Seismic risk associated with the Magallanes-Fagnano continental transform fault, Tierra del Fuego, Southern Argentina

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Introduction

The Magallanes-Fagnano (MF) and the North Scotia Ridge fault systems constitute the remnant of a transform fault extending from the Sandwich Islands mid-ocean ridge to the Chilean subduction trench, along the boundary between the South American and the Scotia lithospheric plates (British Antarctic Survey, 1985; Pelayo and Wiens, 1989). The MF fault represents the continental segment of this transform fault in the island of Tierra del Fuego, in southernmost South America, where it delimits two structural domains: a thin-skinned domain north of the fault, and a thick-skinned domain south of the fault (Winslow, 1982). The MF fault trace measures about 200 km in length; it strikes EW in eastern Tierra del Fuego, and curves smoothly to the NW in western parts of the island, in Chilean territory. This fault system comprises distinct tectonic lineaments arranged in an "en échelon" geometry. The master segments are near-vertical faults (Lodolo *et al.*, 2003). A left-lateral dominant direction of movement along this fault at a rate of 6.6 mm/yr was documented by Smalley *et al.* (2003).

From the IRIS database (http:// www.iris.washington.edu/ SeismiQuery/ events.htm) were taken 3993 seismic events recorded between 1/I/1970 and 25/VIII/2007, within the area between 48ºS and 70ºS, and 20ºW and 76ºW, encompassing the Scotia Arc and southernmost Patagonia; magnitudes ranged from 3.1 to 7.8; aftershocks were filtered out. Several supplementary seismic events from other sourced were also included. On the basis of fault geometry and mechanics, and clustering of epicenters, seven seismogenic zones were defined: North Scotia Ridge zone, South Scotia Ridge zone, Sandwich Islands subduction zone, Schackleton Fault Zone, Chilean subduction zone, and the MF zone. Only the latter two seismogenic zones lie sufficiently close to urban centers in Tierra del Fuego to represent a hazard. We wish to state that the possibility of tsunami generation from seismic activity in the Scotia Arc fault systems was not evaluated in this work.

On December 1949 two earthquakes with similar Richter magnitudes of 7.8 shook the island of Tierra del Fuego with a 9-hour interval. Secondary effects were large wave setup in Lake Fagnano and downdrop of a southeastern sector of Lake Fagnano and the adjacent Turbio River deltaic plain, giving rise to a coastal lagoon. On the basis of personal accounts of damage distribution, it has been assumed that the first event had epicenter to the east of the second event (Costa *et al.*, 2006). Recent relocation of the 1949 epicenters, as well as that for the June 1970 earthquake (M=7.0), shows all three clearly aligned with the trace of the MF fault (P. Alvarado, pers. comm., 2007).

This paper presents the first quantified assessment of seismic hazard for the province of Tierra del Fuego. This assessment is largely based on local data and takes into account the amplifying effect of the Quaternary deposits. Two previous studies are of a regional scope. In 1985, the Argentine Institute for Seismic Prevention (INPRES) divided Argentina into 5 seismic zones. Data for Tierra del Fuego relied on information from accelerographs located outside the island. Major flaws in the zonation were that the MF fault lay at the boundary between two seismic zones and that highest hazard was located well away from the MF fault. A more recent assessment of seismic hazard in Tierra del Fuego is due to the Global Seismic Hazard Assessment Program (GSHAP), which assigns the island Peak Ground Accelerations (PGA) between 0.8 and 1.6 m/sec^2, with an exceedance probability of 10% in 50 years.

In addition to the regional-scale seismic hazard evaluation, the seismic risk for Tolhuin associated with the MF fault is considered. Tolhuin, with a population of about 3,000, sits on the eastern end of Lake Fagnano, less than one kilometer from the trace of the MF fault. Evaluation of the seismic risk for Tolhuin followed the procedures outlined by the United Nations in Risk Assessment tools for Diagnosis of Urban areas against Seismic disasters (RADIUS). The RADIUS methodology comprises 5 major steps: 1 – Definition of the seismic scenario, setting likely epicenter locations and earthquake magnitudes; 2 – Designing, or selecting from preexisting formulas, the seismic attenuation law to be applied; 3 – Calculating the amplifying effect of substrate layers on the basis of their geotechnical properties; 4 – Converting Peak Ground Acceleration values to Modified Mercalli Intensity scale values; and 5 –Applying vulnerability functions according to construction type.

Results

The seismic scenario assumed in the evaluation of the provincial seismic hazard was as follows: a M=8.5 Maximum Credible Earthquake, with epicenter where the MF fault intersects the Chile-Argentina border; such location corresponds well with recorded earthquakes. Tierra del Fuego is largely covered by thick glacial drift and by thinner fluvio-glacial deposits and peat bogs. Preliminary geotechnical studies suggest that the drift behaves as a stiff soil and may represent an amplification factor in the order of 1.2, mainly due to thicknesses in excess of 10 meters, whereas the fluvio-glacial and the peat bog deposits may represent an amplification factor in the order of 2.0 (estimates were obtaine with EERA software; Bardet *et al.*, 19). Due to insufficient local data, the attenuation law of Campbell (1997) was used. PGA values obtained from Campbell`s (1997) attenuation law were converted to MMI values through the equation MMI = 3,333*(log10(PGA*980) – 0,014) (Trifunac y Brady, 1975). Overall, MMI decreases radially from the epicenter but noticeable anomalies can be observed in areas of soft soil (Fig. 1).

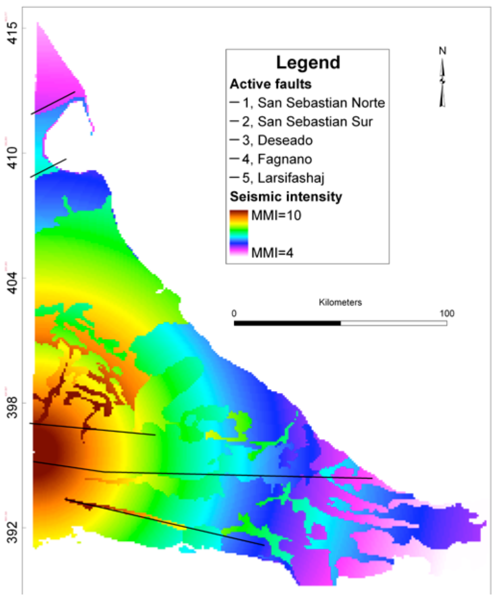

Figure 1. Seismic hazard distribution for Tierra del Fuego Province.

Constructions in Tolhuin were classified into two categories, depending on whether they are seismic-resistant or not. Tolhuin is a recently developed urban center and buildings are mostly younger than 10 years old. Public buildings, and household dwellings built by the provincial and national government agencies, generally fall in the seismic resistant category; that is, they comply with the CIRSOC-103 regulations issued by the INPRES. The majority of the households do not, however, having been built on the rush by small local constructors. Tolhuin is built on terraced ground generally sloping toward Lake Fagnano, the SW. The town center, and the majority of the public buildings are in high ground, approximately 100 m above lake level. The thicker Quaternary section (>150 m in thickness) underlies the town center. In this area, however, stiff glacial drift and gravelly glacifluvial deposits dominate the upper levels, resulting in an amplification factor of about 1.2. Lower parts of the town rest on thinner but more clay-rich substrate, and resulted in an amplification factor of about 2. Two seismic scenarios were evaluated for Tolhuin, both for M=8.5 earthquakes located on the MF fault, one with epicenter on the Chilean border, approximately 80 km away, the other distant only 20 km from Tolhuin`s urban center. The results are shown in Figure 3.

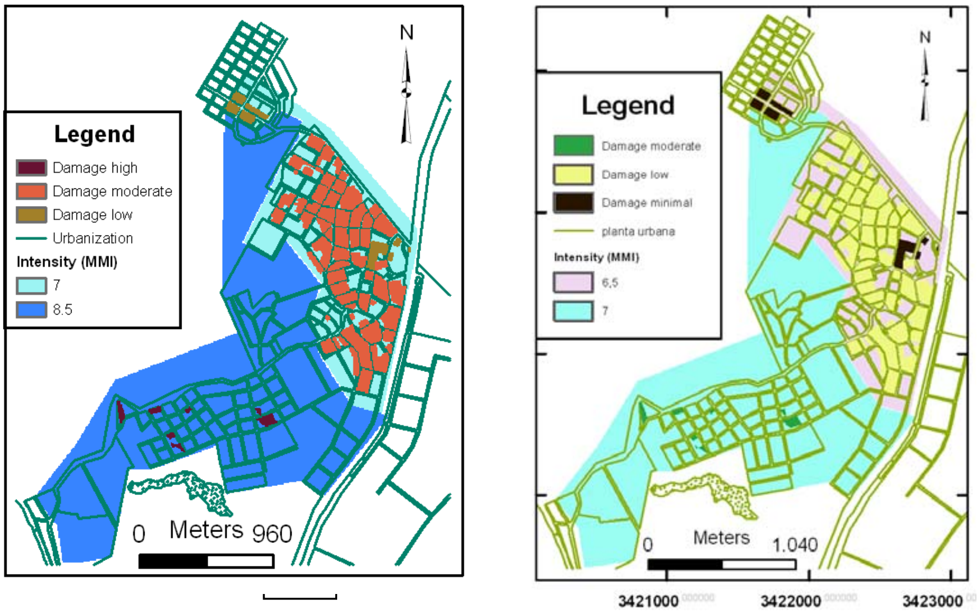

Figure 2. Seismic scenarios for Tolhuin. A) Epicenter 20 km from city center. B) Epicenter 80 km from Tolhuin.

Seismic resistant buildings would resist and MMI=8.5 with little damage but precarious construction would suffer considerable damage, especially those located on the lower slopes.

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