EARTHQUAKE IN CHILE, MARCH 3, 1985

This insert to the May Newsletter consists of contributions from members of the EERI team who visited Chile during the few weeks following the earthquake. We have edited the material more than somewhat. Contributors represented here are Bruce Bolt, Norm Abrahamsen, Mehmet Celebi, Lonie Wyllie, Jim Gates, Gonzalo Castro, Paul Smith, David McCormack, Rene Luft, Luis Escalante, and Rick Olson.

Several other sponsors, in addition to EERI, were responsible for the success of the trip, namely, Federal Highways Administration, National Research Council, National Science Foundation, Seismic Qualifications Utilities Group (SQUG), and U.C. Berkeley. We are grateful for their efforts. In addition, the contributors acknowledge the assistance given in Chile by members of the earthquake engineering community there - the universities' staffs, particularly Professors Saragoni and Kaufel of the University of Chile, Santiago, the structural engineers, the civic leaders, and guides.

The Preliminary Determination of Epicenters weekly summary provides the following information:

Date: March 3, 1985; origin time: 22h47m06.9s; epicenter: 33.155S, 71.980W; depth 33 km (an estimate); magnitude Mw 7.8; data from 69 stations. The earthquake occurred near the coast of central Chile. At least 147 people killed, nearly 2,000 injured and extensive damage in central Chile, including the cities of San Antonio, Valparaiso, Vina del Mar, Santiago, and Rancagua. Maximum intensity VIII in the Valparaiso area. Felt in Chile along a 2,000 kilometer strip from Copiapo to Valdivia. Felt (VI) at Mendoza and (V) at San Juan, Argentina. Also felt by people in high-rise buildings in Buenos Aires, Argentina and Sao Paulo, Brazil.

Tsunami generated with wave heights at selected tide stations as follows: 1.1 m at Valparaiso; 48 cm at Hilo, Hawaii; 15 cm at Sard Point, Alaska; 12 cm at Adak, Alaska; 11 cm at Rikitea, Gambier Islands; 10 cm at Papeete, Tahiti; 10 cm at Kushiro, Nemuro and Miyako, Japan; 5 cm at Seward, Alaska; and 3 cm at Honolulu and Pearl Harbor, Hawaii.

A foreshock was identified at 22h46m56.4s at 33.118S, 71.822W, magnitude MB of 5.2.
SEISMOLOGY

1. The Earthquake Sequence

The principal shock occurred at 7:47 p.m. local time on Sunday, March 3. The Department of Geology and Geophysics at the University of Chile gives a preliminary epicenter just off the coast about 15 km northwest of Algarrobo at 33.29°S, 71.79°W with a focal depth of 6 km. The surface wave magnitude has been increased based on worldwide recordings, from the initial \( M_s = 7.4 \) to \( M_s = 7.8 \) by the National Earthquake Information Service (NEIS). The Berkeley (BKS) magnitude is \( M_b = 7.4 \). These values may be compared with the magnitudes for the July 9, 1971 earthquake located approximately 100 km north of the 1985 epicenter: \( M_s = 7.9 \) (NEIS) and \( M_b = 7.5 \) (BKS).

There was a foreshock sequence that began about one month prior to the mainshock, consisting of a swarm of about 300 earthquakes with magnitudes up to 4.5. The swarm began to decrease about 10 days before the mainshock and the last event in the swarm occurred 20 hours before the mainshock. No prediction of the mainshock was made based on the occurrence of the foreshocks.

The principal shock was followed by a large aftershock sequence. During the first 24 hours, the recordings from the sensitive stations were unusable due to high seismicity. After 24 hours, we were able to distinguish about 22 earthquakes per hour with magnitude above 3.5. The aftershock region is shown in Figure 1. The area of the aftershocks is about 140 km long (north-south) by 70 wide (east-west) with focal depths ranging from 5 to 40 km.

2. The Strong Ground Motion Recordings

The strong motion program in Chile is operated by two groups, the Department of Geology and Geophysics at the University of Chile (DG) and the Department of Civil Engineering at the University of Chile (DIC). There are also a few additional accelerograms operated by other groups. In Figure 1, we have shown the locations of the instruments operated by the two University of Chile groups. The locations of the other stations are not available at this time.

The accompanying table includes descriptions and locations of instruments providing records available at this time, and sample peak accelerations are summarized. Of particular interest is the record obtained from the accelerograph (SMA-1) located in the basement of a 1-story building in Llolleo exhibiting 0.75 g peak acceleration in the nominal E-W direction, 0.41 g in the nominal N-S direction, and 0.82 g in the vertical direction. In the coastal town of Vina del Mar, the peak accelerations on rock were 0.22 g (E-W) and 0.36 g (N-S) whereas in a reclaimed area of Valparaiso, the peak accelerations were 0.27 g (E-W) and 0.19 g (N-S) direction. Chilean scientists wish to digitize the records themselves; however, assistance has been offered if they need any.

We expect 20-30 high quality recordings of the strong ground motion to be obtained from this earthquake. The ground motions are more "energetic" than those from previous recordings of California earthquakes. The Chilean strong motions are recorded on different soil and rock foundations and will allow correlations with the amount of damage to buildings and other structures.
GENERAL EFFECTS OF THE EARTHQUAKE

1. Numerous structures were located within the area of strong ground shaking. Many modern buildings of reinforced concrete performed well while some had significant structural damage. Adobe buildings were generally destroyed, with many adobe buildings damaged even in Santiago, where damage otherwise was relatively light. Small wooden homes which are numerous, were typically undamaged. One small village had every adobe home destroyed and every wooden home undamaged.

2. In San Antonio, the four-story, 240-bed reinforced concrete Claudio Vicuna Hospital, dedicated in 1982, sustained considerable structural damage. The rectangular building had a central expansion joint creating two structures and both had no concrete nor masonry infilled walls in the second story, creating a more flexible story. The northern half had spalling and cracking in each column exposing much of the reinforcing. There was also spalling at wall-frame junctions in the upper two stories.

Four-story reinforced concrete shear wall residential buildings in San Antonio were undamaged except one unit which had experienced ground movement and failure of its slab on grade. Many buildings had experienced foundation failure or major settlement due to the ground failures in San Antonio. Older adobe buildings appeared universally damaged severely.

3. Melipilla also had several silo complexes, and an interesting story of silo performance was obtained at Agricola Ariztia Petra. Silos built between 1956 and 1981 and increasing in size from 6.1 meter diameter by 16 meters to 8.15 meter diameter by 30 meters high were on the site. The older silos had virtually no vertical steel and they failed by sliding and working at horizontal construction joints, with one complete failure. The newer silos progressively had more longitudinal steel and the damage reduced to cracking and spalling at joints to hairline cracks in the newest, largest silos.

4. Valparaiso is the major port city of Chile and contains numerous multi-story buildings. Time did not permit a detailed survey of the buildings and few reports of damage were heard. The main port had considerable spreading of the ground and a portion of the port structure collapsed at an expansion joint where the spreading was greater than the 400 mm (16 in.) slab. An older L-shaped building near the port had considerable cracking at the re-entrant corner. The C. van Burem Hospital had no damage in the eight-story 1982 concrete wing, considerable cracking of masonry infill in the six-story 1968 wing and serious damage to the supports of the connecting bridge.

5. Vina del Mar, a resort community just north of Valparaiso, contains numerous high-rise reinforced concrete structures and many items of interest to structural engineers. Along the beach, the fifteen-story Acalpucum condominium, built in 1964, had working of some horizontal construction joints and chord failures at several locations in the numerous concrete shear walls. The adjacent fifteen-story Hanga Roa condominiums, had odd and even floor plans so doors in the numerous concrete shear walls were offset for greater strength. One wall had a vertical shear failure through these story-deep horizontal beams for

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**SUMMARY OF PRELIMINARY DATA**

(MARCH 3, 1985 CHILE EARTHQUAKE)

(COURTESY: CIVIL ENGINEERING DEPARTMENT, UNIVERSITY OF CHILE)

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of Instr.</th>
<th>Coordinates</th>
<th>Site Geology</th>
<th>Structure Type/Size</th>
<th>Instrument Location</th>
<th>Model</th>
<th>Operated/Maintained by</th>
<th>Notes</th>
<th>Acceleration</th>
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<tbody>
<tr>
<td>San Felipe</td>
<td>1</td>
<td>32.75 S</td>
<td>70.73 W</td>
<td>Alluvium</td>
<td>1 story building</td>
<td>Ground Level SMA-1</td>
<td>Civil Eng. Dest., (Univ. of Chile)</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.39g</td>
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<td>Llollilo</td>
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<td>32.63 S</td>
<td>71.63 W</td>
<td>Soft alluvium</td>
<td>1 story building</td>
<td>Ground Level SMA-1</td>
<td>Civil Eng. Dest., (Univ. of Chile)</td>
<td></td>
<td>0.35g</td>
</tr>
<tr>
<td></td>
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<td>Sandstone &amp; Volcanic Rock</td>
<td>10 story building</td>
<td>Basement</td>
<td>SMA-1</td>
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<td>*</td>
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<tr>
<td>Valparaiso</td>
<td>2</td>
<td>33.03 S</td>
<td>71.62 W</td>
<td>a) Volcanic rock</td>
<td>a) Univ. of Santa Maria Campus</td>
<td>Ground Level SMA-1</td>
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<td>*</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Precambrian/ Paleozoic)</td>
<td>1 story building</td>
<td></td>
<td></td>
<td>b) Ave du Argentina Basement</td>
<td>SMA-1</td>
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<td></td>
<td></td>
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<td></td>
<td>0.41 g</td>
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<tr>
<td>Melipilla</td>
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<td>33.68 S</td>
<td>71.22 W</td>
<td>Sandstone &amp; Volcanic Rock (Paleozoic)</td>
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<td>34.03 S</td>
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<td>*</td>
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<td>RFT-250</td>
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Two undamaged four-story apartment buildings at the foot of one of the ridges of the Canal Beagle government housing development of Vina del Mar. Other structures, on the ridges, were severely damaged. These buildings, constructed 10-12 years ago, were all of similar plan. However, incipient landslides, terrain amplification and possible design and construction errors caused severe damage to some of these structures.

the full depth of the building with the resulting crack about one foot wide. The nearby Edificio Tahiti had cracks in the cantilever balconies, apparently due to torsion as the balconies responded to adjacent wall movements. Two nearby twenty-story triangular-shaped buildings had ground offsets of nearly one foot around the buildings, either due to ground settlement or rocking of the building. The twenty-three-story Plaza del Mar reportedly had furniture thrown around above the thirteenth story and some spalling of coupling beams between shear walls. Three new seventeen-story condominiums, Torres del Pacifico, appeared undamaged. All of these buildings on the Vina del Mar Beach had substantial shear wall systems, considerably more than would be provided by normal U.S. design. The older buildings which were damaged not only lacked the most modern detailing but were also damaged in the 1955 and 1971 earthquakes and only superficially patched.

6. Other complexes were damaged in Vina del Mar. Canal Beagle, a housing complex of about forty buildings for army and navy personnel was financed by BID (an Inter-American Bank) and partially by AID (Agency for International Development). Canal Beagle is located in the northeast of the city on two steep ridges, and sustained heavy damage. These four- and five-story reinforced concrete apartment buildings had substantial shear wall layouts which typically hinged at the base and slid at some construction joints. About thirty of the buildings had to be evacuated. Adjacent two-story homes of unreinforced masonry were undamaged, suggesting a resonance of the Canal Beagle units with the steep geometry of the ridges. Siete Hermanas, a multi-building complex on another ridge, had undamaged reinforced concrete shear wall buildings but heavily damaged connecting bridges, several of which collapsed. The bridges had expansion joints with restrainer details that proved inadequate.

7. In the northern portion of Vina del Mar, called Renaca, the eight-story El Faro condominiums had a structural failure in the lowest story columns or walls and was leaning considerably. The building was dynamized to the ground before the Team could inspect it. On the nearby sand dunes, various homes had slid down the hill for distances of up to several yards, and one large apartment had experienced major differential settlement, apparently when sand backfill compacted.
Typical scene in Reneca, a suburb of Vina del Mar. These vacation apartments are constructed on 8-10 m thick sand on the sand dune hill. There was evidence of landsliding in the area. One of these structures, that did not extend all the way down to street level, broke literally into two as a result of differential settlement.


The structural lessons from the Chilean earthquake of 1985 repeat many lessons previously learned and add a few. Rigid shear wall buildings with well-conceived layouts and details perform well in strong ground shaking and limit damage to contents. Unreinforced masonry and adobe structures are subject to collapse in earthquakes. Buildings which sustain structural damage and are only superficially patched are weakened and more vulnerable to damage in future earthquakes. Construction joints in shear walls, silos and other elements need to be cleaned, roughened and have sufficient normal reinforcement to perform acceptably in strong ground motion.

Silos in Melipilla. These silos appeared to have sufficient hoop but insufficient vertical reinforcement. In addition, a stiff, gable-roofed reinforced concrete building was constructed behind them.
Bridge Damage

1. Meipo R. near Llo-llo (about 3 km south of San Antonio)

This bridge consists of 28 simple prestressed spans of 30 m each. The bridge is about 5 to 6 m high and is 2 lanes wide. The bridge was designed by the Ministry in 1956 and built about 1958. The piers and abutments are founded on 30 cm square concrete piles about 14 m long. As far as could be determined, no borings were made for the 1956 design, but a single boring dated 1927 for a previous bridge was used. The piers were full width and consisted of five, one meter thick columns, infilled with wall to obtain a monolithic pier. The footings for the river piers were very close to the water surface and were 1.8 m thick. The pile pattern at the piers was 2 x 9 piles. The piers and abutments have a seat width of about 0.5 m for the end of each girder. The girders were keyed transversely with external keys and were tied together with cast-in-place diaphragms but there was no longitudinal restraint between the spans.

A repetition of Niligata? Liquefaction caused a pier of this bridge, three km south of San Antonio, to disappear and one deck span fell into the Meipo River. Another deck span and the pier supporting it also severely damaged.

Failure at the site consisted of loss of the first pier from the north abutment, settlement of the next pier to the south and dropping of two spans a little further to the south. Other damage noted was evidence of baring of the remaining adjacent spans, cracked shear keys at a few bents near the south end and moderate cracking at the south abutment. The approach fills at both abutments were extensively damaged, with severe settlement and spreading extending for 100-200 m from each abutment.

Based on interviews at the site with Mr. Jaime Canales, engineer for the Ministry, the primary cause for the collapse was scour at the site which had exposed the footing and a portion of the piles and thus lowered the lateral capacity of the shallow river piers. This scour was probably unprecedented at the site, and could have been caused by the record rainfall the previous year.

2. An adjacent, unused and older bridge a few yards upstream also suffered a similar collapse, although the Army told us that they had used the old bridge for demolition practice and so it may have been weakened to an unknown extent. Only a few spans of this older cast-in-place bridge remained, even before the earthquake.

3. The Army built a small pontoon bridge for pedestrians at the site and were slowly proceeding with the construction of a Bailey bridge for use as a detour. They were also doing extensive earthwork, building long approaches on the flood plain, bypassing the remaining bridge completely.

Lateral restraint at the abutments is provided by external rods attaching the superstructure to the corbels. Damage at this site consisted entirely of excessive (at least 3 m) settlement of the westery pier. Interviews of persons in the area revealed that the settlement had occurred on Monday, March 11, in the afternoon (almost 8 days after the March 3 event). Traffic was still using the bridge but apparently some settlement had taken place at the bridge as a result of the earthquake and a survey crew measuring settlements had just taken their lunch break when the bridge very quickly settled, pulling apart the joints supporting the drop-in-span. A taxi driver told Franz that a heavy cement truck had just passed over the bridge before it went down. We could not determine if there were any witnesses to the collapse.

5. Conclusions on Bridge Damage

The major damage observed was subsidence and spreading of fills. The fill materials appeared to be poorly graded and generally were of very coarse rock.

Lack of adequate inspection and maintenance should have been responsible for two of the major failures observed.

All of the bridges observed had many well-thought-out seismic resistant details, even those over 25 years old. These details include the use of wide seats at expansion joints and abutments, the use of large reinforced shear keys for lateral restraint and the use of long steel rod X-ties at abutments to tie the superstructure to the abutment in a transverse direction.
The insulation on numerous pipes at the Las Ventanas power plant was damaged as a result of impacts with structural members. In the photograph above, the structural member was bent slightly but the pipe was not damaged.

The lateral motion restraints for the rod-hung boilers at the Renca power plant were damaged, indicating that the boiler experienced large motions. Bolts sheared, welds failed, and members were deformed or bent, as shown in the photographs. Significantly, the boilers were not damaged and were operational after the earthquake.

INDUSTRIAL FACILITIES

1. Las Ventanas Copper Refinery and Foundry. The copper refinery and foundry is located immediately adjacent to the power plant. It was constructed in the early 1960s and has a capacity of approximately 900 metric tons per day. The facility is operated by ENAMI and includes a large number of buildings and one large brick oven.

Both the refinery and the foundry halted operations after the earthquake. Off-site power was lost, but emergency generators operated immediately. The refinery could not operate because electrolytic bars fell and caused a short circuit. Repairs were completed in two days and the refinery was operating the third day after the earthquake.

The foundry oven bricks failed. Many of these bricks fell into the molten copper and repairs to the oven will involve dynamite; it is expected that the repairs will take approximately 45 days. Identical damage occurred in the 1965 and 1971 earthquakes.

There was no major damage reported to any of the other structures including the main concrete stack which is over 155 meters tall. The stack was inspected both inside and out. Minor problems included conveyor belts which jumped their tracks, one transformer which leaked oil, and a pipe at an off-site well which broke.

2. Summary

Several large industrial facilities and power plants were inspected. Typically, the structures were designed to be earthquake resistant and most equipment was adequately anchored. Minor damage was experienced at all facilities. The more significant equipment and systems damage was related to building damage or to poor detailing. The power plants performed well and were back on line within a few hours after the main shock.

LIFELINES

1. Of the lifelines, water systems were the most severely affected. Valparaíso and Vina del Mar lost their water supply due to ruptures of the aqueduct from Las Vegas on the Aconcagua River and the power loss at the Concon pumping station on the same river. The pumping station was back in operation within one day, but supplied only lower lying areas on Vina del Mar and Valparaíso. Higher level areas had to be supplied by emergency tanks and tank trucks.

2. The City of San Antonio lost its water supply when the pumping station at Estero San Juan, a tributary to the Maipo River suffered severe settlement and damage to buildings, equipment and pipelines. Much of the water in two tanks located on high ground was lost due to the rupture of pipelines supplying them. San Antonio residents were being furnished water from Fire Department and rental tank trucks.

3. Asbestos cement water distribution pipelines in Valparaíso, Vina del Mar, San Antonio and other towns failed due to open joints caused by ground displacement which was moderate to severe in many areas.

4. Sewer systems did not function in areas where water supply was lost, but were increasingly functional with the restoration of water distribution systems. Damage to sewage systems could not be determined until service was restored; some damage due to ground movement was observed.

5. Telephone service in some areas was temporarily lost. As usual after an earthquake, telephone systems were heavily used and overloaded.

6. Butane and liquefied natural gas are supplied to individual homes or to community tanks. Supplies were interrupted by shutoffs to damaged buildings for safety reasons, and were rapidly restored as inspection showed no damage or repairs were made.
GEOTECHNICAL EFFECTS

Tailings Dams

Two copper tailings dams failed by liquefaction during the earthquake. Dams were built by the upstream method. The failed dams were Veta de Agua, located near the town of El Cobre, and Cerro Negro, near the town of the same name.

Embarkment Dams

A small irrigation dam developed substantial slumping and downstream movement; however, the reservoir was not released.

Roads

Many observations were made of slumping of road embankments, particularly at bridge abutments.

Harbor Installations

Sea walls at the San Antonio and Valparaíso harbors developed permanent movements consisting mainly of wall rotations. The San Antonio harbor sea wall was damaged extensively with about half of its length having overturned into the sea. Tilting of the sea walls in the Valparaíso harbor resulted in lateral movement of a few inches at the top of the wall which was sufficient to cause the cranes to become nonoperational because of differential rail movements. One dock crane in Valparaíso fell due to a girder failure, and six dock cranes in San Antonio over- turned due to ground failure of a mole. The moles and piers suffered severe settlements caused by soil liquefaction.

Slope Instability

Steep slopes in San Antonio developed movements that caused failure of structures resting on the slopes.

Three aftershock epicenters

POLITICAL AND SOCIOECONOMIC OBSERVATIONS

For earthquake consequences of which we do not usually become aware, consider the following notes:

1. This earthquake is deceptive. Low human casualties (176 dead, approximately 2,500 injured) obscure widespread destruction, especially outside Santiago (370,000 people homeless was an official figure on 12 March).

2. This is a "working class" earthquake. The very poor in Chile build in wood and walked away from this earthquake more or less unscathed. The working class and lower middle class, however, build in adobe and inadequately reinforced concrete, and they are bearing the brunt of the losses.

3. Slow, control-minded response by the right-wing Chilean military government is exacerbating already tense relations between government and lower classes. U.S. government is caught in policy dilemma: massive help to Pinochet regime from U.S. would further cement our image of being supportive of very repressive regimes, but doing little or nothing would have tragic results.

4. Results from 700 interviews conducted one week after the earthquake in and around Vélpillos (half-way between Santiago and the coast) show tremendous concern about bronchial infections, especially in children. With the usual severe Chilean winter now upon them, "death from disease" rates among children and elderly likely to rise dramatically.

5. Because of low initial death toll and "invisible" winter time subsequent human losses, the media will ignore this disaster.