Bolivia railway yard, located downtown. To date, there has been sampling and cleaning in the area and it is estimated that 75% of the problem has been solved. Presently, the lead is collected outside the urban area.

2.6 Fundamentals of RADIUS Project

Considering the fast growth of Antofagasta, both in population and economic activity, the damage caused by an earthquake could be enormous. Therefore, it is very important to assess seismic risk and related phenomena like “tsunami” and landslides. There is inadequate soil use for housing, industry, recreation, services, etc. in the urban bordering zones, which contributes to increase seismic risk especially and natural risks in general.

On the other hand, there are no studies related to seismic risk and its secondary effects for Antofagasta. Thus, RADIUS will enable the study and implementation of strategies adequate for prevention and emergency. Likewise, the knowledge of potential risks and the special features of the zone will be very useful for decision-making in relation to soil use.

The risks mentioned require specialized work because, as far as prediction is concerned, the scientific community does not know exactly what is needed in order to determine and provide the exact date of an earthquake and its possible effects both on the natural environment and man-made facilities.

The possibility of an earthquake in the northern zone of Chile has been widely discussed by the regional, national and international scientific community. However, RADIUS is the first effort to arouse awareness, both local and national, of this risk. Population and construction growth could cause more damage than expected, not only in relation to human lives, but also economic and social loss.

Chapter 3 CASE STUDY

Antofagasta is one in nine cities selected worldwide that developed seismic scenarios and risk management plan as case study. It aims to raise public awareness of seismic risk and strengthen the collaboration between local government and local scientists. Geo-Hazards International transferred the appropriate technologies for seismic risk mitigation to the city.

The assessment tool is the **R**isk **A**ssessment Tool for **Di**agnosis of **U**rban Areas against **S**eismic Disaster, RADIUS. It is funded and supervised by the IDNDR Secretariat.

3.1 Objectives of the Study

3.1.1 General Objectives

Determination of seismic risk for Antofagasta: Describing the local seismic history and analyze the possibility of an eventual major seismic activity.

Scenario of earthquake damage and its immediate effects on Antofagasta: In case of a great earthquake, describe fully the possible damage, impact and effects on institutions and the city.

Plan for risk management: Make plans for proper seismic risk management in order to reduce impact, damage and to set up emergency and administrative plans.

3.1.2 Specific Objectives

Determination seismic risk: Collecting historical data to assess statistically seismic risk.

Geological characterization of the underground: This study sets the conditions seismic wave increase or decrease, which can be favored by the presence of geological faults, slopes and other conditions typical of the of the geology in the area.

Determination of an eventual earthquake: A highly destructive earthquake is designed in terms of magnitude, epicenter distance, and local geotectonic conditions influencing the spreading of seismic waves.

Map of seismic intensity: potential risk areas are identified considering possible acceleration levels (seismic wave intensity). This definition comprises added potential risks such as soil liquefaction and landslides and an eventual "tsunami". This is based on SHOA (Chilean Navy Hydrographic and Oceanographic Service) studies.

City data: This study is aimed at establishing the population density and distribution and also the classification and distribution of existing buildings. Sewage and sewerage networks are identified for pipe diameter, material used and its distribution, and tap water pipelines. Furthermore, the electric power network of the city and the generating plant networks of Tocopilla and Mejillones are identified. Highways, especially city access, railway networks, airport, and seaport are depicted. Hospitals, clinics, medical institutions, schools, day-care centers, fire stations, Red Cross, Civil Defense, police stations, and barracks are identified for facility, capacity and location.

City damage: The seismic scenario is plotted considering the occurrence of a big earthquake. Damage is estimated for buildings, victims, public service facilities and vital networks such as sewage and sewerage, tap water, street, electric, and telecommunications networks, seaport, airport, hospitals, clinics and medical centers, fire stations, etc.

Plan for seismic risk management: Description of specific actions to reduce seismic risk.

Promotion of multidisciplinary commitment to seismic risk management: Motivation activities directed to decision-makers and public officials in charge of preventing and mitigating disasters. These activities should also be addressed to company leaders and the private sector so that they can understand the seismic risk for their properties and projects and so to prevent human and economic loss. All organized groups, non-government organizations and every citizen must be included so that they can understand their vulnerability and risks.

3.2 Study Scope

It is estimated that 100% the Antofagasta population would be psychologically, physically, socially, and economically affected by a big earthquake. Also, 50% of its facilities (including buildings, distribution networks, equipment, installations, material, etc.) would be damaged to a certain extent. The study is aimed at managing specific variables to assess the seismic risk for the city and elaborating mitigation and risk management plans. The vulnerability study is divided into three stages

3.2.1 Data collection, Studies and Interviews

Historical and seismological data were collected in order to study the probability of re-occurrence and seismic risk. Many data aiming at determining the population density and its geographic distribution were collected. The most common building processes were detected so as to analyze the quality of construction and its geographic distribution. Technical data for public service networks, street network, railways, seaport and airport was also gathered. These processes involved having many interviews in order to get proper data, learn about the vulnerability and sensitivity of the city services, and their dependence and operation systems, both normal and emergency. Interviews were held with regional government institutions, city hall organizations, hospitals, clinics, service industries (tap water, sewage and sewerage, power supply, fuel stations, telecommunications, transport, housing and urbanism), prisons, business and commerce organizations, emergency organizations (fire stations, Red Cross, Civil Defense), educational institutions, police and investigation services, control institutions at the airport and seaport and the armed forces (Army, Navy and Air Force). Data connected with the soil geotectonics and quality, and potential wreck and landslide risk was collected. The tsunami data were provided by the Chilean Navy.

3.2.2 Seismic Scenario and Damage Estimation

Based on the data available, a hypothetical earthquake with its parameters and conditions was stated. The design includes its hypo-center and magnitude: date, and hour of occurrence. The special features of the city, population behavior, idiosyncrasy, and specific variable management that make it possible to assess the city seismic risk and to establish mitigation and risk management are considered. By using attenuation expressions that relate soil acceleration at basal level to epicenter distance, depth and magnitude, the possible acceleration threshold was characterized at foundation level in order to establish the potential intensity that buildings would face. Thus, the "Intensity Map" for each sector of the city was plotted. The map is therefore the definite seismic risk map for the hypothetical earthquake. In order to estimate damage, the "Vulnerability Curves" are drawn for the different types of structures built on the various types of foundations. These curves determine building damage, given a definite acceleration rate of the foundation soil. These curves also used for tap water and sewerage networks, power supply network, streets and highways, seaport and airport. Investment costs for reconstruction, number of victims and economic impact are also determined.

3.2.3 Action plans: Several recommendations are made for seismic emergency management, which involves everyone's participation. Action plans are determined, plans are prioritized, institutional commitment to implement the plans are established funding sources are set up, and the organism in charge of the whole process is chosen.

This presentation resulted from the joint work of many city organizations and is made up of a great deal of activities organized during interviews and workshops.

3.3 Work Plan

Objetives	Activities	Results
Seismic threat	Local data collection	Statistical assessment of seismic risk
Geological characterization of the underground	Geological study of urban areas and surroundings	Geological mapping
Geotectonic characterization of foundation soils	Classification and location of soil types	Zone mapping of the city
Earthquake design determination	Determination based on the statistical assessment of the destructive features of local earthquakes	Earthquake characteristics
Intensity map	Application of attenuation laws and determination of local soil acceleration	Risk area identification based on seismic wave intensity
City antecedents	Characteristic determination and distribution of the population, buildings, vital service networks and public service facilities	City geographical identification and distribution
City damage	Development of seismic scenario	Estimation of damage for the population, buildings, vital service networks and public service facilities
Risk management plan	Meetings with the local community	Ideas to reduce seismic risk
Actions for risk reduction	Analysis and discussion of ideas proposed	Description of specific actions
City commitment	Liable ideas	Leaders, organized community and population

3.4 Activity Schedule

3.4.- Activity schedule

1998			1999																	
STEPS	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**
Proyect Starting Phase		—	—																	
Kick-off meeting				●																
Seismic thrert				—	—															
Undergound geology					—	—														
Soil mechanics					—	—														
Earthquake intensity							—	—												
City data							—	—	—	—										
Interviews							—	—	—	—										
Risk and vulnerability elements									—	—	—									
Workshop on Seismic Scenario											—									
Seismic Scenario report												●								
Risk management plan design												—	—	—						

Damage assessment															—	—				
Workshop on Action Plan																	●			
Action Plan Report																		—	—	
Closing workshop																				●
Spreading the Action Plan																			—	—
International workshop																				●

3.5 Project Costs

3.5.1 Grant From IDNDR Secretariat

Advisory		
Patricio Tapia	USD	1.670
Walter Roldán	USD	1.670
Ma. Soledad Bembow	USD	1.670
Mauricio Ponce	USD	1.670
Mario Pereira	USD	1.670
Others		
Translation	USD	662
Workshop prepare, assistant	USD	1.267
Fee Secretry	USD	4.397
Fee Data and Seismic Scenario (student)	USD	3.480
Filming, Audiorecord, Photograpy, etc.	USD	1.843
Total	**USD**	**20.000**

3.5.2 Locally Allocated Resources (FNDR)

Software GHI	USD	6.609
Plotter	USD	3.565
Computer Software (paper, cartrige, etc)	USD	1.357
Event Services	USD	2.100
Progress and Final Reports	USD	7.879
Stacionary (photocopies, folders, paper, etc)	USD	2.841
Total	**USD**	**24.351**

FNDR: Fondo Nacional de Desarrollo Regional, II Región, Antofagasta

Chapter 4 SEISMIC HAZARD AND RISK ASSESSMENT

4.1 Seismic and Geological Data Collection

4.1.1.- Plate tectonics

Chilean seismic activity and tectonics up to latitude 46° s. is characterized mainly by the ocean or Nazca plate subduction under the American continent. To the south of this latitude, the interaction of the Antarctic plate with the South American plate controls the geodynamics up to Magallanes, where the continental plate also interacts with the Scotia Plate. (Figure 4.1).

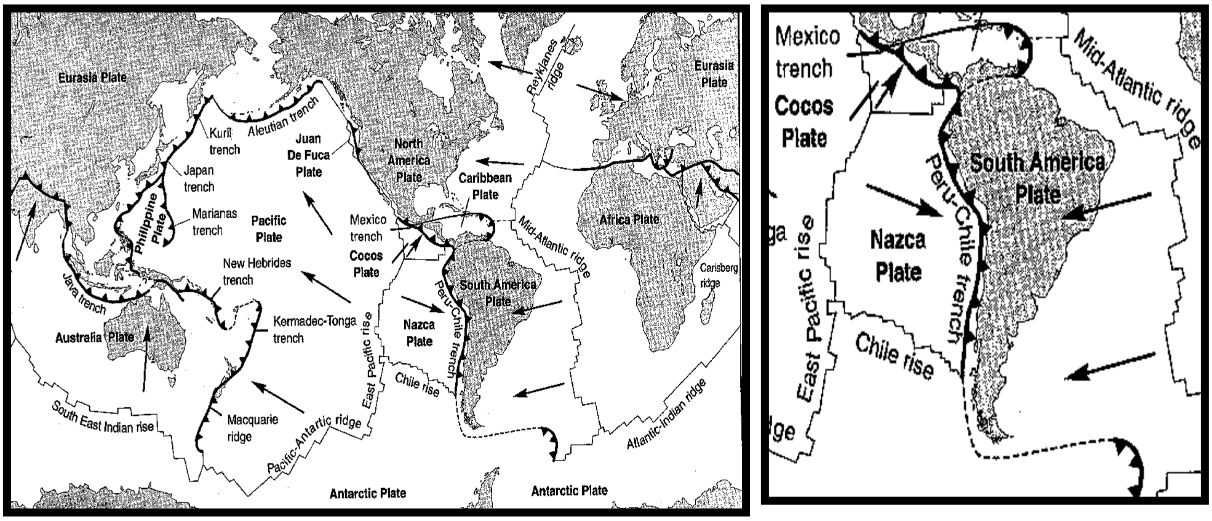


Figure 4.1.- Plate interaction and its influence on the Chilean coast .

According to the current movement pattern of the tectonic plates and the rotation poles that define the Euler vectors of the pairs of plates interacting in the region, the following relative convergence velocities have been determined:

PLATE	DIRECTION	***RELATIVE VELOCITIES (cm/year)***
NAZCA-SUDAMERICANA	*N 78º E*	***8.5***
ANTARTICA-SUDAMERICANA	***N 93º E***	***2***
NAZCA-ANTARTICA	***N 74º E***	***6***
SCOTIA-SUDAMERICANA	***N 110º E***	***0.6***

Table 4.1 Relative velocity of plate movement

The Nazca Plate subducts under the continent at about latitude 46° S., where it forms a triple point with the Antarctic plate. Numerous studies have shown that the Nazca plate has important lateral variations in its penetration angle under the continent. These changes in geometry occur at greater depths than those of interplate coupling, possibly associated to the age variation of the ocean plate along the basin and the subduction of important batimetric features.

By using tele-seismic and local data, Chilean researchers (Pardo et al.) have determined that maximum interplate coupling is of the order of 50 km to 60 km (between 200 km and 250 km from the basin) along the Nazca plate subduction zone.

The stress determined by focal mechanisms along the subducted zone indicates that interplate contact is mainly subjected to compression stress, with pressure axes aligned, on an average, with the convergent direction. Between 60 and 350 km deep, the dominant stress area is tensional with axes parallel to the subduction direction, meanwhile at greater depths; there is dominant compression stress, with compression axes in the direction of the downward moving plate.

Interplate relative movements are prevented by the coarseness generated in the contact zone, leading to a permanent accumulation of stress. Due to this connection, which comes usually from the subduction of geological structures and batimetric features in the ocean plate, the distribution of accumulated stress in the contact zone is varied. As well as causing deformations in the plates involved, whenever the accumulated stress exceeds materials resistance in a specific contact zone, an earthquake is produced, releasing an amount of energy proportional to the area and the interplate average slide.

All the active Chilean boundary between the Nazca and South American plates is highly seismic, with average interplate earthquakes of moment magnitude greater than 8.0 ($M_w > 8.0$) every ten years.

4.1.2.- Seismic Activity of the Zone

The Pacific Ocean is surrounded by a zone of great seismic activity, known as the Pacific Fire Belt, where the most violent earthquakes occur.

Most South American earthquakes occur along the contact between the Cocos and Nazca plates and the South American. The movement of these plates is perpendicular to the continental border, where the ocean or Nazca plate goes in as a wedge under the continental plate, giving rise to rather shallow earthquakes near the sea trench and increasingly deeper in the east.

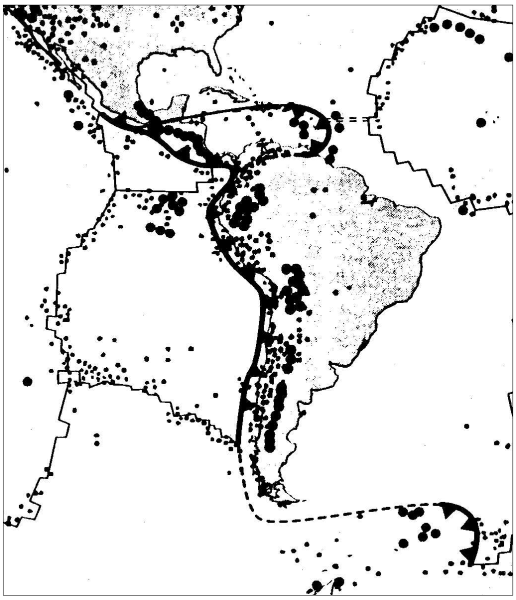


Figure 4.2 Historic earthquake on the Chilean coast

Earthquakes 600 km deep occur in the interior of the continent at about 700 km from the pacific coast.

Chile, as part of the so-called Pacific Fire Belt, is the world's most seismic region, with the exception of Japan. It has the world's longest continuous seismic area, from 18° S. to 56° S.; however, given the great length of the Chilean territory, there is a variation in its seismic features.

A preliminary study of the epicenters shows conclusively that seismic activity decreases notably to the south of parallel 46° S. This is because the interaction between the South American plate and the Nazca plate subduction zone extends to this parallel 46° S. (Puerto Aysen). Thus, the territory with the greatest continuous seismic activity is located to the north of parallel 46° S. Labbe and Saragoni divided Chile into four seismic zones.

- Zone 1, from Arica to Taltal, between parallels 18° S and 26° S, shows the greatest seismic activity of the country's four zones.
- Zone 2, from Taltal to Linares, between parallels 26° S and 36° S, with a seismic activity lower than Zone 1.
- Zone 3, from Linares to Puerto Aysen, between parallels 36° S and 46° S, with a seismic activity similar to Zone 2.
- Zone 4, from Puerto Aysen to Horn Cape, between parallels 46° S and 56° S, with a seismic activity significantly smaller than the others.

Generally speaking, the most frequent seismic activity occurs between parallels 18°S and 26° S, but its intensity is lower than in the other zones. Seismic analyses of northern and southern Chile proves this. Zones 1 and 2 show greater seismic activity than zone 3, although with lower intensity. Since seismic events in these areas occur near the surface and are likely to have a very local effect.

Antofagasta lies in zone 1, whose seismic events range from 40 to 120 km deep. There is little information on past earthquakes in this zone; however, a thorough seismic record from 1604 to 1999 was created by using catalogs from SISRA, NOAA, NEIC, PDE and PDE-W. More than 720 events with focal mechanisms along Zone 1 are registered.

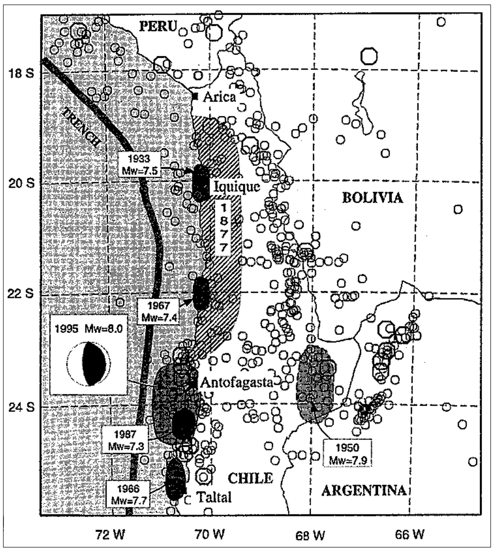


Figure 4.3 Earthquake in the North Zone of Chile (Region I and II)

Figure 4.4 shows the location of the most important earthquakes, with Richter magnitude equal or greater than 6.0 ($M_s > 6.0$). The last seismic event adjacent to Antofagasta took place on July 30th 1995 with a magnitude of $M_s = 7.3$ ($M_w = 8.0$).

4.1.3 Geological Framework Antofagasta Zone

On the Mejillones peninsula, lithological Pre-Mesozoic units that make up the metamorphic basement of the Paleozoic are intruded by granitoids probably belonging to the upper Paleozoic age. Meanwhile to the east, in the Coast Cordillera, there are mainly Jurassic volcanites in La Negra formation (the main foundation soil in Antofagasta), together with Mesozoic plutonic complexes. To the east and southeast, there are sea and continental sedimentites of the Upper-Cretaceous Jurassic, corresponding to Caleta Coloso and El Way formations. Between the Coast Cordillera and the Mejillones peninsula horst, there are several sedimentary units, mainly marine, that give evidence of a complex evolution from the Lower Miocene to the Pleistocene.

The Atacama fault zone, with its various ramifications, is the most important structure in the zone of Antofagasta. Geo-chronological data shows its activity since the Lower Cretaceous with evidence of sinestral cross-current movements and, apparently, only common displacements during the Miocene and Pleistocene.

Common fault structures are also seen along the western side of the peninsula horst. These correspond to the Mejillones and Caleta Herradura faults with direction north-northeast (10). With an absolutely atypical direction N60° W, the Salar de Navidad fault, located to the east of the Salar del Carmen, presents a escarpment with the SW block as a slope. Most of these faults show the longitudinal trenches produced by the complementary shear displacement, typical of normal faults.

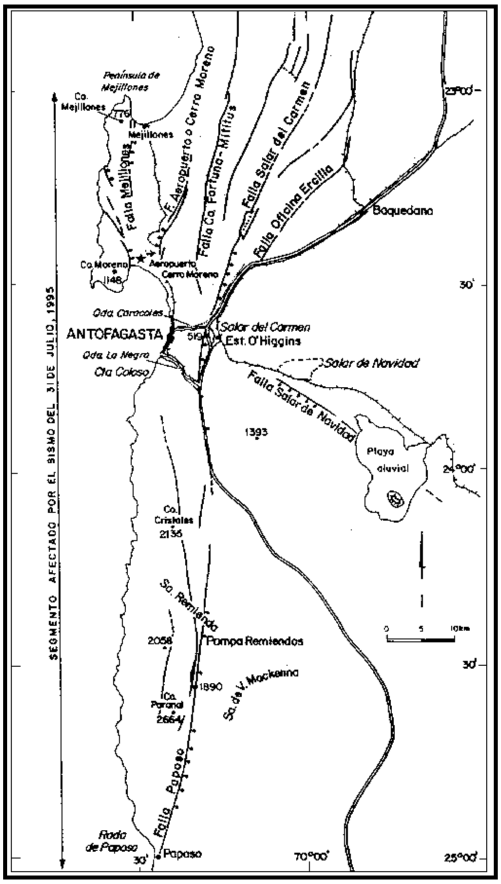


Figure 4.4 Atacama Fault and its branches

4.1.4 Geological Description of Antofagasta Soils

The most important aspect to take in consideration in defining a seismic movement and its effect on structures is to know and assess correctly the city soil. Therefore a complete study is presented here.

In Antofagasta, there are geological units belonging to two well-defined groups: a) the Mesozoic basement, made up of volcanites and volcano-clastites at La Negra formation - a mainly dioritic-granitoid - and a unit of conglomerates and red sandstone belonging to Caleta Coloso formation; the last two come out in and to the south of the El Way creek, and b) the Cenozoic coverage, formed of sea and continental sediments and non- or semi-granular deposits originated from basal rock denudation.

4.1.4.1 Mesozoic Basement

La Negra formation (Lias-Oxfordian): a strong sequence, up to 10,000 m thick, of andesitic lava, scarcely amygdaloid, with sandstone inter-layers and continental trenches. This formation is occasionally seen in the urban area, in the slopes of the paleo-cliffs, in the submeridian outcroppings and in the coastal border south of La Negra ravine.

Caleta Coloso Formation (Titonian-Neocomian): a sedimentary continental unit 2,000 m thick, made up of alluvion trenches and conglomerates and fine red sandstone striking upwards smoothly to the southeast. These are also found in the coastal border, 1 km to the south of La Negra ravine until Jorgillo ravine to the south.

Jorgillo Diorite (Oxfordian-Barremian): It corresponds mainly to a diorite, though it varies locally from the composition of granodiorite. It appears at the south of El Way creek, in contact with the units aforementioned due to the fault.

4.1.4.2 Cenozoic Coverage

Terraced gravels (Oligocene-Miocece): This is the name of a series of alluvion deposits belonging to the "Coastal Tarapacá Pediplain" whose deposition must have taken place before the appearance of the Coast Cordillera. They are found to the east of La Negra creek, in the form of hanging lava, mainly on the sedimentites of the Caleta Coloso formation.

Terraced sea deposits (Upper Pleistocene- Lower Pleistocene): Old sea terrace deposits made up of a coarse conglomerate at the bottom, with clasts whose size vary from pebble to block. They are rounded or semi-rounded, with varying composition of coarse sand matrix and shell remnants. A very fosiliferous coarse sandstone 3 m thick overlies this conglomerate.

Subactual alluvion deposits (Lower Pleistocene): They correspond to old dejection cones at the main accesses and they are dissected by present drainage. Recent alluvion deposits are clearly seen because they lie higher than the base of the platform where the city rests, thus forming smooth slopes.

Wind sands (Lower Pleistocene-Holocene): fine or medium sand, with carefully selected rounded grains, but with low composition maturity; they also have little fragments of transported seashells. They are mainly found in the northern sector of the city, where they become 15 m thick in the upper area.

Current sea deposits: Sea sediments consist of a mixture of sand and loose seashell pieces texturally mature though not in their composition and gravel rounded by abrasive action and the action of sea waves. They are found along the coastal border forming middle-size beaches coinciding with the axis of the main ravines.

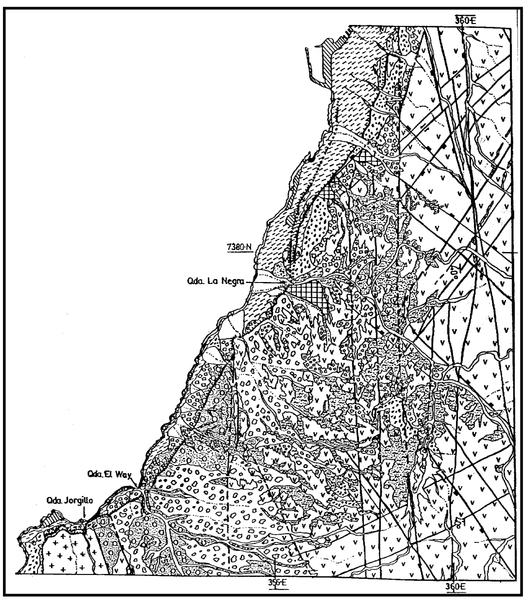
Artificial deposits: They are fill deposits, commonly sands, gravel and debris from building sites, blocks used as breakwaters and spoil heaps in the Ruinas de Huanchaca sector.

Alluvion deposits or slope debris: they correspond to a slow fluid mass removal phenomenon whose detritic materials come from the decomposition or fragmentation of the bedrock in smooth slopes that go down gradually due to gravity. These deposits are located in the eastern part of the city, at the bottom of the Coast Cordillera.

Deposits due to detritic flux: This is a medium- or fine-grained material belonging to the distal facie of alluvial deposits produced by a viscous transport of the particles during rainfall. The detritus flows are generally classified as Fast Fluid Mass Removal Phenomenon on steep slopes.

Terraced earth deposits: They are due to landslides produced by fine and coarse materials removed over periods of weeks and months from smooth slopes (10°°-15°), and deposited on the terraced sea deposits or on bedrock.

Present alluvial deposits: They are detritic materials transported by water fluids, running through ravines that dissect the Coast Cordillera. They expand at the end forming ejection cones or alluvial fans. They are characterized by a low transport efficiency, a high efficiency in rainy periods and with many fast mass removal phenomena.



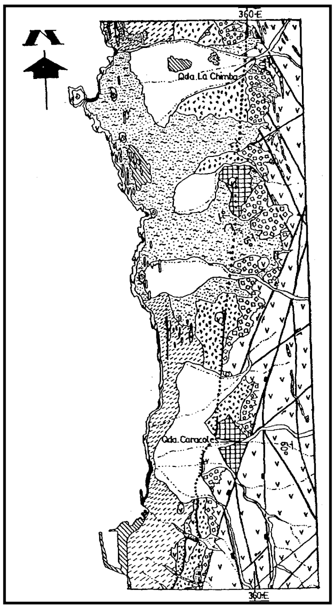


Figure 4.5 Geology of Antofagasta Zone. The blank areas indicate alluvial deposits

4.1.5 Geologic faults

The main structures affecting the sea abrasion platform in Antofagasta and the Coast Cordillera correspond to branches of the faults of Salar del Carmen and Caleta Coloso to the south. Both belong to the Atacama fault zone. The structural prevalence of the Salar del Carmen fault controls, to a certain extent, the trace and lifting of Jorgillo diorite. In this way, sub-meridian NNW and NNE faults are found. Based on field observations, these were proved to be the ones that modeled the current morphology of the city coastal border. During their tectonic history they have been active and passive successively, with sinestral and normal movements. At present, a dextral movement appears to be occurring in the EN direction of the Nazca plate advance axis.
The probability of activation of some of the secondary faults at the Great Atacama fault was assessed. There are not enough data to make a final statement.

4.1.6 Slide Risk Zones

An analysis of the city's potential landslides risk areas was made. The sectors of greatest risk were assessed and a geo-referenced map was made, classifying the landslide risk as high, medium or low.

Criteria used

- Roads and paths in cuttings where sliding takes the form of falling blocks.
- Areas with steep slopes and fractured rocks
- Water Tanks located in high areas and founded on soil or fill

The places of risk identified by the above analysis are:

- Salar del Carmen access (Rout Nº26), with the likely loosening of cobbles (40cm diametre)
- A natural slope in the Gran Vía sector, which could affect the residential area
- A water tank founded on sand
- A slope in the new residential sector

4.1.7 Collateral RiskTsunami

The tsunami occurrence assessment was based on the Flood Maps of the Chilean Hydrographic and Oceanographic Navy Service (SHOA). SHOA numerically simulated the post tsunami water level. This model was compared with the real events of 1877 and 1995, and a good correlation was achieved. The disadvantage of this model is that it does not consider some of the present coastal structures, and therefore overestimates the inundation zone. The tsunami study is shown below.

As mentioned before, the Pacific Ocean is surrounded by a zone of great seismic activity (Circum-Pacific Belt). The Chilean coast between Arica and Puerto Montt is in that belt and according to available data, 60% to 70% of the world's tsunamis occur in this area.

In 1958, SHOA became a member of the Pacific Tsunami Alarm International System which it based in Honolulu, Hawaii and is part of the U.S.A. Hydrographic and Geodesic Service. On January 11th 1966, SHOA was appointed official Chilean representative of the organization. The National System for Alarm and Tsunami was officially established, though it had been working since July 30th 1994. This institution is in charge of coordinating the alarm system for the country, giving notice of possible tsunamis and evaluating the reports from Honolulu.

4.1.7.1 Antofagasta Coast Characteristic

The coastal area of Antofagasta is limited to the south by Punta Brava and it extends for six miles to the northeast, up to the mouth of La Negra ravine. The coast is mainly rocky with some rock reefs. The harbor is open to the west and exposed to tide and wind.

Punta Tetas is the northern limit at the southwest end of the Mejillones peninsula. In the central area of Antofagasta are the beaches El Cable and El Cuadro, in front of which oil ships are moored. The oil and gasoline supply companies have two groups of buoys in this area.

4.1.7.2 Antofagasta Seaport Characteristics

The port of Antofagasta represents the most vulnerable point of the city in terms of the Tsunami action. For this reason a complete analysis of its characteristics was carried out.

The port is formed by a dike made up of two arms, A-C in Figure 1,5, which is almost parallel to the coast and the main arm CDF, which is orientated S to N. It has three piers: GKL, parallel to the coast; GN, attached to the short arm of the dike; and JN, attached to the main arm. This facility is 745 m for KL, 370 m for GN and 730 m in NJ, amounting to 1,850 m. Later, a second dike was built. It is 180 m long and is located 875 m at the north of GN, 264° to the north of the coast

Between both dikes, there is an entrance 250 m wide leading to the inner dock. The dock is well protected against winds and tides. It is 830 m long NS. Its north width is 420 m and its south width is 230 m.

In the inner part of the main dike and on the east section, docks for merchant ship mooring, merchandise transport facilities and storage houses have been built. All types of ship can moor here because the dock is deep. Shallow areas have been dredged to a minimum of 10 m.

4.1.7.3 Probability of Occurrence of a Tsunami in the Zone

According to the statistics, the most disastrous Chilean tsunamis have occurred on the northern coast. They were due to earthquakes whose epicenters were near the coast. However, tsunamis generated by an earthquake which occurs far from land arrive at the coast in a much attenuated form.

For this reason and because of the objectives of RADIUS, it will be only necessary to calculate the probability of the occurrence of a big earthquake generating a tsunami whose epicenter is located near to the coast (18° and 26° S.)

Based on the statistics of wave height measured and the magnitude of the earthquakes that generated them, the greatest absolute and relative amplitude detected have been due to earthquakes whose epicenters are located to the south of the port. This is due to the geographical location of the port and harbor whose northern part is well protected by Punta de Tetas while the west and south are not protected.

Tsunami risk is closely related to sea seismic risk. If all the earthquakes with an epicenter on the sea floor had generated a tsunami, tsunami risk would be the same as sea seismic risk. But only some sea earthquakes generate a tsunami so it can be assumed that tsunami risk is lower than sea seismic risk.

According to the plate theory mentioned before, most Chilean earthquakes have a tectonic origin due to the relative displacement between the sea and continental plates. Seismic activity occurs on the continental plate or on the sea plate or in the contact zone between both plates. Of these, only the interplate contact zone could cause a tsunami since, on the sea plate, the internal earthquakes are of minor intensity. Those generated on the surface of the continental plate, in the zone of maximum curvature, are due to failure of materials and the cracking produced is unlikely to be intense enough to transmit sufficient deformation to the water surface and generate a tsunami.

However, the interplate contact zone is potentially more likely to generate a tsunami since its movement has greater magnitude, the most critical movement being that which produces shear stress caused by the subduction. A large rise or fall of the sea floor could cause a great deformation of the water surface above, thus generating a tsunami.

According to Lida (1973, Lecture notes and seismology), the maximum earthquake magnitude for generating a disastrous tsunami is given by the following relationship:

$$M = 0.008*D + 7.75$$

Where M = Richter magnitude of the disastrous earthquake; D = focal depth

Let D = 35 cm. This is considered as an average value for the collected hypo-central depths, a value for M = 8.03 is obtained as the minimum magnitude for a tsunami-producing earthquake.

A disastrous tsunami causes significant damage on the coastal zones, destroying seaports, coast and urban facilities. It also causes floods and endangers peoples' lives.

4.7.1.4.- Tsunami Wave Height and Ranup

The maximum height of a tsunami is considered to be the vertical distance between the minimum trough level and the maximum crest height as the wave approaches the coast.

Various relationships are used to estimate the tsunami height. The most reasonable is to study its propagation by means of a refraction diagram which applies Green’s Law. For the Antofagasta seaport zone, studies show that the tidal wave would reach approximately 1 m.

Ranup is defined as the vertical height between the mean sea level and the wave height at the moment of reaching the shore. In order to estimate the ranup, the Wilson relationship was applied as follows:

$$\text{Log } R = 0.75 * M - 5.07; \quad M : \text{earthquake magnitude.}$$

So, for M= 8,0, R= 8.5 metros.

The Antofagasta litoral has a variable depth and the port is the deepest area. Because of this a wave of 8.5 m corresponds to the critical case. The implications of an occurrence of a tsunami are discussed further in the section relating to transport infrastructure.

4.1.8 Collateral Risk. Fires

The city does not have a gas network. This reduces fire risk after a disastrous earthquake. Electricity is distributed to small closed areas and each area has a system of protection, which reduces the risk of short circuits and therefore fire.

Wood is little used for construction nowadays and only a small amount of old and informal houses still exist, also reducing the risk of fire.

4.1.9 Collateral Risk Activation of Geological Faults

There are no data to determine if an event of magnitude M_s=8.0 would activate the Atacama fault. So it is difficult to estimate the movement amplification, intensity and damage due to this occurrence. Known data refers to surface movements generate only by plate subduction.

4.1.10 Other collateral risks

In the city there are no deposits of dangerous materials, with the exception of fuel deposits, that can be exposed during a seismic event. Toxic clouds are unlikely to occur.

4.2 Determination of Vulnerability Curves

4.2.1 Introduction

Vulnerability curves are developed using statistics relating to damage incurred during previous earthquakes to buildings, public services (water and electric supply, etc.), emergency services and others. They are designed on the basis of the damage incurred (i.e. investment costs in order to re-start services compared to total cost) for different intensities of seismo. When an earthquake is simulated, these curves enable the definition of the damage and related costs. This is carried out by locating the structure within a seismic classification of the city.

4.2.2 Building Vulnerability

The following predominant structural types were classified to estimate potential damage:

Informal building (ACON): Construction without professional supervision, lacking quality control and uncertain material origin. This includes roof and wall materials. Also in this category are uncontrolled extensions on houses built with an acceptable level of control. This type of construction is considered dangerous mainly due to over-occupation.

Concrete and wood (HMAD):
Old structures with walls made of concrete with wooden trusses. This type of building is characteristic in the centre of the city. The walls are over 3.0 m. and the slabs are of wood.

Simple Masonry concrete block (ASIM):
Structures of low-quality concrete block walls, without adequate reinforcement. This type of block masonry is marginal to its respective code and includes masonry with. reinforcement inadequate in form and quantity. The slabs considered are of reinforced concrete and relatively thin (12 cm).

Masonry block concrete (reinforced) (1-r) (AERa):
Structures of brick or block masonry walls, with reinforced concrete columns and beams (1-3 floors). This is the most common type of construction in the city. This type of masonry is regulated by the code Nch1537 and Nch1928. Also considered here is reinforced masonry without border concrete columns and with special block units to form beam and column frames. In both cases the slabs are of reinforced concrete and sometimes in the latter case special block units are used.

Structural Masonry block concrete (reinforced) (m-r) (AERb):
This is the same as the previous case but for buildings over 3 floors. Until 1985 this was the most common structure and material in the city. The boom in construction and the increased land prices encouraged construction of high buildings and consequently the use of concrete over masonry. The slabs are made of reinforced concrete.

Concrete and other materials (MHMY):
One or two level structures with walls made of a mixture of concrete and plaster. The walls have considerable thickness (25 cm) with minimum steel reinforcement. The slabs are of reinforced concrete.

Reinforced concrete (MHAR):
Structures based on reinforced concrete walls, according to Nch430 or ACI318. This is the material most used in high buildings. The Chilean practice uses a high density of walls in plan (3% in each direction). This gives an adequate stiffness to the building. In some cases reinforced concrete walls are combined with masonry walls. The slabs are of reinforced concrete.

Reinforced concrete framework (FHAS):
Structures based on reinforced concrete frames, according to Nch430 or ACI31.8. They are buildings of up to 5 stories built of beams and columns either made in situ or prefabricated. The slabs are of reinforced concrete.

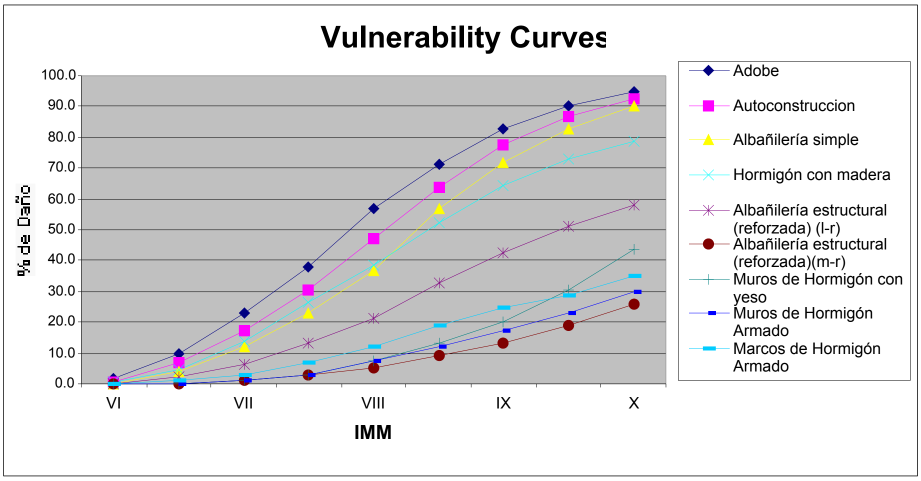


Figure 4.6 Vulnerability curves for different structural types and materials.

The determination of the vulnerability curves for each of these structures was based on the vulnerability study for the typical buildings in central Chile (M. Astroza et al.). Adjustments were made for local vulnerability curves based on the different quality of the materials and manpower between central zone and north zone.

4.2.3 Lifelines and Facilities Vulnerability Curves

To determine the vulnerability curves for water supply, sewage and electric power, the curves for Quito, Ecuador were referred to. They were adapted for Antofagasta in terms of materials, diameters, length and construction methods. The assessment of other elements such as tanks for potable water, pumping plants for sewage and an electrical sub-station, was done by considering each element individually. All tanks were visited and assessed, determining a very low probability of cracking. The pumping plants are not functioning yet, therefore they were not observed. The information relating to the electrical sub-station was supplied by the electrical company.

Assessment of the vulnerability for local hospitals was based on studies of the largest Chilean hospitals. This study includes the Antofagasta Regional Hospital.

4.2.4 Transport Vulnerability Curves

The determination of vulnerability curves for transport facilities and streets is unreliable because there is little information regarding the correlation of damage to seismic intensity. SERVIU and the Direction of Highways defined the curves for urban streets and main accesses as accurately as possible. This work was based on Quito data, giving emphasis to streets that run along slopes and cuts. These are abundant because Antofagasta is an ocean city limited by the Coast Cordillera. For the main access, their special features and the data for the 1995 damage were taken into account. The vulnerability of the accesses to the city is strongly linked to the water system, which run parallel to them. Historically the accesses have been affected by floods due to ruptures in the pipelines.

There is little information relating to the damage caused by previous earthquakes to the seaport, airport and railway facilities and so each was analyzed theoretically. The seaport was significantly affected by 1995 event, so the data could be extrapolated for events of greater magnitude (taking into account the actual degree of recuperation). The port vulnerability is developed with more details in the following section.

4.3 Systems Risks Data Inventory

4.3.1 Edification

4.3.1.1 General Aspects

The regulation organism in charge of city buildings is the Direction of City Hall Works (DOM). It is responsible for construction permits in the urban area based on the City Regulation Map, Local Orders and General Orders of Urbanism and Construction. To obtain a permit the DOM demands the presence of the owner, the engineer, and the contractor. These people along with the materials supplier have a legal liability. DOM makes them responsible for any structural problem either during or after construction. This entity, however, does not have the tools and resources to assess the seismic safety of buildings, and is confined to participate only in the aspects relating to land use and architectural issues

By the law, any new building or change must be accepted by the DOM; however, in low- and middle income sectors there are many unregulated houses that do not have the technical support to make them safe.

In order to accept officially any work, the DOM demands all the project data including architectural plans, engineering plans, and service plans. Certificates of material quality are also required. This information legalizes the construction the house or building. The owner receives a legal certificate including inspection date and construction period.

4.3.1.2 Public Construction

The main building organism in Chile is the Service of Housing and Urbanism (SERVIU)), dependent on the Ministry of Housing and Urbanism (MINVU). SERVIU designs and builds houses in fiscal sites. For building houses, it hires contractors by public auction and supervises work.

The most used material is reinforced concrete block work. Houses generally have one or two floors. There are also apartment buildings of three or four floors. In 1995, buildings supervised by SERVIU were scarcely damaged although some damage was suffered by buildings originally supervised by the service but with extensions added at a later date.

4.3.1.3 Private Construction

Today, private buildings are the most common in the city. There is a great demand for houses because the mineral and industrial development has encouraged the influx of people to the city. This greater demand, together with scarce supply has increased building costs, thus leading to a construction boom, especially in relation to high buildings. There are high buildings along the coastal area and all available sites have been occupied. Many houses are built on the upper central and southern sites.

4.3.1.4 High buildings

Due to the construction boom mentioned, the urban sector was modified and population density distribution changed. There is an increase in the construction of 5-storey buildings in the center of the city.

In order to analyze building behavior, a survey was made for structures with 5 floors. The following data was recorded: the address, number of floors, geographic location (on a city map), and type of structure.

As the structural type of the buildings was only checked visually it is estimated that a 10% error was incurred in the classification of the structure and materials especially in low buildings.

Buildings must comply with the strict existing seismic code (NCH-433 Of.96). Chilean seismic-resistant design advocates the correct distribution of shear walls promoting rigidity and resistance to deformations so buildings are not liable to suffer structural damage.

4.3.1.5 Construction Risk

The buildings most liable to suffer damage are informal houses. In general the sites used for this type of construction were illegally obtained in the past and today, although the legal situation has been resolved, the constructions remain unsafe. They are usually located in high areas that are dangerous due to the existence of steep slopes, alluvial deposits and landslide risk.

4.3.2 Public Services

4.3.2.1 Hospital and clinics

The hospital characteristics differ depending on the source of their funding. Private clinics have excellent facilities, upkeep and service while the main public hospital is in a poor state of maintenance. Although at present it is not structurally dangerous, its state of disrepair could affect its functioning in an emergency

Private clinics are in good working condition although not all have adequate emergency exits. The 1995 event did not affect the clinics significantly and they have the potential to serve in an emergency as they are well equipped. All of them have blood banks and they are structurally safe. However two of them lie in the tsunami zone.

Water supply tanks supports at the Regional hospital were damaged in 1995. Columns on the first floor suffered structural damage, many windows were broken and are some cracks appeared in non-structural walls. The majority of this damage was adequately repaired. The emergency exists in the hospital are not in a good conditions. The Regional Hospital was designed to meet the needs of the whole second region, so it has 702 beds.

4.3.2.2 Schools and Universities

Even though schools were all registered in the RADIUS Geographic Information System, only those damaged in 1995 were analyzed and visited. Only some have been repaired. None were in danger of collapse after the 1995 earthquake.

All schools have evacuation drills in the case of an emergency. Emergency exercises called DEYSE (school clearing and safety) are carried out twice a year. It is clearly established which schools have been capacitated as temporary shelters in case of an emergency.

Some schools are located in the tsunami flood area; these institutions have specially defined evacuation drills and do exercises to prepare for such an event.

However, the corresponding Ministry does not exercise the same control over childcare centers (kindergartens). During visits to different centres in the city it was observed that some are functioning in dangerous building either due to the location or the structural quality.

There are three universities in the city with adequate infrastructure. They were not damaged in 1995 and their present condition suggests that they would remain safe in the event of another earthquake. The Universidad Católica del Norte is independent with regards to the water supply (it has its own tank). This aspect has always been important when it has been necessary to provide water for the population in event of a disaster. The Jose Santos Ossa University is located near to Tsunami inundation zone but its buildings are relatively new. The Antofagasta University is located to the south of the city and is at no direct nor secondary risk due to an earthquake.

4.3.2.3 Emergency Services Police

All police stations were examined. There are two main police stations and two substations. The buildings do not have any structural problems, but the water and electricity supplies are inappropriate because they are not independent from the city networks. The Chilean police have been traditionally prepared for facing emergencies but their capacity can be easily surpassed depending on the magnitude of the disaster.

4.3.2.4 Emergency Service Fire Stations

There are 9 fire stations in the city. Their main problem is their distribution since most of them are in the centre and two of them are located in the tsunami zone. Chilean firemen are a state recognized organization but they are all voluntary workers. This can be considered as a disadvantage, although the commitment and dedication of these firemen should not be underestimated. Their high quality training makes them one of the most important building blocks for solving emergency problems.

4.3.2.4.- Civil Defense

This organism is semi-voluntary. It is possible to enter this body by two means firstly as a volunteer and secondly as an alternative to the Military Service. It is a branch of the Chilean armed forces. Presently it is based in the Septimo de Linea Regiment. It has adequate telecommunication equipment which can access the entire region. Its function is to help the population in the event of a disaster or any other situation that might require the maintenance of internal order.

4.3.2.4.- The Red Cross

This is an international organization with over 30 volunteers in Antofagasta. Its main function is help to casualties in the event of a disaster. They also give talks on security and procedures to vulnerable people such as the elderly and children. They have minimal emergency supplies that include tents, medicine and non-perishable foods.

4.3.3 Lifelines

4.3.3.1 Potable Water System

4.3.3.1.1 Collection and Regulation

The Antofagasta commune is part of the Great Northern Drinking Water System of the second region. This system is a series of collection, storage, treatment and distribution works that captures the surface water from areas in the Andes (Lequena, Quinchamale and Toconce) located in the higher Loa river basin. This water also meets the needs of Calama, Tocopilla, Mejillones, and the nitrate towns Pedro de Valdivia, María Elena, Coya Sur and El Toco.

The water is collected at a rate of about 1350 liters per second. It is directed by gravity to the Cerro Topater plant outside Calama. Part of this water is then treated for supplies to Calama, Tocopilla and the nitrate towns. The rest is directed by gravity to the treatment plant at the Salar del Carmen 15 km to the east of Antofagasta. It supplies Antofagasta, Cerro Moreno and Mejillones.

The water is treated at the treatment plant to reduce the high content of arsenic by a process using ferric chloride. From here, it is directed through two pipelines to the Caracoles tanks (two tanks of 12,500 m^3 each) located at the head of the system, in the Salar del Carmen ravine, about 6 km to the east of the city. These tanks provide the city with a flow of 750 to 800 liters per second through three pipelines: South Feeder, Toconce Feeder and Cerro Moreno Pipeline. The South Feeder branches out to the North Feeder. These pipelines distribute the volume regulated in the Caracoles tanks through 19 tanks located in the upper part of the city.

From the Salar del Carmen ravine to the north, water is supplied through the North Feeder and Cerro Moreno Pipeline. The North Feeder supplies water for the Prat, Balmaceda and Bonilla (1 and 2) tanks. Cerro Moreno Pipeline supplies water for the Cerro Moreno FACH tank and the Low and High Cerro Moreno tanks (belonging to ESSAN). The first two, in turn supply water for the Air Force Base and the Airport. They also supply water to Mejillones through the Mejillones Pipeline. Sometimes Cerro Moreno Pipeline supplies water for the Bonilla and Prat tanks.

From the Bonilla tanks and sometimes from the Cerro Moreno Pipeline, water is supplied to the North Rural Feeder that, in turn, supplies the northern sector.

From the Salar del Carmen ravine to La Negra ravine, water is supplied through the South Feeder and the Toconce Feeder. The latter supplies the liquid for Ancla 1 and Ancla 2 tanks, where it ends.

The South Feeder supplies water for the El Salto, Centro, Huanchaca (1 to 5), Independencia and Sur tanks. There is also a connection with the Ancla tanks, which is presently used only for emergency. From the Independencia tank network water is supplied to the Chumil and Jardines del Sur tanks. These, in turn, supply the southern barracks and the people in Jardines del Sur. Servicios Sanitarios Playa Brava S.A. distributes the water farther south.

There is an emergency feeder from El Ancla 2 and/ or Toconce Feeder to the Huanchaca tanks. The Toconce Feeder is a matrix.

From La Negra ravine to the south, water is supplied through two matrixes that are derived from the South tank. The feeder originating in the Independencia and Jardines del Sur tanks was closed. Jardines del Sur receives water from the Sur tank.

The Antofagasta potable water regulation and distribution system is ESSAN's largest and most complex project. The 19-tank system is made up of 50,200 m^3 nominally, 31 pressure-reducing stations and more than 390 km of pipelines with varying diameter.

Topographically the city is characterised by its great length in the north south direction compared to its much smaller width and a steep slope to the west. It is necessary to divide it into sectors for potable water distribution, considering regulation tanks and areas of influence and pressure. These three factors are shown in the table below for each tank.

Regulating Tanks Feature, influence area and population served are indicated in the following table

Tank	**Material**	**Type**	**Volume (M3)**	**Area of Influence (Ha)**	**Supplied population (Hab.)**
Bonilla	R.C.	half-buried	4,000	215.45	27,238
Balmaceda	R.C.	half-buried	2,000	72.12	17,634
Prat	R.C.	half-buried	2,000	248.43	35,826
El Salto	R.C.	half -buried	500	71.40	9,365
Ancla 1	R.C.	half-buried	10,000	493.06	33,322
Ancla 2	Steel	Superficial	12,500	239.83	30,770
Centro	R.C..	half-buried	2,000	161.88	20,187
Huanchaca	Steel	Superficial	8,260	312.20	40,226
Sur	R.C..	Half-buried	2,000	133.60	2,912
Independencia	R.C.	Superficial	940	68.00	7,004
C.M. FACH	R.C.	Half-buried	1,000		1,600
C.M. Bajo	R.C.	Half-buried	1,000	198.50	5,321
C.M. Alto	R.C.	Half-buried	1,000	198.50	5,321
Chumil	Steel	Superficial	400		
Jardín del Sur	R.C.	Half-buried	300	28.82	559

Table 4.2 Tank characteristic

Damage and the foundation soil characteristics for some tanks were checked during fieldwork:

Caracoles Tank: some evidence of undercutting or lack of fill material around the basal perimeter. The foundation soil is gravelly sand with some silt

Balmaceda Tank: cracks in the intersection between the pipeline and the tank. There are also fissures in the slab. The foundation soil is gravelly sand with rock fragments.

Prat Tank: fissures in the framework from the concrete pouring process. The foundation soil is gravelly sand with some silt. In the event of leakage its slope is potentially unstable.

Bonilla Tanks: small fissures at the east side.

The main problems in the potable water system are linked to regulation and macro-distribution procedures (pipelines that feed the tanks), due to the extreme inflexibility of the system. Consequently the system is unsafe and unreliable. The current tank capacity, however, is sufficient to supply the city's needs until year 2016.

The basic problem is that the distribution network has been inappropriately divided into subsection. In fact, even though the tanks' capacity would suffice, it is not compatible with the demand of the respective areas of influence. This situation is due to the disorganized development of the city and the fact that the tanks were originally designed only as storage tanks.

The fact that the tanks have their own zones of influence independent from one another and that they differ in size and number of users makes regulation difficult, and prevents resource optimization. In the event of an earthquake, which causes the interruption of the water supply in some sectors, the system does not have alternative supplies or a method of re-distribution. The advantage associated with the independent influence zone is discussed in the following section (4.3.3.1.2).

The regulation and conduction vulnerability of the water supply system is related to the Treatment Plant vulnerability. The plant is founded over one of the branches of the Atacama Fault and according to information from the company, the structural design considered a fault movement, but this has not been corroborated. Other faults cross the pipe, which brings the water from the interior but their degree of influence could not be established. To study the vulnerability of the water supply system of Antofagasta it is necessary to extend the study to the whole of the Second Region, because important interruptions to the system could be generated by a deep earthquake in the interior.

4.3.3.1.2 Distribution Network

The city distribution network is long and thin in accordance to the geographic location. It consists of pipelines made of different materials, with diameters that range mainly between 75 and 250 mm.

The distribution network has been divided into sectors according to the zones of influence of the tanks. This permits greater independence in case of failure. Given the steep slopes of the coastal hills, it was necessary to set up pressure-reducing stations. These are placed at 31 and 235 m.a.s.l.

City features have made it necessary to consider pressure sub-zones. In this way, the higher areas are directly supplied from the tanks and the lower ones from reducing stations.

The Antofagasta network has 2,304 valves. They are not in good conditions for operation and their maintenance is not good. There are also 460 public fire hydrants according to 1991 study.

With respect to the operative condition of the supply to the tanks, the diagnosis indicate the following problems:

a) South Feeder:
- Operation under very high pressure
- Long spans without suckers
- Adequate capacity until 2005

b) North Feeder:
- Operation under very high pressure
- Long spans without suckers
- No capacity for future requirements

c) Toconce Feeder:
- Leakage along almost all its length
- Adequate capacity until 2016

d) Cerro Moreno Pipeline:
- Pressure reducers in poor condition
- Maximum capacity 43l/s (limited due to possible maximum pressure)
- Passes beneath highways along part of its length
- Long spans without suckers
- No capacity for future requirements

e) Toconce Pipeline:
- Underground throughout its length
- Adequate capacity for future requirements

In order to solve these problems, the feeder pipelines for present and future requirements must be strengthened and replaced, maintaining the current feeding design.

Almost all the city is serviced, but the network is very old in important sections. The breakdown of matrixes and home outlets are frequent in the oldest sectors, situated in the centre, where most of the installations date from 1900 and 1949. These areas are supplied by the Huanchaca tanks.

Vulnerability of the pipeline distribution system is related to the location of this system on slopes with a risk of sliding, and is established by superimposing plans of pipelines on plans of slopes.

Information Incorporated in G.I.S.

Collection and Regulation.
- Geographic location of regulation tanks.
- Tanks materials.
- Installment date and materials for the tank-feeding pipelines.

Potable Water Distribution Network:
- Geographic location of the Distribution network.
- Diameter, materials and installation date.
- Geographic location of the fire hydrants.
- Geographic location of the pressure reducers.
- Geographic location of the valves (in operation and closed).

4.3.3.2 Sewage System

The sewage system has 315 km of pipelines with diameters ranging from 175 to 1000 mm. Most of them work by gravity due to the topographic features of the city; however, a small area of about 25 hectares in the centre (near the port) uses a pump system to elevate the sewage before discharging it to the sea.

From the operational point of view, the city is divided into sectors according to the tributary areas of the 8 main collectors that discharge into the sea without previous treatment. 7 of them discharge directly to the coast (one of them being a temporary outlet) and the other is an offshore outlet, 300 m long. The outlets are distributed along the seashore for about 15km.

The discharges, characteristics and area of influence of these collectors are shown in the table below :

Main discharge collector	Diameter (mm)	Length (m)	Material	Tributary area (Ha)	Serviced population
U. de Antofagasta	200-350	1,422	C.A.	152.0	4,020
Offshore outlet	250-500	4,422	C.A.	283.3	34,384
Zenteno	400-600	4,376	C.A.	192.9	27,648
Treatment plant	200-800	18,806	S.C.-C.A.	593.5	72,088
Tocopilla	450-600	3,942	C.A.	172.7	19,945
North	200-300	7,688	C.A.	235.5	27,928
Las Rocas	200-400	4,965	C.A.	298.1	11,815
Total		45,621		1.928.0	197,828

Table 4.3 Characteristics of the main collectors

C.A.: asbestos-cement.
S.C.: simple concrete.

The secondary collector network is fundamentally made up of asbestos-cement pipes, except in the most recent buildings where PVC has been used, diameters being between 175 and 400 mm. The city can be divided into three sectors according to the state of repair of the installations.

- North and coastal sector.

The general state of the facilities can be considered critical. Due to topographic conditions in this area the collectors with large diameters have less gradient and therefore the flow has a lower velocity. This causes sedimentation of soil in the pipeline and impedes the self-washing mechanism, affecting the capacity of the system. Many outlet chambers in the sector are flooded and collectors work under low pressure. Pipes with a low gradient are more sensitive to changes in gradient in the event of a severe earthquake. So an earthquake in these areas is more likely to cause operational damage which would manifest itself in a loss of service sometime after the earthquake has occurred.

It is necessary to include the possible presence of industrial wastewater in the sewage as discharges are periodically made to the lower discharge areas. Oily sewer waters have been detected and are likely to due to discharges to the sewer system from truck washing.

- Central sector.

The saturation of some outlet chambers causes wastewater to overflow to pipelines with an inadequate diameter to receive this flow. This generates more overflow and flooding of the inspection chambers.

There is a problem of service rationalization in this area due to excess in the users of one collector. Also, restaurants in this sector discharge greasy materials that adhere and accumulate inside the collector pipelines.

In summary, the Antofagasta sewage system has some problems that must be taken into account when designing a construction project. These problems are the following:

- The existence of a network without an initial overall design has made the system inefficient. Some sections are not in good conditions and in spite of the steep slopes east-west, inappropriate maintenance generates overflows. Some of the pumping plant is worn out and there are no plans for its replacement, thus rendering the system non-operative.
- The final discharge of the city's sewage is through an offshore pipeline (300m long) and seven direct discharge pipelines, which function inadequately. This creates contamination problems along almost all the city coastline, including residential and tourist sectors.
- In general, the system of large collectors (diameters equal or greater than 250 mm) is in need of an operational analysis and without it a maintenance policy can not be established.

The company’s investment program includes rationalization of the wastewater discharge. The plan is to concentrate the 8 current discharges in two outlets, from which the non-treated final discharge will be carried out offshore. This solution implies the construction of intercepting collectors and pumping plant to make the necessary adjustments.

The information incorporated in G.I.S was:
- Geographic location of sewer chambers.
- Ground level and chamber height.
- Geographic location of main collectors
- Diameter and materials for the main collectors.

4.3.3.3 Telecommunications System

The telecommunications system is shared mainly by 4 companies: Telefonica (previously C.T.C., ENTEL Chile, Chilesat and VTR.
The majority of private telephones are owned by Telefonica the rest belong to VTR, a new company in the local market. All the companies include long distance service and mobile telephones. Two of the companies are described in more detail in the following section:

4.3.3.3.1 Telefonica

Telefonica has a modern building with a seismic resistant design and it is founded on rock to avoid settlement. Therefore it is supposed that in the event of an earthquake any damage incurred will be to the external installations and not to the main building and computer system.

The company counts on emergency equipment and personnel ready 24 hours a day. If there is service interruption, it has an emergency system, which starts working in five seconds with enough oil to last for one day and a battery that works for 8 hours.

Apart from the traditional service, Telefonica provides cellular phones and a satellite service. It has an optic fiber network (underground and aerial) throughout the length of the country. If these stop working, the company has emergency personnel working 24 hours a day. Finally, Telefonica has a microwave communications network.

In practice, every time there is a major emergency, as in 1995, the service is interrupted for long periods due to saturation of the lines.

4.3.3.3.2 CHILESAT

This company does not have a home telephone network, but it provides a service to companies, has street telephone booths in the central area and offers a long distance service.

The companies have facilities in two areas in the city. One is in the central area and includes the exchange installations and emergency equipment (generator and batteries). This facility is located in a steel container inside a building. The other is located in a building near the coast and houses the parabolic antenna. The building is old and has severe structural damage on the third floor slab.

There is no information on the other telecommunications companies.

4.3.3.3.3 Telecommunication Conclusions

In general, telecommunications systems do not suffer from infrastructure problems during earthquakes. But experience shows that the system saturates for a few minutes after a seismic event due to excess demand.

The Regional Government of Transport and Telecommunications is the organism in charge of controlling the proper functioning of telecommunications enterprises. It checks telecommunications networks and radio service. They inspect the emergency programs of telecommunications companies and radio stations once a year.

All the telecommunications antennas are concentrated on Los Morros hill. It is located 25 km northeast of the city at an elevation of 650 m. The foundation ground is categorized as rock in the geotechnical identification.

4.3.3.4 Electric Power Supply System

Electric power in northern Chile is supplied through the Interconnected System of the Great North (SING). It includes the First and Second Regions of the country. SING is controlled by a critical unit called the Load Dispatch Center located in the city centre.

SING faces various problems, especially in relation to the loss of reserve power, which is due to a number of reasons. For example, when mining companies set up equipment, which demands a great deal of energy (such as an electric digger), the system stability is affected.

In Antofagasta, electric power is supplied by the Mejillones Thermoelectric Plant and distributed by the Antofagasta Electric Power Supply Company (ELECDA), which have two stations one in the Salar del Carmen and the other in the Antofagasta Diesel Center.

The main distribution center for mining enterprises is located in La Negra and has a capacity of 16 MWa.

Main electricity is used throughout the city and there is a dense network of posts and overhead wires. In some areas the network is underground and there are about 434 transformers in the city.

The electric power system can resist earthquakes of magnitude 7 to 7.5 (Richter scale) and in 1995 damage to the system was less than 1%.

4.3.3.5 Other Energy Systems

A safety assessment was made of fuel storage companies. At present the legislation and its implementation is lax and some of the safety processes are not in accordance with international standards. The companies have their own safety procedures in case of an emergency. The companies assessed had security components for fire and spillage. A good classification and identification system exists for the type of fuel stored and all tanks have the necessary equipment to detect any anomalous situation. The main problem relating to the fuel stores are that they are all concentrated in the North very close to the main access to the city.

There is no main pipeline gas supply but some buildings have their own distribution networks where gas is stored in tanks with a capacity of 4-6 m^3.

4.3.4 Transporting Infrastructure

The importance of the 2nd Region in the country's economy makes it necessary to carry out a special analysis of the transport system. The critical cases are the port and railway systems, both of which are related to the transport of copper.

4.3.4.1 Seaport System

4.3.4.1.1 Synthesis of the Seaport Operations

Antofagasta's port is located in the centre of the city half way between La Negra ravine and Salar del Carmen. It has an area 319.000 m2. The soil conditions are fills placed on cement modules. The inner pool, which is 31 hectares, is made up of three dikes and there are 7 docks for loading and unloading.

The excellent climatic conditions of the region enable easy load transfer throughout the year.

4.3.4.1.2 Seaport Services

The seaport facility belongs to the Chilean government and is administered by the Chilean Seaport Company. The main services offered are:

1. Docks.
   a) for ships: use of piers.
   b) for the load: use of load transfer sites.
2. Merchandise storage and collection.
3. Fuel and tap water supply.
4. Truck and railway wagon weighing.
5. Container use and rent, truck and equipment parking

The private sector that uses the port includes ship, storage and customs agencies, highway and railway transport companies (FCAB), equipment renting companies, underwater service companies and boats which support seaport work.

The seaport works 24 hours a day, 365 days a year. There is an average of 100 people working each shift.

The following table shows the composition of the cargo moved in the last three years:

YEAR	COPPER (ton)	GENERAL (ton)	BULK (ton)	COASTAL TRADE (ton)	OTHER LOAD (ton)	Nº OF SHIPS	TOTAL (ton)
1996	1.129.945	256.761	692.690	46.814	386.582	544	2.512.792
1997	1.400.902	407.702	795.416	75.289	321.950	582	3.001.259
1998	1.515.349	442.388	658.180	71.958	303.941	656	2.994.816

Table 4.4 Load movement distribution

An average of 1.8 ships arrives daily although the port has a maximum capacity for 7 ships.

4.3.4.1.3 Seismic Damage

The 1995 earthquake caused the following damage in the seaport:

Piers 1, 2 and 3
According to underwater inspection and damage assessment, these piers suffered less damaged than the others. The wall displacements were less than 30 cm and slabs settled 20 to 30 cm, the largest settlements occurring in piers 1 and 2. These settlements affected the buildings and installations on the piers such as railways, crane driveways, trolley channels, storage houses and offices.

The cranes were removed due to the danger of being on an uneven ground. The railway operations continued as the settlement beneath the tracks was uniform.

Although the dock slabs were leveled and damaged facilities were torn down the repairs were not sufficient to fully recover the previous efficiency.

Piers 4 and 5
These piers were the most affected by the earthquake suffering a displacement of 1.1 m towards the inner pool and decreasing at the edges. The slabs settled up to 40 cm.

Up until now, repairs have been directed to solve specific problems relating to leveling the ground and repairing railways at the back of the dock, capacitating the use of the railways to piers 6 and 7.

Piers 6 and 7
These are founded on blocks and gavions. Their slabs settled up to 1 m during the earthquake, causing damage to installations such as the water and electric supply and railways. The dock walls did not suffer significant damage and their operation was almost unaffected.

The repair of the slab level and facilities was carried out from late 1995 to early 1996 with an investment of $ 750,000,000. Later, the transition area between piers 5 and 6 was repaired enabling the recovery of a greater supporting area and the construction of a new electric power station. Investment amounted to $ 250.000.000.

Although the seaport was seriously damaged in 1995, only one shift stopped operating.

The damage has been repaired gradually, and Piers 6 and 7 are now in full operation as is the railway, so all sectors are accessible.

Up to 1994, 1,800,000 tons of cargo were moved in and out of the port, while in 1995-1996 an average of 2,700,000 tons were moved annually, this figure increased in 1997 to 3,000,000 tons.

4.3.4.1.4 Probable Effects of Tsunamis in the Port

The main port dike is built of overlapped monolithic concrete blocks placed on a rock layer and is 18 m high with a 150 cm deep foundation.

A tsunami would occur after an earthquake of magnitude 8.0 in the Richter scale and with its epicenter located in the sea trench between parallels 26 S and 28 S. The height of this wave in deep water would be 1.3 m. and it would decrease to about 0.8 m at the port due to energy dissipation and batimetric characteristics.

The most common cargo which passes through the port is copper, and other metal and non-metal minerals. These cargos are deposited on piers 6 and 7 and do not present a risk to the nearby population. In the event of a tsunami the worst case scenario would be that they were washed out to sea.

For the port, the effect of the tsunami is less important than the original earthquake and acts only to complement the destructive effects of the latter.

The same is not applicable to the coastal areas surrounding the port since a tsunami could cause serious damage due to extensive flooding caused by the 8,5m ranup.

4.3.4.2 Railway System

The Antofagasta-Bolivia Railway Company PLC, known as FCAB, provides a variety of services, including small and bulk freights and containers. The railway has an national and international range as FCAB owns 927.3 km of track which connects it to the Chilean railway network (FERRONOR) and to the Bolivian and Argentinian systems.

FCAB supports the mineral and industrial companies of the region by transporting their products to the port and receiving imports and spare parts.

FCAB offers a variety of services, from the transport of freight in bulk, packaged or liquid form. It also transports fuel and hazardous materials (mainly sulfuric acid). A new type of wagon was purchased recently for container traffic.

FCAB owns about 2000 wagons for all types of load and counts on advanced control diesel engines, specialized equipment and personnel for vehicle upkeep.

4.3.4.2.1 Railway routes

Due to its strategic position FCAB plays an important role in the export of products from northern Argentina and the regions covered by the South American Center-West Interregional Enterprise Group (GEICOS) which includes Argentina, Bolivia, Chile, Paraguay and Peru.

The railway system has two main narrow-span tracks, like the tracks of Bolivia, Argentina and FERRONOR, Chile and it is via these networks that FCAB is connected to Paraguayan and Brazilian railways.

The main railway connects Antofagasta and Ollague (at the Bolivian border) and the other track connects Antofagasta and Augusta Victoria, where it joins with FERRONOR and the traffic with Argentina, via Socompa. There are also railways connecting Antofagasta with Mejillones, Pampa with Estación Prat, Antofagasta with El Abra and Ollague with Ujina.

4.3.4.2.2 Railway Vulnerability

The north south railway system starts in La Negra. Here, there is a 7m span bridge. During the first part of its trayectoria the railway runs along natural embankments and cuttings up to 5 m high. It then passes through COVIEFI, where in general the cuttings are smaller (1 to 2 m) although there are three big cuttings.

Towards the centre of the city the railway runs parallel to Andres Sabella Avenue, in this section there are no large cuttings or embankments. It reaches the railway facility at the intersection of Manuel Antonio Matta street and Andres Sabella Avenue. Then it exits the facility and passes over a natural embankment of about 0.8 m high, parallel to Azapa street

Finally, the railway runs parallel to Heroes de la Concepcion Avenue, where there are no embankments or cuttings, until the northern end of the city.

The 1995 earthquake scarcely damaged the railway. There were some small rocks falls, especially in the areas with many cuttings. The operative vulnerability of the railway is related to the seaport vulnerability.

4.3.4.3 Airport System

Cerro Moreno airport provides a national service and is the largest airport of the northern zone with 20 flights arriving daily. The runway was scarcely affected in 1995 and there was little damage to the main building. The runway is directed in such a way that it is not affected by displacement.

There is a small private airport for small aircraft serving the industries in the desert. This is located in La Chimba (the northern area of the city).

4.3.4.4 Urban Road Service System

The roads are mainly asphalt, although lately the tendency is to use concrete for heavy traffic. The main problems are the ravines and steep slopes that transect the principal streets. Most of the damage in 1995 occurred in these areas where there was a displacement of the pavements.

An emerging problem is the great increase of vehicles in the city, which has doubled in the last ten years. This has saturated the central streets. The traffic, which moves along the length of the city, passes through 5 main avenues. Work is under away at present, to rehabilitate some of the transversal streets to allow faster connections between these longitudinal roads. There are no high-level highways in the city but there are plans to construct one in the year 2000. Antofagasta shares the typical problem of the country's coastal cities. It has steep slopes (up to 40º) along the Coast Cordillera.

The construction and maintenance of urban roads is realized by SERVIU and the transit control is carried out by Transit Direction of Municipality.

4.3.4.5 Highway Access to the city

The city has three principal accesses and other minor accesses. The main routes are Route 26, Route 28 and Route 1. The first two connect the city with Route 5 (the Panamericana) which in turn links Antofagasta with Calama, Taltal, and Santiago. Route 1 connects the city with Mejillones, Tocopilla and Iquique.

The main problem with these routes is that they run parallel to the water supply pipelines and the vulnerability of the latter directly effects the roads. Rock falls are another potential problem in the south sector, due to slopes or cuttings possibly affecting Route 26 and 28. Route 1 connects Antofagasta to the airport and its unlikely that this road could be rendered impassable, except in the event of flooding due to the rupture of a pipeline (in this case the Cerro Moreno feeder).

The design, construction and maintenance of access highways and interurban roads are carried out by the Highways Department which is part of the Ministry of Public Works.

4.4 Seismic Risk Assessment

4.4.1 Seismic Intensity Map Design

The objective of micro mapping the area is to determine those zones or sectors, which behave differently during a destructive earthquake. Based on this zonification it is possible to recommend the special precautions necessary for seismic protection. For example certain types of buildings could be prohibited in certain areas. So it is extremely important to determine the vulnerability of buildings, transport facilities and vital networks.

One of the main advantages of microzonification in a country with limited funds, like Chile, is that it allows planners to make the most of certain seismic security criteria resulting in safer constructions without high cost. In other words, micro zone maps enable resources to be directed more efficiently to seismic protection and avoids the construction of buildings in dangerous zones.

The following information was taken into account for the design of the Antofagasta seismic intensity map:

- Seismic activity in the zone
- Geological study of Antofagasta
- Geotechnical zone mapping of Antofagasta.
- Landslide risk

4.4.2 Recent data earthquake

In order to establish the city intensity level it is necessary to assess the soil characteristics and its behavior in recorded past seismic events. Unfortunately, not much data exists since only a few earthquakes have been recorded. The largest earthquake in the North occurred in 1877, with an estimated magnitude of M_w = 9.0. This earthquake affected the zone between Arica and Tocopilla. The southern limit of the rupture coincided with the northern limit of the 1995 earthquake. It is estimated that the 1995 earthquake (M_w = 8.0) is only part of a future event similar to that in 1877. In 1995 the earthquake was recorded on one digital acelerograph. It had an isolated acceleration peak of 0,28g EW and the strong movement lasted 40 seconds.

4.4.3 Intensity Map Generation

The seismic intensity level map considers the seismic activity of the zone and the geological and geotectonic conditions of the ground, together with historical data and secondary effects.

A map of the ground quality distribution in relation to its seismic behavior was established. The soils were classified as Rock, Dense Soil, Medium Soil, and Loose Soil. The most abundant soil is medium compacted silty sand characterized here as Dense Soil. In some sectors, there is a very hard saline crust up to 2 m thick.

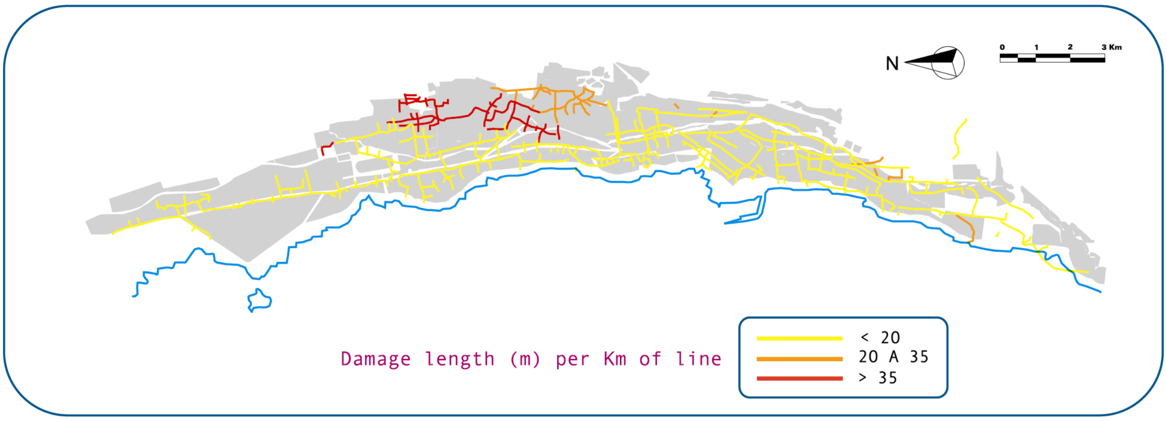
With the acceleration values for the 1995 earthquake (Ms =7.3 and an intensity of VI to VII in the IMM scale), a likely soil behavior was extrapolated for a seismic event of magnitude $M_s = 8.0$. This magnitude is based on the deformation accumulated due to the interaction of the Nazca and South American plates during 120 years (time lapsed since the last large earthquake in 1877). This accumulated deformation would be about 12m and would imply a release of energy generating an earthquake of at least magnitude 8.

With an appropriate attenuation relationship, calibrated for Chilean earthquakes in the central zone and adapted for the only existing record for the region, the rock acceleration level was determined for an earthquake larger than in 1995. The acceleration level for low density soils (as are the city's soils) was obtained from tables that relate the acceleration of rock with certain types of soils by using amplification factors. By using a relationship between acceleration and IMM, the city seismic intensity map was determined. Adjustments were made to the map in relation to landslides and the presence of the saline crust, these factors increase the intensity level in the areas where they exist.

4.4.4 Damage Plans Generation

The digital superposition between the seismic intensity plan and the vulnerability curves for each of the topics considered (Edification, Lifelines, Facilities and Essential Services and Transport Infrastructure), yielded the damage plans were obtained through thematic plans in GIS. These plans are the following:

4.7a Estimated Damage to the Electric System



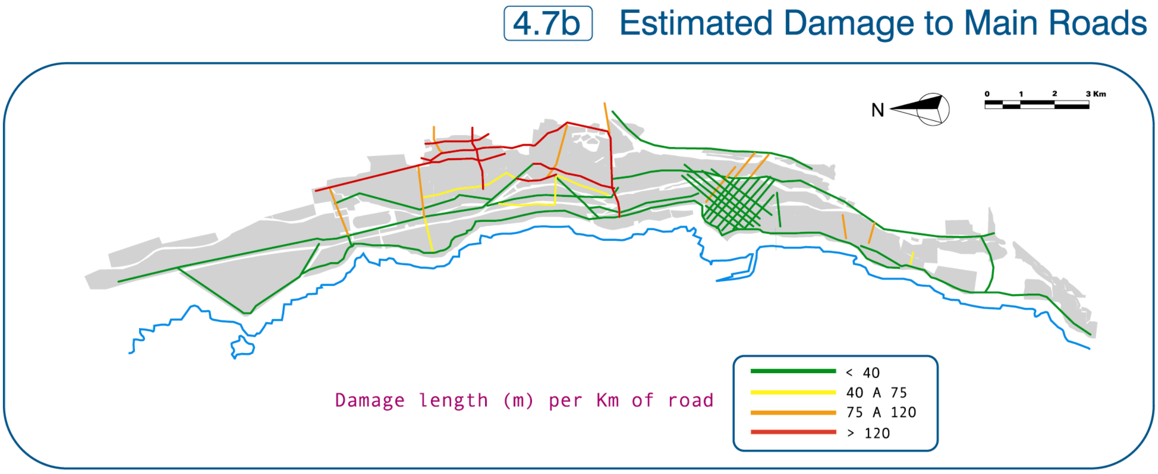


Figure 4.7 Electric System and Road Damage

4.5 Interviews Procedures and Results

More than 40 interviews were held with the main city companies and institutions such as hospitals, the police, the port, etc. Technical inspections also took place. Meetings were held at the institution in question and also in the Emergency Office at the Regional Government building.

Interviews and meetings related to the Urban Building area

SERVIU, Housing and Urbanization Service: part of the Ministry of Housing and Urbanization, it is responsible for the housing and urbanization projects.

Department of Architecture: part of the Ministry of Public Works, it is responsible for government buildings.

Department of City Hall Works (DOM): part of Antofagasta City Hall, it is responsible for the regulation of building processes in the city.

Chilean Chamber of Construction, Antofagasta Delegation: Association grouping all the building entrepreneurs in the city.

Interviews and meetings related to the Vital Networks

ESSAN S.A. Sanitary service company in charge of collecting, transporting and distributing potable water and urban sewage water
ELECDA S.A., Company in responsible for the distribution of electric power.

EDELNOR: One of the companies responsible for the generation electric power.

ENTEL, CHILESAT, CTC: Private telecommunications companies.

ESSO, COPEC: Private companies for fuel storage and distribution.

Interviews and meetings related to the vital service area

Antofagasta Regional Hospital: **T**he main public hospital in the region, owned by the state health service.

Antofagasta, Central and Baquedano Clinics: Private medical care.

Hospital del Trabajador, Mutual de Seguridad: Clinics dealing with workers' health and occupational illnesses, especially traumatism.

Ambulatory health centers: In charge of public primary medical care, owned by the state.

Schools: 10 of the 60 schools affected by the 1995 earthquake were chosen for analysis

Chilean Police: Responsible of the country's law and order.

Fire stations: Voluntary organization for emergencies.

Chilean Army: Armed force for helping in an emergency.

Chilean Red Cross: Emergency medical institution.

Medical Legal Institution, Identification Office and Civil Court: Institutions supporting court lawsuits and information processes.

Interviews and meetings related to the Transport area

Department of Highways: Entity belonging to the Ministry of Public Works (MOP), responsible for the inter-urban highways.

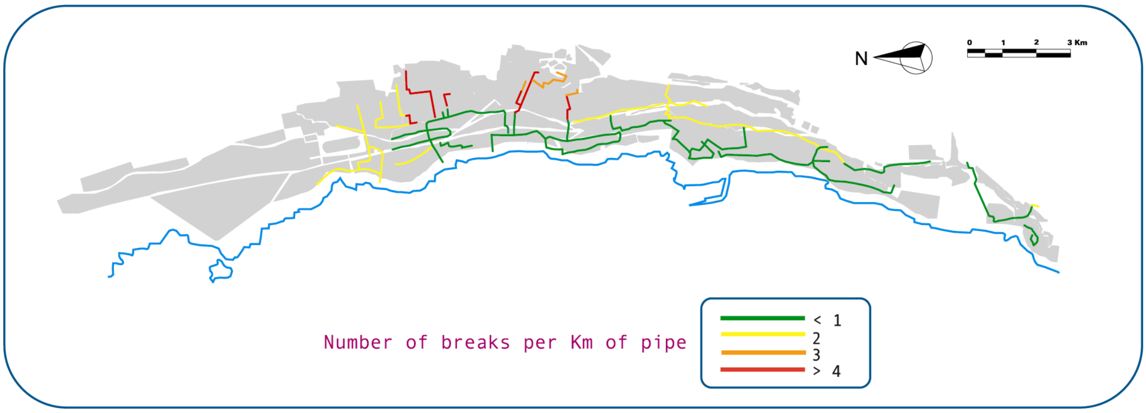
Department of Airports: Entity belonging to the Ministry of Public Works, responsible for the airport facilities.

Department of Seaport Works: Entity belonging to the Ministry of Public Works, responsible for the coast and port facilities.

Antofagasta Seaport Company (EPA) : Public-private company, which administers Antofagasta's port, which exports the majority of the country's copper

Antofagasta-Bolivia Railway (FCAB): Private company responsible for the copper transport from the mines to the seaports.

4.8a Estimated Damage to Water Supply System



4.8b Estimated Damage in Sewage Network

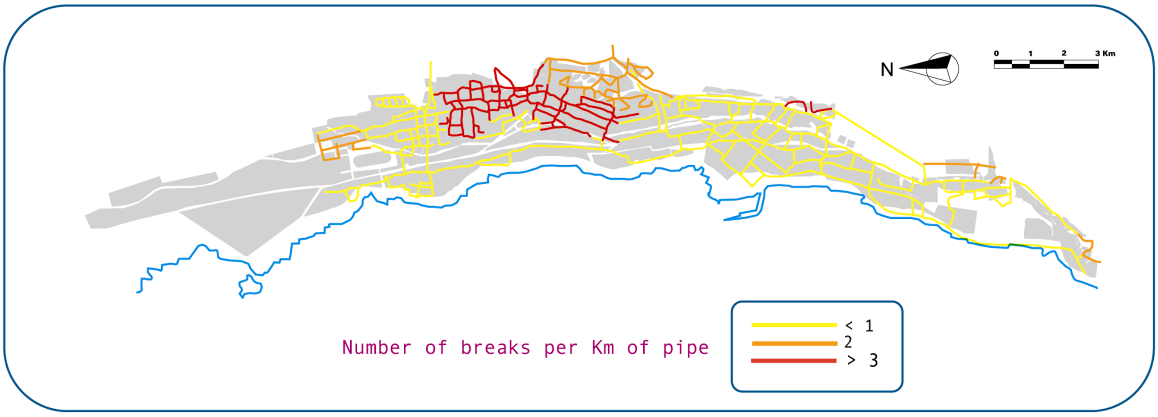


Figure 4.8 Water Supply and Sewage System damage

4.9 Schools Buildings Location and Schools Population Density

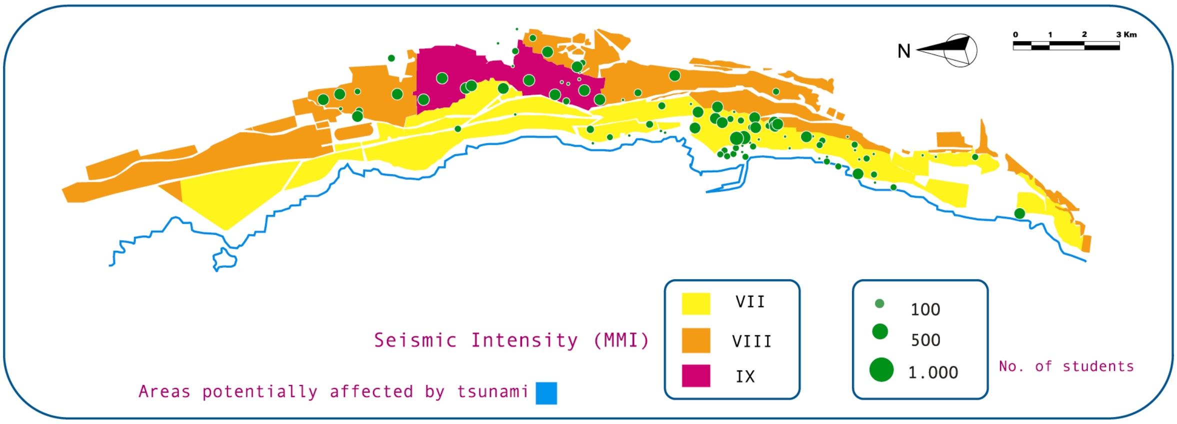


Figure 4.9 Educational Center Location

4.10 Critical Emergency Response Facilities

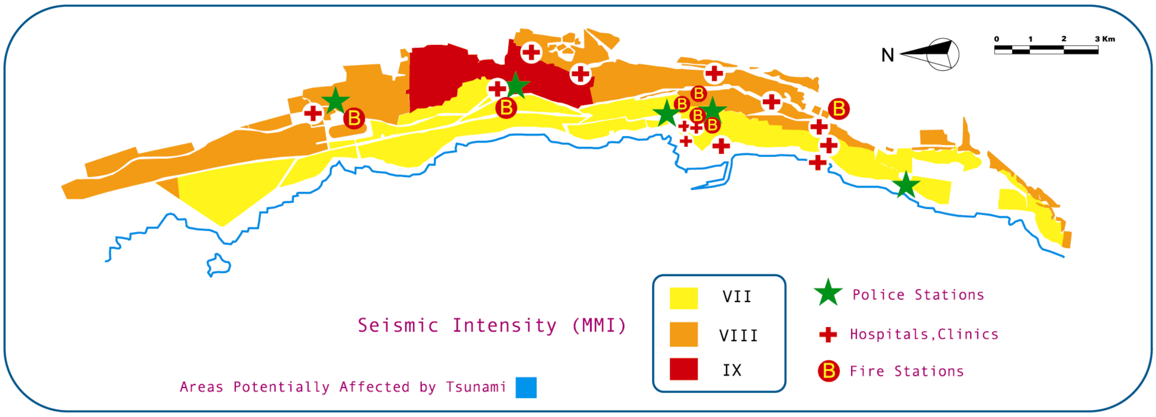


Figure 4.10 Essential Service Location

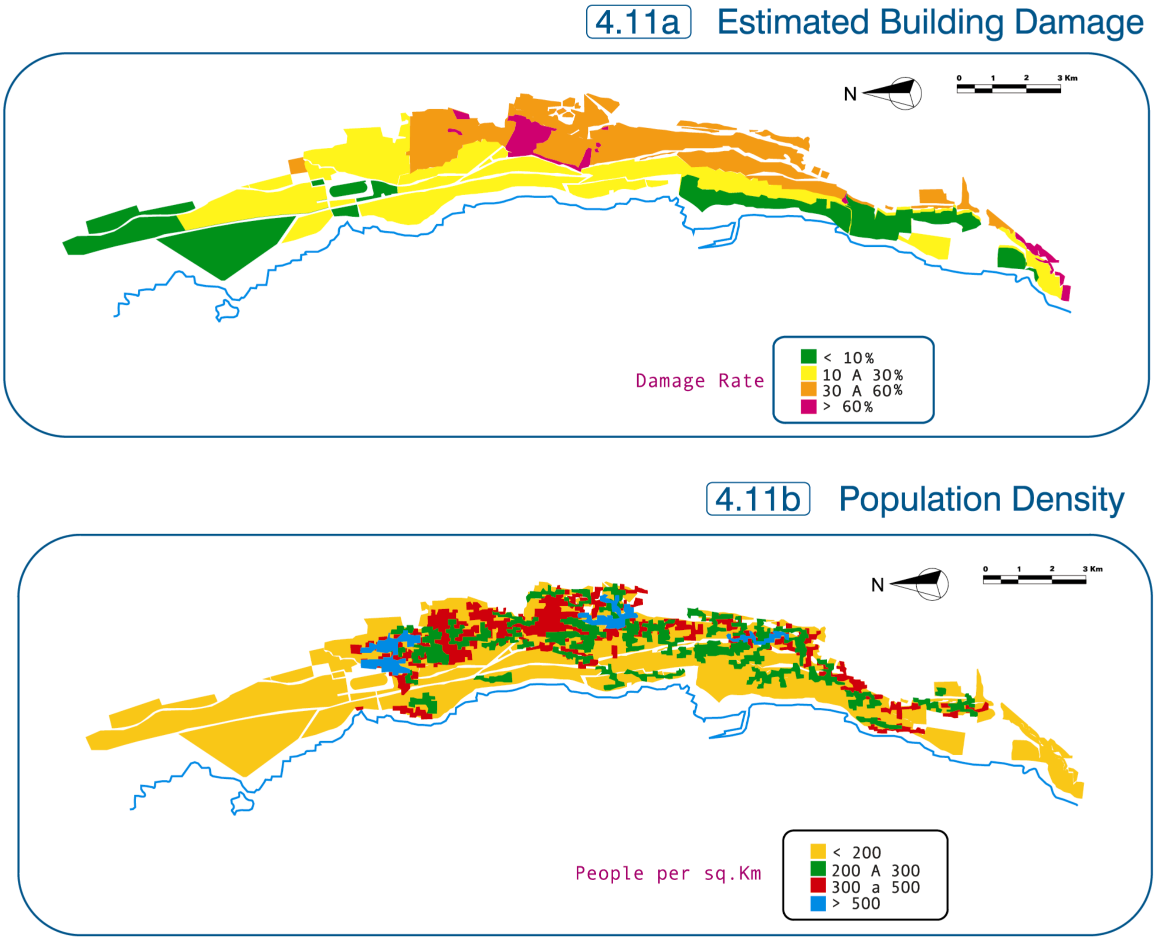


Figure 4.11 Building damage and affected persons

4.6 Seismic Scenario - The Earthquake and its Consequences

The following is the hypothetical scenario of a large earthquake in the city .

05:30 p.m. It is Monday in winter in Antofagasta. Work and study activities are about to finish and traffic is beginning to increase. Suddenly, a light earth movement shakes the city, and this is followed by a larger and more lasting earthquake.

05:32 p.m. People panic because of the noise and earth movements. The ground oscillates visibly and buildings move with unexpected violence. Buildings in the high-risk sector begin to fall down (the red sector in the damaged building plan that corresponds to Corvallis and the high sections of the city). This is influenced by the poor quality of the ground and buildings. 30 people die crushed beneath the walls of their own houses. There are other isolated incidents of severe damage in the center-north section; the hospital area; Favorecedora Neighborhood; Ricardo Mora neighborhood; Villa Constancia; Miramar Central neighborhood; and Prat A and Prat B sectors killing 20 other people. Electric power supply is interrupted due to numerous short circuits in the aerial distribution network. There is chaos inside the big shopping centers.

05:35 p.m. Old buildings in the central area have been seriously damaged and are now structurally unstable. Some high walls (of private properties and businesses) collapse, killing owners and workers. Several neon-hanging signs fall to the ground injuring passers-by. Diagonal cracks have appeared in many houses. The edges of block walls drop off and there are also horizontal cracks. Windows in old and new buildings shatter.

The number of casualties is estimated as 500 and increasing. Telephone lines are saturated. There is damage in the electric power plant, posts and some transformers. This will delay the re-starting of the service. Traffic lights are out of order and there are collisions in the central area. The seaport is seriously damaged in those places that were not repaired after the last earthquake. Piers 6 and 7 are partly out of use. Blocks have fallen from some of the protection walls and slabs have settled. Some important buildings like the City Hall, SERVIU, the Court of Justice, DIGEDER, and AIEP Institute are damaged.

05:40 p.m. Landslides have affected low-quality housing in Central, East and South Miramar; Ricardo Mora; Juan Papic; Villa Constancia;. Pedro Aguirre Cerda section; Jardines del Sur (sand sector)
There is a traffic jam on Balmaceda Street and in the central area traffic lights are not working.
There is a traffic jam on Carrera, Club Hípico, Díaz Gana, Augusto D'Halmar Streets and Argentina Avenue.
Citizens are making for the high areas in fear of a tsunami.
There are collisions in the access to COVIEFI. This road is partly blocked by landslides on the western side.
The first fire engines appear beginning their emergency work but they cannot operate because the streets are blocked by traffic jams.
The Oriental Avenue is blocked in the area of slopes due to earth and rock falls.
One of the lanes of Padre Hurtado avenue is open but the western side is blocked by rock falls.
There is damage in some schools but they have not collapsed. Children panic and teachers, in accordance with earthquake drills, keep them in the playground.
There are small and large floods due to ruptures in the main water supply pipelines. The soil supporting these pipes has been swept away by the water and some houses are flooded. The sectors involved are Pedro Aguirre Cerda and Juan Papic.
El Jote bridge is partially damaged. There are landslides and rock falls in La Negra reducing the traffic capacity. The situation is the same in the access Salar del Carmen.
The airport building for passengers and the control tower are seriously affected. The runway has cracks and is now so uneven airplanes cannot land.

05:50 p.m. The Emergency Regional Office organizes assistance.
Parents arrive at schools to pick up their children; this causes congestion especially in front of the private school entrances in the centre (Colegio San Luis, Instituto Santa María, Colegio Eagle School, Colegio San Esteban, Giant School, etc.). There are traffic jams on longitudinal streets of Matta and Ossa and the same is true on the transversal streets of Maipu, Baquedano and Sucre.

The first wave of the tsunami gets to the coastline. It is 2-4m high and a large part of the Paseo del Mar and the Plaza de Los Eventos are destroyed. The seaport is almost completely damaged and all types materials are swept away. The basements of the coastline buildings are flooded and many windows broken. The basement and first floors of the Antofagasta Clinic, ACHS Hospital, Public Works Office, and the Antofagasta Hotel are flooded and also the 3rd and 4th Fire Stations but the fire engines are safe. The Yacht Club, DIGEDER, Customs Office and AIEP structures are severely affected. The railway yards are flooded and the railway partially collapses.
The Children Care Center Ardillitas floods and so does the first floor of a near-by hotel. The school F-60 also floods.
Water supply fails in the high-risk sectors.

05:55 p.m. The first tidal waves arrive at the city centre. Colon Square and the first floors of the Mutual Fund Hospital and 3rd Police Station are flooded and many windows are broken. The water carries away some small vehicles damaging posts and other public and private properties.
The water recedes producing eddies which destabilizes some division walls and surface foundations. The pavement on Grecia and Balmaceda Avenues is lifted up. These avenues cannot carry traffic, so Grecia traffic is diverted to Brasil Avenue and Galleguillos Lorca Street, while Balmaceda traffic is derived to Washington and San Martín Streets.
The northern section of Perez Zujovic Avenue cannot be fully used. The alternative is Iquique Street. All the protection walls, both private and public, along the coastline are partially destroyed.

Half an hour later
It is getting dark and cold. The last tidal wave has not receded yet. Most people have not arrived home and they are desperate because they have not met up with their families. There is not much communication among relatives. Firemen, policemen and the Civil Defense are working hard. The authorities are as yet unaware of most damaged places. They are using their instinct and help the people nearest to them.

90 people have died and 1500 are hurt. 2,000 people are homeless. There are still some car accidents occurring because people are desperate to get home before it gets completely dark.
There is an after-quake that causes more panic and some low-quality houses are fall down. There are more landslides and the houses in the high sectors are damaged.
The first wounded arrive at the hospital. Its entrance is blocked due to the many cars parked outside and the inadequate location of the casualty department. Some people get to the medical centers in the northern sector. Their capacity is limited, so they cannot help everybody.

One hour later
The Army and the Red Cross start to participate.
Most people have gathered on the high sectors (above Argentina Avenue).
Water supplies system collapses in the north and south sectors due to the destabilization of the main pipelines.
The electric power supply is still not working and the city is dark.

Three hours later
30% of the electric power supply has been restored.
Telecommunications are not operating.
Help to the wounded and the search for missing people starts.

24 hours later
Debris removal begins.
60% of the electric power supply system is working.
30% of the population has potable water.
Road clearing begins in the main sections.
Almost 100% of telecommunications systems are operating.
New temporary shelters are set up in the schools designated for that purpose.

Three days later
Electric power supply is operating.
60% of the potable water system is functioning
There are some sewage problems in the lower areas.
Some buildings are demolished.
The airport runway is in working condition.
80% of the city's accesses are open.
Railway repair begins
The number of victims and people who disappeared is known.

A week later
100% of the potable water system is operating
There are about 3,000 people in the temporary shelters.
100% of the accesses and roads are operating.
60% of the sewage system is in operation.

One month later
Repairs begin at the seaport.
The first emergency housing is assigned.
Subsidies are provided for repairing houses.
100% of the sewage problems are solved.
The railway system is operating.
80% of the city streets are in use.

Three months later
50% of the seaport is in operation.
The first subsidies are provided to the families affected.
There are no people in the temporary shelters.

Six months later
City streets are in use.
70% of the seaport is working.

Chapter 5 SEISMIC RISK MANAGEMENT PLAN

5.1 Objective

Seismic risk actions in the last few years have not been continuous. This has been partly due scarce human and economic resources and partly because of lack of interest or people and government unawareness.

Chile has had a great economic development in the last few years, favoring the concentration of resources and efforts in emergency and catastrophe management.

As several social problems of underdeveloped countries are solved, the Chilean society concentrates on important issues like the improvement of living standards and safety.

This is not only a society's demand for better safety or protection in case of emergency or natural disasters, but it makes up an ethical and value demand of a society really concerned with development. In other words, Chilean greater social and economic development is based on equity and justice. This is strengthened by the dramatic experience of previous disasters. Indeed, earthquakes, alluvions, floods, tsunamis, volcanic eruptions, etc. have been part of our history for centuries.

In spite of the arguments for a better emergency or disaster management, we need other viewpoints and systematic and global administration for lessening the effects of disasters, especially seismic risk.

RADIUS is a challenge for the city to become aware of the need, advantage, and positive effects of a permanent attention to seismic risk, from a holistic viewpoint.

Under this long-term perspective, RADIUS must become the starting point for a permanent and dynamic conscience awakening, and a useful tool to set up action plans and projects for a safer city.

The seismic risk management plant below is aimed at:

a) Improving public knowledge and conscience of seismic risk.
b) Designing a general plan, directed to the integration of many ideas to reduce risk.
c) Promoting the setting-up and participation of multidisciplinary teams.
d) Putting proposals into effect during RADIUS application.

5.2 Management Plan Design

RADIUS technical team has been the organizing and leading element for the design of the general issues of the plan management. The plan, however, has been nourished by the data obtained in interviews, the seismic scenario workshop held in December 1998, and the action plan workshop in June 1999.

Three related issues have greatly influenced this plan. Firstly, previous individual and institutional experience with earthquakes. particularly in 1995. Secondly, the seismic scenario as a previous and essential step, and finally, interviews to get specific data for the plan design.

5.3 **Interviews and Discussion.**

The interviews were mainly held during the organization of the Seismic Scenario Workshop in December 1998. The information focused on the estimation of possible damage. Most institutions, however, gave immediately their opinion on the activities for seismic risk reduction, simply as a logical result of their work, although this was not considered as the main task for the workshop.

Interviews were also held with the different sectors in March and May, before organizing the action Plan Workshop. In January and February, data was collected and organized.

5.4 Action Plan Workshop

5.4.1 Two-days work

This workshop was held at the Salón Andres Sabella at Catholic University of the North, from June 9 and 10.
There were 60 participants from 46 institutions, both public and private.

Public: Regional Government for the II Región, Gobernación Provincial, Antofagasta City Hall, Army, Navy, Air Force, Police, Health Service, House and Urban Service, Firemen, Civil Defense, Red Cross, Regional Government of Transport and Telecommunications, Direction of Housing and Urbanism, Civil Identification and Registration Office, Environment Regional Commission, Investigations Bureau, Cerro Moreno Airport, Regional Government of Economy, Regional Government of Public Works, Regional Government of Education, Regional Government of Health, Regional Government of Planning and Coordination, Prisons.

Private: Mutual de Seguridad, Chilean Safety Association, Antofagasta Electric Power Company, Northern Electric Power Company, Antofagasta Seaport Company, Chilean Telecommunications CompanyEvangelist Church, Catholic Church, Antofagasta Industrial Association, Chilean Chamber of Construction, Chamber of Commerce, CHILESAT, Shell Chile, Esso Chile Petroleum S.A, ENTEL Chile, Escondida Mining Company, Zaldivar Mining Company , INACESA, Antofagasta-Bolivia Railway, Antofagasta Sanitary Service Company, Catholic University of the North and University of Antofagasta.

Dr. Osvaldo Muñiz, UCN Director of Research, Extension and Technical Assistance, welcomed the participants and pointed out the commitment of UCN to these activities and especially RADIUS. Mr. Mario Carvajal, Director of the Regional Emergency Office and Co-director of RADIUS explained briefly the project progress and its importance for the city. Dr. Carlos Villacis, consultant and Co-director of RADIUS pointed out the international issues RADIUS progress in Latin America. Mr. Mauricio Ponce was the moderator.

a) First Day: Morning: focus on the objectives of the project; RADIUS progress; summary of damage estimation; and seismic risk. The participants were Mr. Walter Roldan and Mr.Patricio Tapia from RADIUS; Mr. Carvajal made a presentation on the current risk management for the city Mr. Roldán spoke about the philosophy and strategies of the action plan.

Afternoon: Group work to discuss the workshop objectives and the strategies and activities of the action plan. Each group presented their opinions and conclusions in a plenary.

Fig. N° 5.1 Action Plan Workshop

b) Second Day: Work was intense. Groups continued discussing criteria for prioritizing activities. Finally, they focused on selecting the most important actions that are stated at the end of this chapter.

Work during these two days led to a commitment to put into effect the activities, to continue RADIUS and the action plan. The Regional Emergency and Civil Protection Plan Office and The Regional Emergency Committee became the organizing and executive entities.

Mr. Carlos Villacís and Mr. Mario Carvajal presented in the closing ceremony. The presentation of the report on the seismic scenario and action plan will take place during an official ceremony in the first week of October. The Chilean Government representative, will be the main guest.

5.4.2 Other Activities and the Press

Simultaneous to the workshop, there were two other activities: An itinerant exhibition named "Living Safer at School" and a training course for teachers in charge of safety in schools. It referred to a new application of The DEYSE School Safety Plan". Both activities were organized by the Antofagasta City Hall, the RADIUS team, and the National emergency Office, which provided the materials and professionals.

Local mass media, especially radios and the written press reported the workshop. The written press published part of the seismic scenario and the action plan in the central pages, thus calling people's attention. It is worth noting the editorial of "El Mercurio" on June 10^{th}, 1999 that values RADIUS as a comprehensive and useful project for the city.

5.5 Action Plan

5.5.1 Objectives

It is aimed at reducing the seismic risk in the city.

a) Short-term Specific Objectives

- Improving the response capacity in case of emergency and update their planning.
- Developing community awareness and knowledge on seismic risk.
- Increasing schoolboy and building safety.

b) Long-term specific Objectives

- Looking for actions to reduce seismic risk when planning the city.
- Planning activities for reducing the effects of dangerous materials and getting response in case of an emergency.
- Increasing seismic resistance in vital service systems.
- Planning the long-term normalization process after a disaster.

5.5.2 Strategies

Seismic risk reduction is a task requiring the permanent participation of many institutions. A strategy is needed to control and conduct the plan and also to implement new actions for improving the plan.

The strategy is based on six essential issues:

a) Setting -up of an organization to conduct the plan application.
b) Permanent coordination and updating of the plan.
c) Activity control and follow-up.
d) Implementation of new activities.
e) Spreading of the activities in the news media.
f) Including the Action Plan in the Regional Plan for Emergency and Civil Protection.

a) **Setting -up of an organization to conduct the plan application**

The activities in the Action Plan must be organized and conducted so as to combine efforts, support the activities, and act as an well-organized coordinated group with plan-related roles and tasks. In order to achieve these objectives, the Regional Emergency Committee must be activated to hold periodical working sessions.

The Regional Emergency Committee is legally established, thus facilitating its work. On the other hand, according to the participants in both workshops, the Regional emergency Office should coordinate the activities of the committee.

b) **Permanent coordination and updating of the plan:**

It is necessary to assess permanently the plan objectives and strategies to verify if they are accomplished. as expected. This involves constant motivation and institutionalization of activities. In other words, The Regional Emergency Committee must have definite responsibilities in the application of the plan.

c) **Activity control and follow-up:**

Every planned activity must be proved to be attainable. This is a commitment for the organism in charge. This organism must be updated as to progress and objectives. Each activity must be promoted and spread for public knowledge. In this way, not only the Regional Emergency Committee will have the control, but also the community will focus its attention on the activities.

Activities:
- Distribution of the programs in the Action Plan
- Periodical progress reports
- Field work
- Final report of each plan

d) **Implementation of new activities.**

Other initiatives will surely appear and the present ones will be improved. These must be carefully discussed in order to support and update the plant. New activities are essential to make the plan permanent and therefore reduce seismic risk.

Objectives:
- Assessment of needs and acceptance of new ideas or projects.
- Setting-up of new activities.
- Priorization of new activities
- Implementation of new activities

e) Spreading of the activities in the news media:
This will motivate other sectors to learn and try some of the activities or merely presenting ideas. In general, it is an effective a way of arising conscience and increasing knowledge about seismic risk. Besides, spreading the activities is a social responsibility, because the community must be updated as to authorities' work for their safety. This must be achieved as follows:

- Giving information to the news media.
- Meeting with sectors and social groups.
- Report publication and spreading.

f) Including the Action Plan in the Regional Plan for Emergency and Civil Protection.

The Action Plan in the Regional Plan for Emergency and Civil Protection is a legal device that will be reviewed and updated to meet the needs of RADIUS. The related Action Plan must be institutionalized and its application must be mandatory.

5.5.3 Activities

a) Short-term Activities

Activity 1: Tsunami Evacuation Training in Schools.

Organisms in charge: Gobernación Provincial de Antofagasta, Antofagasta City Hall, Police, Navy, Firemen, Civil Defense, Government Representative of Education and Regional Emergency Office..

Objectives: to try massive and simultaneous evacuation of schools in case of a tsunami.

Brief description: Some schools are located at the seismic risk border or zone. In these cases people must be evacuated to safer areas. Moving 6,000 students to the downtown area, however, must be planned and exercised in order to reduce risks such as heavy traffic, electric wires, walls, jams, etc.

Estimated time: Three months to do the first trial evacuation. It must be repeated as many times as necessary.

Activity 2: Tsunami Evacuation Training for Coastal Neighborhoods.

Organisms in charge**:** Antofagasta City Hall Direction of Emergency, Police, Navy, Civil Defense.

Objectives: Promoting and training these sectors for tsunami evacuation.

Brief description: There is previous experience in school evacuation, but in some neighborhoods it is much more difficult to have the community cooperate. This activity must be permanent.

Estimated time: 4 months for the design and first application. It must be repeated .

Activity 3: Design of the Inter-Institution Coordination Plan for Helping Victims.

Organisms in Charge: Antofagasta Health Service, Police, Military Hospital, Safety Mutual Fund, Chilean Safety Association, Antofagasta Clinic, Fire Departments.

Objectives: Designing a coordination plan among the Regional Hospital, City Hall primary Care Centers and private clinics and hospitals.

Brief Description: There has been important progress in helping victims in emergencies or disasters. The Antofagasta Health Service has worked for years in this respect. The coordination with other health centers, mainly private is still pending. This Action Plan will solve this problem. Proceedings, communication mechanisms, resource use and others will be determined.

Estimated Time: 4 months.

Activity 4: Annual Rescue Simulation and Victims' Care.

Organisms in charge: Antofagasta Health Service, Police, Military Hospital, Safety Mutual Fund, Chilean Safety Association, Antofagasta Clinic, Fire Departments.

Objectives: Designing a coordination plan among the Regional Hospital, City Hall Primary Care Centers, and private clinics and hospitals. Training field rescuing and transfer to care centers.

Brief Description: There is previous experience in this respect, but simulations have not continued. It is important to do practice on simulation, because new personnel is hired in the different institutions, and training sites and conditions change.

Estimated time: Six months till the first simulation and periodicity determination.

Activity 5: Emergency Plan Updating and Improvement.

Organisms in charge: Regional Emergency Office and all the institutions participating in RADIUS workshops.

Objectives: Updating the Regional Emergency Plan.

Brief Description: The present emergency plan was reviewed 4 years ago, so it needs to be modified in order to add new viewpoints in risk and emergency management. The Regional Government is not involved in the plan, but its active and direct participation is essential because Civil Protection laws demand it.

Estimated Time: 6 months.

Activity 6: Assessment of F-60 School Evacuation and/or Transfer.

Objectives: Assessing transfer alternatives for F-60 School.

Brief Description: F-60 School is in the tsunami and flood risk zone. Its evacuation is very difficult because of the heavy traffic around it. The evacuation efficiency, the possible transfer zones and the construction project must be studied.

Estimated Time: 6 months.

Activity 7: Study of Ardillitas Children Care Center Transfer.

Organism in charge: Chilean Army.
Objectives: Assessing the alternatives for Ardillitas children care center transfer.
Brief Description: this care center is located in a high-risk tsunami area. The area is difficult to evacuate. The entrance has a steep slope reaching a two-lane avenue.
Estimated time: six months.

Activity 8: Evacuation Training for Churches.

Organisms in charge: Evangelist Church Association, Catholic Church, Antofagsta City Hall, Civil Defense.
Objectives: Training Shepherds and supporting personnel to evacuate during cult hours.
Brief Description: Religious groups are closely involved in training their communities in the church evacuation during massive religious activities. They want simulations to be permanent.
Estimated Time: 4 months.

Activity 9: Design of a Web Site for Natural Disaster Prevention.

Organisms in charge: Chilean Telecommunications Company, Regional emergency Office, Universidad Catolica del Norte, Regional Government of Education.
Objectives: Collecting data on natural disaster prevention that can be accessed via Internet.
Brief Description: The Chilean Telecommunications Office has offered its computer and communication resources to spread information on the genesis and causes of natural phenomena, their effects. mitigation activities, prevention, and training.
Estimated Time: 6 months.

Activity 10: Tsunami Alarm and Alert Plan Updating.

Organisms in charge: Navy, Gobernación Provincial de Antofagasta, Antofagasta City Hall, Army, Air Force, Police, Fire Departments, Universidad de Antofagasta, Regional Government of Education, Regional Health Service and Regional Emergency Office.
Brief Description: Chile, through the Navy Oceanographic and Hydrographic Institute, is a member of the Pacific Tsunami Alarm and Alert International System. The National Tsunami Alarm and Alert System is considering the formulation of new local and regional plans because the existing one is obsolete. This updating implies new tasks and proceedings, simulations and active work of the committee suggested in order to make it permanent.
Estimated Time: 6 months.

Activity 11: Designing the Reconstruction and Refurbishing Plan.

Organisms in Charge: Regional Government of Public Works, Regional Government Representative, Regional Government of Housing and Urbanism, Antofagasta City Hall (Technical Cooperation Service, and Department of Civil Works) and the Regional Emergency Office.
Brief Description: The city does not have a reconstruction plan. It must be designed based on the seismic scenario and assessed by the Regional emergency Committee.
Estimated Time: 7 months.

b) Long-term Activities

Activity 12: Adding Training and Self -protection Activities for Natural Risks in the Cross-Curriculum of Pre-Primary, Primary and Secondary Schools.

Organisms in charge: Regional Government of Education, Catholic University of the North, Antofagasta City Hall.

Objectives: Adding the study of natural risks, their effects, and self-protection in the school cross-curriculum.
Brief Description: It is aimed at teaching human settlement risks and their relationship with nature in schools. Risks and self-protection as a comprehensive concept is not studied. This is a long-term program since it includes the formulation of new curriculum and pilot application.
Estimated time: 2 and a half years.

Activity 13: Emergency Training for Neighborhoods.

Organisms in charge: Red Cross, Neighborhood Organizations, Catholic University of the North, Regional emergency Office and Regional Government.
Objectives: Training neighborhoods, especially their representatives, to organize themselves in order to face an earthquake, by giving information on self-, family and neighborhood protection.
Brief Description: These institutions have participated in conferences on neighborhood protection. It is necessary, however to systematize the information and train the monitors in conference techniques and methodology. The content of the pamphlets must also be systematized.
Estimated Time: 6 months.

Activity 14: Design and Implementation of a Periodic Informative Campaign on Protection and Natural Risks, particularly Earthquakes.

Organisms in charge: Regional Government Representative, Regional Government, Regional Emergency Office.
Objectives: Spreading protection measures in case of earthquakes.
Brief Description: It is aimed at designing and applying a permanent campaign via the mass media and mainly pamphlets to spread information on adequate behavior and precautions for protection.
Estimated Time: two and a half years.

Activity 15: Designing Street Signs for Safety and Risk Zones.

Organisms in charge: Antofagasta City Hall (Direction of Emergency and Direction of Traffic), Chilean Navy, University of Antofagasta.
Objectives: Putting street signs in tsunami safety and risk areas.
Brief Description: There are two studies with similar results on tsunami inundation. The plan consists in signaling risk and safety zones to increase knowledge about evacuation. Traffic regulation can be applied and place the signs in strategic spots, indicating safety and risk zones above the sea level along with the recommended evacuation routes.
Estimated Time: 1 and half years.

Activity 16: Formulation of a Project on Urbanization and Seismic Risk Management and Reduction.

Organisms in charge: Antofagasta City Hall (SECOPLAC, Department of Civil Works, Direction of Emergency), Housing and Urbanism Service and Regional Emergency Office.
Objectives: Incorporating the seismic vulnerability areas in the City Hall urban planning devices and implementing a risk reduction urban politics.
Brief Description: The City hall must state the directions and precautions for soil use and architectural design. For this purpose, a multi-disciplinary team for urban planning will be established, with the participation of the City Hall and local universities.
Estimated Time: approx. 8 months.

Activity 17: Analysis and Assessment of Mandatory Technical Requirements for Risk Assessment in Public Investment Projects.

Organism in charge**:** Regional Representative of Planning, Regional represenative of Public Works, Housing and Urban Service, Regional Government and Regional Emergency Office.
Objectives: Including risk assessment and management in the state-funded regional development projects.
Brief Description: There is a variety of natural co-lateral risks in the region. Many of them are not considered in the technical assessment of projects. Thus, the quality of the construction projects does not reflect the amount of public investment. The activity is aimed at stating the technical requirements

for projects including risk assessment and reduction under different soil conditions. A proper technical nomenclature must be devised. Risk conditions, proceedings and assessment patterns must be determined according to the usual technical requirements for state projects.
Estimated Time: 12 months. The results should be applied to all regional state-funded projects, which must be revised permanently.

Activity 18: Seminar on Urbanization and Antropic and Natural Risk Reduction.

Organisms in charge: Universidad Catolica del Norte Departments of Geology, Civil Engineering and Architecture.
Objectives: Promoting professional and academic activities for urban seismic risk reduction planning.
Brief Description: A seminar will be held at Universidad Catolica del Norte. National and regional presenters will be invited and it will be directed to regional professionals and students.
Estimated Time: 4 months.

Activity 19: Design of Social Seismic-resistant Construction Modules.

Organism in charge: Department of Civil Engineering at Catholic University of the North.
Objectives: Designing structures for enlarging social houses.
Brief Description: Low-income sectors usually enlarge their houses with informal construction, without technical assistance. The activity is aimed at designing better-quality construction modules and give advice on low costs and seismic resistance. These modules must be available for those people interested.
Estimated Time: not more than 5 months.

Chapter 6 ACTIVITIES IN THE CITY: CONFERENCES, SEMINARS AND WORKSHOPS

6.1 Introduction

RADIUS is especially interesting for the city of Antofagasta and the northern region of Chile (including Arica, Iquique, and Tocopilla among others) since it is referred to increasing natural risks. The recent earthquake on July 30th 1995 and the alluvions on June 18th 1991 are still remembered by the population. These affected the city of Antofagasta directly.

On the other hand, authorities are increasingly aware of this situation and actions have been taken by OREMI, the organism in charge of emergency, and by some local university researchers who are making projects related to natural risks.

For this reason, some links between public institutions (OREMI) and local universities (Catholic University of the North and University of Antofagasta) had been established previous to RADIUS.

RADIUS made the government institution and UCN to come closer. A collaboration agreement for RADIUS was signed. The Departments of Civil Engineering and Geology at UCN and OREMI-Antofagasta were responsible for the project design.

Several activities leading to community participation and RADIUS promotion were carried out by IDNDR Secretariat with Geohazards International as a consultant.

6.2 RADIUS Opening

RADIUS first official activity was the seminar "RADIUS Project" on May 5th, 1998 With the participation of the Provincial Governor of Antofagasta, Mr. Tomislav Ostoic, Mr. Kenji Okazaki from IDNDR, Dr. Carlos Villacis from Geohazards International, the regional and municipal authorities of heath services, armed forces, police, and public and private education - numbering over 50 people total, the RADIUS Project was initiated in the port-city of Antofagasta. The inaugural event was 2 hours and thirty minutes in duration and the event was well covered by the media. Both newspaper and television reporters were present.

6.3 Workshop Seismic Scenario

In accord with the program established for the workshop of siesmic scenario on December 17 and 18 1998, during the first day of the workshop Ms. Cardona introduced the RADIUS Project and described the impact of earthquakes in urban areas. Then the local RADIUS team presented an update of the RADIUS project in Antofagasta and the earthquake scenario.

Around 40 participants attended the workshop and were divided into four groups, which analyzed and evaluated the earthquake scenario. They revised the estimated damages and formulated ideas to reduce the seismic risk. Comments were also made about the institutionalization and implementation of those actions.

Specials mention it is necessary for Ms. Mattingly’s presentation, who spoke about the reduction of seismic risk in existing and future structures, methods of educating and informing the community and the importance of adequate organisation and planning before to the occurrence of an emergency.

6.4 Informative Talks about Earthquakes

As was estimated in the RADIUS application form, the probability of a significant seismic event in the North of Chile is high. Frequently the press publishes information about earthquakes and the RADIUS project initiative.

In brief, the press had an active participation and the main newspaper published a summary of the results presented on the everry workshoop and some times caused a strong impact among the people of the city

A summary of the main activities carried out by RADIUS is shown below.

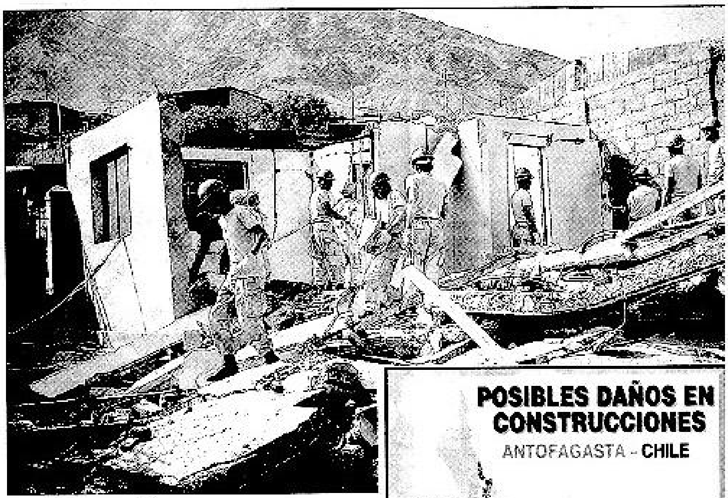
RADIUS Activities Summary

Activities	Date	Objetive	Participants	Lectures
Initial Seminar	May 5th, 1998	RADIUS Presentation Antofagasta	Local authorities, public and private organization representatives	Dr. Kenji Okazaki, IDNDR Dr. Carlos Villacís, GHI Mr. Mario Carvajal, OREMI Mr. Mario Pereira Mr. Walter Roldán
Workshop	October 7th, 1998	Spreading RADIUS progress	Public and private organization representatives	Mr. Mario Carvajal Mr. Patricio Tapia Mr. Walter Roldán Miss. Marisol Bembow Mr. Alberto Maturana
Interviews	July-October, 1998	Getting information from public and private organizations.	One or two members of RADIUS and institution representatives	Mr. Mario Carvajal Mr. Mario Pereira Mr. Patricio Tapia Mr. Walter Roldán Miss. Marisol Bembow
Conferences	October 1998-May 1999	Spreading RADIUS Antofagasta	Children care centers. Police and Investigation	Mr. Mario Carvajal Mr. Mario Pereira
Training course		Trainee, Japan	Mr. Patricio Tapia, Dept. Civil Engineering	
Training course		Trainee, Japan	Mr. Mario Carvajal	
Workshop I	Dec., 1998	Seismic scenario presentation	Public and private organization representatives	Mrs. Mattingly Ms. Cynthia Cardona Mr. Mario Carvajal Mr. Patricio Tapia Mr. Mario Pereira Miss. Marisol Bembow Mr. Walter Roldán
Summer School, UCN	January 14th, 1999	RADIUS promotion	General public	Mr. Mario Pereira Miss. Marisol Bembow
Workshop II	June, 1999	Action Plan "Seismic Risk Management"	Public and private organization representatives	Mr. Carlos Villacís Mr. Mario Carvajal Mr. Patricio Tapia Mr. Mauricio Ponce
Major in Industrial Mineral Environmental Management	July 23rd 24th, 1999			Miss. Marisol Bembow Mr. Mario Carvajal
Report to CORE				Mr. Mario Carvajal Mr. Patricio Tapia

EL MERCURIO **DESARROLLO REGIONAL** A-2 DOMINGO 24 DE ENERO DE 1999

4 **EL TIEMPO** Lo positivo y negativo de "La Niña"
6 **CAPITALES** Millonario flujo de inversión extranjera

El violento terremoto de 1995 ocasionó daños mínimos, en comparación a la magnitud del movimiento (7.3 grados en la escala de Richter). Hoy se estudia qué sucedería si se produce un movimiento telúrico de mayor cuantía.



Esta pregunta tratan de contestarse los investigadores del proyecto Radius de Naciones Unidas en base a la simulación de un violento sismo en nuestra ciudad, que sirve de laboratorio virtual frente a daños y reacción de la comunidad

¿Qué pasará con otro terremoto?

Son las 17.30 horas del lunes 21 de junio de 1999. Es un día como cualquier otro. Sin embargo, de improviso, un suave movimiento en segundos pasa a convertirse en un terremoto de 8 grados en la escala de Richter, con epicentro a 60 kilómetros al noroeste de Antofagasta.

No se asuste. Estos datos son ficticios, pero sirven de base al laboratorio sísmico del proyecto Radius-Antofagasta para determinar qué daños y situaciones de emergencia puede provocar otro violento sismo en nuestra ciudad, eso sí más fuerte que el terremoto del 30 de julio de 1995, que alcanzó 7.3 grados en la escala de Richter.

ANALISIS TECNICO

Para ello resultó necesario "crear" este temblor porque así puede determinarse en base a análisis técnicos qué ocurrirá a las construcciones (edificios y viviendas), agua potable, alcantarillado, electricidad y sistemas telefónicos, pero además cómo deberá administrarse esta emergencia por toda la comunidad.

El proyecto Radius -que significa Risk Assesment Tools for Diagnosis of Urban Areas against Seismic Disasters (algo así como estudio, diagnóstico del riesgo sísmico) es llevado adelante por Naciones Unidas a través de su secretaría para mitigación de desastres naturales en ciudades con altas probabilidades de sismos, entre ellas Antofagasta y otras seis urbes de varias partes del mundo.

Este programa está siendo desarrollado por el Departamento de Geología de la Universidad Católica del Norte (UCN) e intendencia a través de la Oficina Regional de Emergencia (Oremi), con asesoría técnica de la firma GeoHazards International.

ESCENARIO VIRTUAL

El escenario sísmico del proyecto Radius -generado por estudios geológicos e históricos de otros terremotos- podrá determinar una microzonificación de riesgo telúrico, por cuanto podrá ser dividida la ciudad en áreas de acuerdo al grado de posibles daños, asociados también al desprendimiento de tierra y tsunamis (olas gigantes). Este estudio determina que cualquier daño físico y comportamiento de edificaciones en general no sólo dependen de los temblores, sino también de la antigüedad, diseño, calidad y dimensiones de cada construcción, por ello además se considera un inventario de infraestructura y su posible respuesta al violento sismo.

Estos datos deberán sumarse a la ocurrencia de otros riesgos, como plantas químicas y de combustibles, estanques y áreas electrificadas, además de la respuesta de los servicios de salud, establecimientos educacionales, bomberos, gobierno y voluntariados, a fin de entregar información detallada de los efectos del temblor.

SU OBJETIVO

El objetivo fundamental de Radius consiste en condensar estos antecedentes en un sistema de información geográfico, que mostrará en un software cómo puede sufrir daños nuestra ciudad por y después del terremoto, con un detalle de cada cuadra por sector habitacional de Antofagasta.

Como último paso -y después de exhaustivos análisis- este estudio preparará un plan de administración de riesgos de emergencia, donde deberán participar todas aquellas instituciones con capacidad de mitigación de desastres naturales, ya sea de Gobierno, sector privado o voluntariados.

El mes pasado, los investigadores de Radius presentaron sus análisis preliminares del escenario sísmico, que se sometió a evaluaciones por parte de instituciones, servicios básicos, policías, municipio, empresa portuaria y ferrocarriles, entre otro organismos, que entregaron recomendaciones al proyecto en sus etapas de avance.

ANALISIS PRELIMINARES

El director del Departamento de Geología de la UCN, Mario Pereira, explicó que este proyecto busca una amplia participación, porque sólo la comunidad conoce en detalle su entorno, lo mismo que empresas y otros organismos que tienen información de primera mano.

Agregó que los efectos de cualquier evento sísmico dependen de la distancia de su epicentro y factores urbanos, que se esperan determinar lo más acotados posibles bajo la simulación de otro terremoto en Antofagasta.

ZONA SISMICA

En este aspecto, la zona norte pasa por un período de "madurez sísmica" en un límite con la península de Mejillones, que tuvo cerca el epicentro del terremoto de 1995. En esta área, que incluye principalmente a la Primera Región y sur de Perú, no ocurre un sismo de características devastadoras desde 1877, que sobrepasó los 8 grados en la escala de Richter.

El retorno de grandes sismos en el norte presenta períodos de 120 años, por ello existe interés científico por analizar al máximo qué ocurrirá en esta área dentro de los próximos años. En todo caso, Antofagasta por su calidad de suelos, puede soportar violentos temblores sin mayores dificultades, como quedó de manifiesto en 1995, cuando quedaron daños mínimos en comparación a la magnitud de terremoto.

Los movimiento telúricos en el norte son provocados por el roce de la Placa de Nazca (corteza oceánica) al momento de "sumergirse" bajo el continente, en razón de diez centímetros al año. Esto produce un contacto cuya liberación de energía corresponde a un sismo en la superficie terrestre.

PABLO MATAMOROS A.

Fig. N° 6.1 A Press Clipping ("El Mercurio") About RADIUS

Chapter 7 CONCLUSIONS

7.1 Grant agreement IDNDR/2nd Region Intendencia

RADIUS was based on a collaboration agreement between IDNDR Secretariat and the Intendencia (Regional Government) of the 2nd Region, Antofagasta, which was selected among nine world cities by IDNDR. The project was carried out in Antofagasta, with the support of GeoHazards International Consultants and the local team made up of Regional Emergency Office (OREMI), dependent on the 2nd Region Intendencia, and the Departments of Civil Engineering, Geological Sciences and Economics at Catholic University of the North (UCN).

At first, Antofagasta was chosen for the application of an auxiliary case study; nevertheless, the Intendencia provided the additional funds to make it a full case study.

The following researchers participated in the project:

Dr. Carlos Villacís	Project Co-Director.
Mr. Mario Carvajal	Local Co-Director, Director of the Regional Emergency Office.
Dr. Mario Pereira	Chief Scientist, Head of the Department of Geological Sciences, UCN.
Miss Ma. Soledad Bembow	Researcher, Department of Geological Sciences, UCN.
Mr. Walter Roldán	Researcher, Head of the Department of Civil Engineering, UCN.
Mr. Patricio Tapia	Researcher, Department of Civil Engineering, UCN.
Mr. Mauricio Ponce	Researcher, Department of Economics, UCN.

Based on the agreement terms, the project was funded by a US$ 20,000 IDNDR grant and a 2nd Region Intendencia grant for US$ 25,000. The latter were provided by the National Fund for Regional Development (FNDR). The IDNDR funds were posted to UCN to finance the consultants and technical city data collection. On the other hand, the Intendencia Funds were used for purchasing software and hardware, publication expenses, stationary and others.

7.2 Objectives Attained

Most RADIUS objectives were fulfilled; others will result from the implementation of the Action Plan. Among the most important objectives fulfilled are the following:

a) Study and design a graphic application to the micro-zone mapping of seismic risk. Its results were used as the basis for the establishment of a seismic scenario.
b) Promotion of multi-disciplinary collaboration among the Regional Government; local scientists; and the industrial, trading, and financial sectors to face eventual seismic events. These institutions will continue working in the Action Plan.
c) The development of a seismic scenario, which called the community's attention when it was published in the central pages of the local magazine "El Mercurio de Antofagasta".
d) Finally, the fact that RADIUS will be applied to other cities in northern Chile, particularly Copiapo, Taltal, Mejillones and Tocopilla.

Today, RADIUS is recognized as an important project to reduce seismic risk in the city. Many organizations and institutions are getting involved in the Action Plan, the most important result of the project.

7.3 Problems Faced

Several difficulties were faced during RADIUS progress; some of them were extraneous while others were internal. Most of them were easily solved; however, some of them influenced its development.

Telecommunications companies did not provide information due to the strong competence for the telephone and telecommunications markets existing in the country. In the first phase, these companies did not detect the comparative advantages that the project could mean for them.

Although the general objectives were fulfilled, the team should have worked more coordinately. This deficiency is due to the researchers' excess work and the lack of personnel at OREMI.

7.4 Problem Solution

Coordination would have been better if one researcher or professional had been hired full-time for the project. This was not possible owing to budget problems.

As to the information from the telecommunications companies, the head of the most important ones were directly addressed. One of them, fortunately the most important, provided all the related information and committed to one of the activities of the Action Plan, related to the setting-up of an Internet site on seismic risk prevention and reduction for students.

7.5 Plans and Future Activities

The Seismic Scenario and Action Plan for Seismic Risk Reduction will be officially delivered to the city on the first week of October. At the same time, the activities still pending will begin. This means putting into practice the Action Plan, thus going on with the seismic risk reduction project.

On the other hand, the development of RADIUS and the knowledge acquired on methodology makes possible the setting-up of similar projects for others northern cities of Chile. To date, an FNDR project has been approved with Miss Marisol Bembow as a scientist in charge. It will study seismic risk in Tocopilla, Mejillones and Taltal. Besides, RADIUS will be put forward in two months for the cities of Arica and Iquique, both located 700 km and 400 km to the north of Antofagasta, respectively. Both cities are located directly on the zone where the next big earthquake is expected at any moment, that is, northern Chile and southern Peru. Copiapo, located 650km to the south of Antofagasta, is also considered in future studies.

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