CRUSTAL MOVEMENTS IN CHILE: THE 1985 EARTHQUAKE

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Resumen: Hundimientos y levantamientos co- y post-sísmicos de la costa de Chile han sido evidentes a través del tiempo. Se presenta el caso del terremoto de 1985 ($M_W = 8.0$) en Chile central para el cual se cuenta con datos de nivelación, gravedad y registros inéditos de dos limnígrafos en el lago Rapel, situado sobre la zona de ruptura del terremoto de 1985. Estos muestran una inclinación post-sísmica de gran amplitud (6 μradianes) con duración cercana a un año. Esta señal se interpreta como creep post-sísmico en la continuación de la ruptura cosísmica sobrepuesta a una relajación visco-elástica regional.

Key Words: Crustal movements, fault creep, postseismic relaxation.

Introduction

Historical records of large earthquakes for the past 400 yr along the central Chile portion of the convergence zone between Nazca and SouthAmerican plates indicate an almost periodic earthquake sequence with a recurrence interval of 82±6 yr (*Nishenko*, 1985). The March 3, 1985 $M_S = 7.8$ central Chile earthquake is the last event in this sequence. Aftershock studies, body-wave modeling, surface wave and strong ground motion analysis, gravimetric observations and geodetic estimates revealed a rupture region approximately 160 km long in a north-south orientation (*Christensen* and *Ruff*, *1986*; *Korrat* and *Madariaga*, 1986; *Comte et al.*, 1986; *Houston* and *Kanamori*, 1987; *Barrientos*, 1988; *Choy* and *Dewey*, 1988). A first order leveling line, repeatedly surveyed in 1981 and four months after the earthquake, evidenced 0.5 m of uplift near the coastal city of San Antonio and a 10-cm subsidence about 60 km inland (*IGM*, 1985). Between these two points, to the south, lies Rapel lake, a body of water artificially dammed to generate hydroelectric power (Fig. 1).

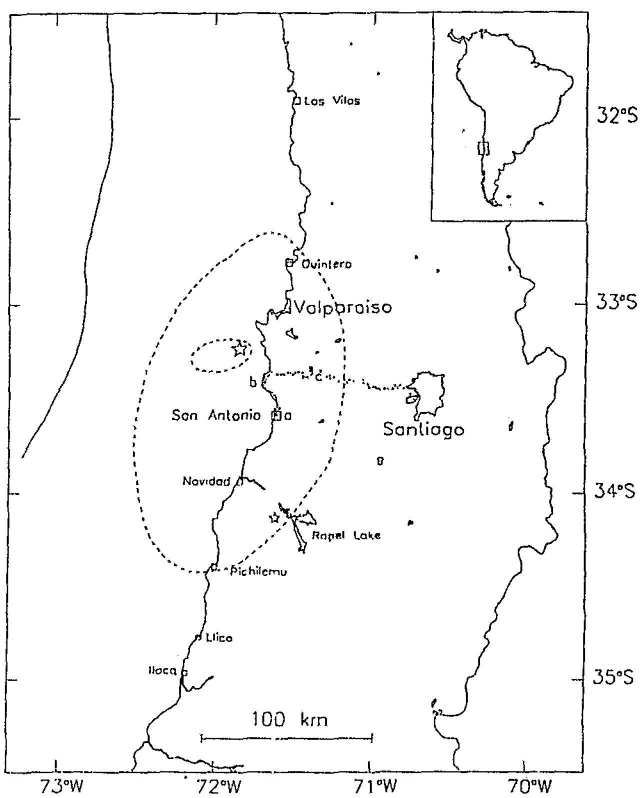

Fig. 1. Location of the foreshock and aftershock areas (small and large dashed ellipse) in reference to Rapel lake. Gages are located on its western and southeastern ends. Leveling line (dots) runs from San Antonio to Santiago.

Two limnigraphs, separated by 20 km, have been recording continuously for more than 10 years the water level of Rapel lake providing a measure of tilt of the lake basin. Gravity data along the leveling line in addition to sea level measurements at a tide gage in Valparaíso complement the information.

Data

The water level of the Rapel lake is recorded by two Stevens A35 limnigraphs. The mechanical principle of operation of these instruments is based on a floating device which transfer water level variations to a recording stylus through a float pulley. A clock connected by suitable gearing, provides the appropriate speed to the drum. From the analog records the daily average is computed by averaging twenty four hourly samples. Figure 2 shows the water level variation at the dam as a function of time. Extreme variations of the lake level reach 6 m, with spectral peaks at periods of one yr, six months and one week (related to seasonal river flow) generated by rain and snow melt, and periodic energy demands. The regional tilt of the lake basin due to deformation associated with the 1985 event can be extracted by directly differencing the records of the two limnigraphs (Fig. 3).

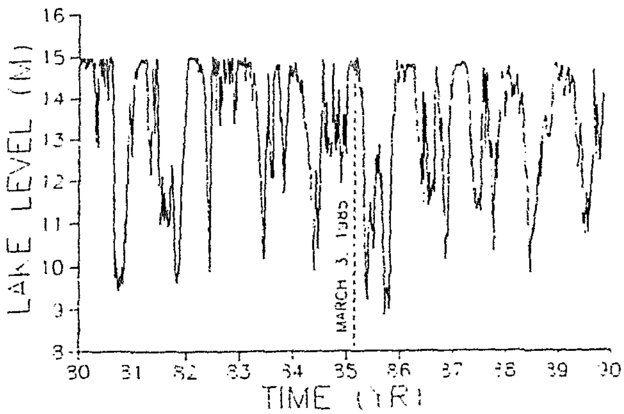

Fig. 2. Water level fluctuations at the western end of Rapel lake. Values beyond the arbitrary height of 15 are not allowed to prevent dam overflow. A one-year cycle dominates the signal.

The time dependent tilt shows several characteristics: a) a steady oscilation around the zero baseline with typical excursions of about 3 cm, which also correspond to typical standard deviations of the daily averages, b) at the time of the earthquake no change was observed, therefore the lake is located in a null coseismic tilt region, c) a progressively larger tilt is developed gradually as a function of time right after the earthquake. It takes between 8 and 12 months to complete, reaching an amplitude of about 12 cm, d) a long term slowly decaying signal which oscilates with a one-year period.

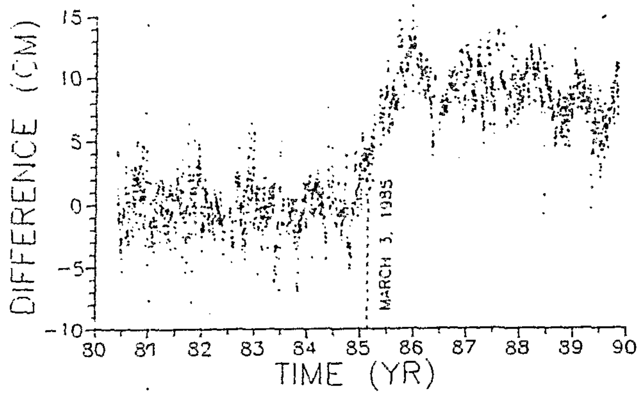

Fig. 3. Daily differences of water level at the two limnigraphs. The three segments of the signal (pre-earthquake, one-year post-earthquake and long post-seismic decay) are discussed in the text.

Analysis

Due to comparable high rates of deformation, the first part of the anomalous signal, which departs significantly from zero and extends for one year after the occurrence of the main event, is modeled as fault creep along the down-dip extension of the coseismic rupture. The second part, which corresponds to the slowly decaying signal, will be modeled independently because it shows a different time scale behavior. Fault creep has been used by *Kasahara* (1975) to explain postseismic deformation associated with the 1973 Nemuro-Oki earthquake along leveling lines and tide gages records. *Savage* and *Plafker* (1991) and *Brown et al.* (1977) offer the same mechanism to model postseismic elevation changes in relation to the 1964 Alaska earthquake.

The vertical displacement $u_z(x, L)$ at a point x on the free surface of a half-space due to an inclined dislocation of width L reaching the surface is (*Barrientos et al.*, 1992):

$$u_z(x, L) = \frac{\Delta s}{\pi} sin\phi[(\pi/2 - \phi) - \frac{Lxsin\phi}{D^2} + tan^{-1}(\frac{L - xcos\phi}{xsin\phi})]$$

where Δs is the amount of fault slip, $D^2 = L^2 - 2Lxcos\phi + x^2$ and ϕ is the dip angle. A more general expression for a buried fault of width $W = L_1 - L_0$ would be $u_z(x, W) = u_z(x, L_1) - u_z(x, L_0)$. The time dependence is incorporated through $L_1(t) = vt$. This is a down-dip expanding rupture with velocity of propagation v of the front L_1. The inputs to the fault model are dip angle, velocity and starting point of the propagating pulse. Dip angle and starting point of creep along the fault are determined by the dip angle and down-dip extension of the coseismic fault. Fig. 4 shows the expected low-pass filtered (30 days) observed vertical movement and that expected due to a down-dip propagating rupture with a velocity of 25 km/yr. The model reproduces amplitude of tilt as well as its time dependence.

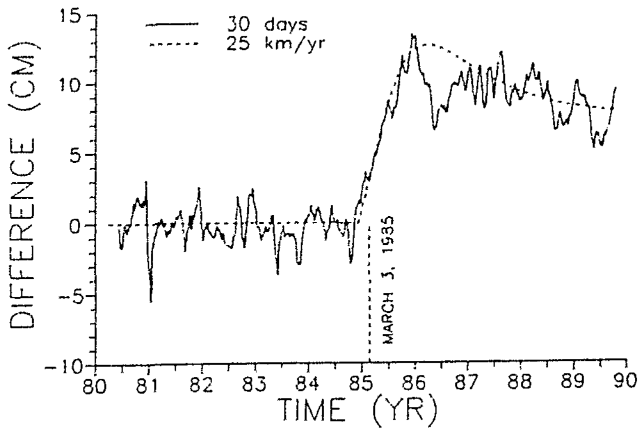

Fig. 4. Expected tilt change produced by the propagating rupture (dashed line) superimposed on the 30-day filtered observations. The model implies a rupture propagation of 25 km/yr.

Coseismic vertical changes established by repeated surveys of the leveling line that extends inland from the coastal city of San Antonio to Casablanca (point labeled c on Fig 1.) are shown in Fig. 5. On the same plot, the difference of three gravity surveys are superimposed; these gravity observations were surveyed in 1983, 1985 (three months after the earthquake) and in 1990. The coseismic stage (85-83), shown by long dashed lines, has been scaled such that the amplitudes are coincident with the values observed along the leveling line. The scaling factor turns out to be very close to the inverse of the Free Air Correction.

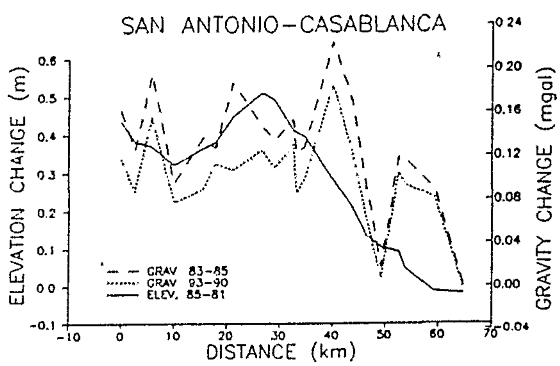

Fig. 5. Observed elevation change based on the leveling line (solid trace) and gravity observations. The gravity co-seismic period (long dashed trace, 85-83) has been scaled to agree with the leveling line. A longer period, 91-83 (small dashed trace) indicates that the region has subsided at a later stage.

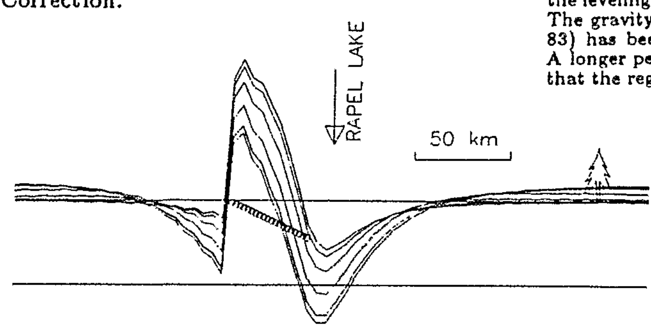

Fig. 6. Visco-elastic response of a layer over a halfspace. The coseismically uplifted region gradually subsides with time.

Even though departures of the gravity derived height changes with respect to those directly observed are important, there is a systematic decrement of the gravity derived height observed in the 90-83 period. This means that the coseismically uplifted region is subsiding in a post-earthquake stage.

To explain the observed differences between the two postseismic gravity surveys in combination with the later part of the observed tilt signal of the lake, a viscoelastic relaxation model is proposed. The procedure used to model the viscoelastic response is a semi-analytical formalism, which can be applied to any two-dimensional dipping fault, based on propagator matrices which allows for variable slip faults embedded in vertically heterogeneous media (*Barrientos*, 1993). Qualitative preliminary results agree with the observed tilt decrement as a function of time (Fig. 6).

Conclusions

Continuous measurements of tilt for ten years at Rapel Lake, located above the rupture region of the 1985 Central Chile earthquake, indicate a lack of coseismic movement. A progressively larger tilt is developed gradually as a function of time immediately after the earthquake. This cumulative tilt takes between 8 and 12 months to complete, reaching an amplitude of approximately 12 cm which is equivalent to 6 μradians considering a baseline of 20 km. After reaching the maximum value, a long term slowly decaying signal is observed. The two parts of the signal are interpreted, due to their different time scales, as the effect of distinct origin. The accelerated part is explained as fault creep on the down-dip extension of the ruptured region and the slowly decaying signal is modeled as the result of viscoelastic adjustments. For a 20° dipping fault a creep velocity of 25 km/yr best fit the observations.

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